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# **Advanced Transportation System Studies**

## **Technical Area 3**

## Alternate Propulsion Subsystem Concepts NAS8-39210 DCN 1-1-PP-02147

## Propulsion Database Task Interim Report DR-4

## April 1993

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TA3-0309a

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#### Introduction

The objective of the database development task is to produce a propulsion database which is easy to use and modify while also being comprehensive in the level of detail available. The database is to be available on the Macintosh computer system. The task is to extend across all three years of the contract. Consequently, a significant fraction of the effort in this first year of the task was devoted to the development of the database structure to ensure a robust base for the following years' efforts. Nonetheless, significant point design propulsion system descriptions and parametric models were also produced.

It is desirable that the database be usable for both the preliminary analysis of whole classes of propulsion systems (e.g., a booster engine using LOX/RP for a wide range of thrust levels) and for the analysis of existing propulsion systems (e.g., SSME, RD-170, etc.). Since it would be very difficult to fulfill both these uses with only one database structure, it was decided to develop two separate tools, one for each type of usage.

The first usage (analysis of classes of propulsion systems) is normally implemented by a series of unrelated tools written as spreadsheet models, or as dedicated code (most commonly written in Fortran) and running on mainframes, workstations, or PCs. These tools normally can not communicate with each other and are written without common structure – they calculate weight breakdowns to different sets of components even for similar engine types and calculate performance in different manners. This usage requires large amounts of calculations, methods of data presentation unique to each propulsion type (and sometimes to different engine classes within a type), and benefits from automated parametric data generation and automated preparation of graphs (e.g., weight versus mixture ratio).

The commercial tool type which comes closest to meeting these needs is a spreadsheet, particularly one with good graphing capabilities, an extensive scripting or macro language, and the ability to access external code written in different computer languages (especially Fortran). Both Resolve and Excel were considered and Resolve was chosen because its scripting language is extensive and very easy to use even by casual users, and because its charting capabilities (including the scripting of all elements of each chart) were more extensive than Excel (at least until Excel 4 which was not available to the author at the time). It subsequently became known that Resolve also puts fewer limits on the use of Fortran externals than Excel. This second usage type will be referred to throughout the rest of the report as a "parametric propulsion database".

The second usage can be implemented with a classic database structure where a large number of pieces of information (as numbers, text blocks, and pictures/graphics) about each of a number of specific existing or conceptual propulsion systems is stored. The information describes the single design point engine with some information about operation at off-design conditions. Each propulsion system can be stored as a record with the individual pieces of information stored as fields within the record. Minimal calculation is needed, but the ability to sort, group, and aggregate (i.e., all engines using RP with vacuum thrust above a specified number) is needed. Consequently, for this usage, referred to throughout the rest of the report as a "propulsion system database" a commercial database was chosen. Both 4th Dimension and FileMaker Pro were considered. FileMaker Pro was chosen because it is much easier to change, both in structure and output, even by casual users. It is also much more readily available because of its much lower cost, cross platform capability (Macintosh and PC with Windows), and lack of need of dedicated, experienced users.

Each of the two propulsion databases, parametric propulsion database and propulsion system database, are described in the rest of the report. The descriptions include a user's guide to each code, write-ups for models used, and sample output. Because of the large number of pages of figures in relation to the length of text, this report is structured with the text all at the front and then followed by the 90 pages of figures relating to the parametric propulsion database, which is in turn followed by the 151 pages of figures relating to the propulsion system database.

An appendix includes three technical notes describing how to attach external code written in Fortran to both Resolve and to Excel. These procedures were developed during this year's effort with the Excel work done on Rocketdyne resources and the

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Resolve work done on a combination of contract and Rocketdyne resources. Interactions with tech support at Claris (the publisher of Resolve), Microsoft (the publisher of Excel), and at the publisher of the Macintosh Fortran compiler used, indicate that the use of Fortran externals with either Resolve or Excel breaks new ground. This capability will be extremely useful for the parametric propulsion database throughout the rest of this effort and should be very useful in general to anyone within the aerospace community using Macintosh computers.

## **Parametric Propulsion Database**

The parametric propulsion database was developed using the Macintosh spreadsheet Resolve, version 1.1v1 (published by Claris). It was developed on a Macintosh II fx running system 7 with the tuneup kit. It was developed using an Apple 13 inch color monitor. It has been checked in black and white mode, on a limited number of other Macintosh computer types, and with system 6.0.5. Two problems were encountered during these checks: some color choices were changed to work in black and white mode, and the Fortran externals were recompiled in two forms so they would work on Macintoshs without math coprocessors, but would also take advantage of the coprocessors when present.

The parametric propulsion database consists of two files and one folder (which in turn contains three files):

Parametric Database Library Externals OHSCC ORPGG NuclearRkt

The file "Library" and the folder "Externals" <u>must</u> be in the same folder as the application "Claris Resolve". The file "Parametric Database" can be placed anywhere. None of these file or folder names can be changed because they are used explicitly by name in calls by scripts in the database. The file "Parametric Database" is a Resolve spreadsheet which is double-clicked to run the parametric propulsion database. It uses the file "Library" to update its worksheet script. "Library" contains a number of functions which are called by other scripts. The file "Library" is actually only needed when changes are made to the worksheet script. The program will run without "Library" (although two error messages will occur) but changes cannot be made, even temporarily, to the worksheet script. The folder "Externals" contains the three compiled Fortran codes (with embedded hooks written in C – see Appendix) currently used by the database.

The model <u>requires</u> the fonts "Bookman", "New Century Schoolbook", and "Helvetica" be installed (Postscript or True Type). If they are not available then most screens and output will be difficult to read and many words will not be fully visible in their defined columns. All three of these fonts came with the various Apple LaserWriters (and many other printers) and are readily available. The use of Adobe Type Manager (ATM) or True Type (with the True Type versions of the fonts) is highly recommended to improve the readability of the screen.

To run the database simply double-click on the file "Parametric Database". The current version (version 1.4, 5 April 1993) contains the following models:

Solid Fuel Boosters

Large Motors (328K-8.9M lbf) using ASRM (ANB3652) propellant Large Motors (328K-8.9M lbf) using neutralized Mg (DL-H435) propellant Medium Motors (62K-328K lbf) using neutralized Mg (DL-H435) propellant Large Motors (328K-8.9M lbf) using non-chlorine (PGN/AN/AL) propellant Hybrid Boosters

Large Motor (380K-21M lbf) using O<sub>2</sub> as oxidizer and HTPB and escorez as fuel – pressure fed

**Cryogenic Engines** 

Large (100k-2M lbf) LOX/H<sub>2</sub> engines using staged combustion cycles

Hydrocarbon Engines

Large (500K-3M lbf) LOX/RP engines using gas generator cycles

Nuclear Thermal Propulsion

NERVA derived prismatic fuel solid core rocket.

The solid fuel rocket booster and hybrid booster models are implemented as spreadsheet models, while the liquid engines and the nuclear engine are implemented as Fortran external functions.

The basic philosophy of the model is to navigate a large spreadsheet by means of buttons that the user "clicks". The buttons invoke scripts which change what portion of the spreadsheet is displayed (i.e., moves to the next "screen"), change the screen scaling to make the display fit, write spreadsheet formulas and data, or call external code. The buttons are where most of the "action" occurs and where most of the calculation is done. The model is structurally dependent on scripting and the use of Fortran externals. About 50 pages of scripts are used and over 130K of compiled Fortran external code is used.

#### Code Overview

Figure 1 shows the result of double-clicking the file "Parametric Database". Pressing the continue button takes the user to Figure 2 which is the main navigation screen. Only the Cryogenic, Hydrocarbon Fuels, Solid Fuels, Hybrid RB, and the Nuclear Thermal buttons are currently active. The Return button, which is present on all screens, always returns to the previous screen.

Tracing the models under the Chemical label, pressing the Cryogenic button brings up Figure 3 and pressing the Hydrocarbon Fuels button brings up Figure 4. Pressing either of the Large LOX/H<sub>2</sub> or Large LOX/RP buttons brings up Figure 5. The figure will be slightly different depending on which button was pressed. Since the LOX/H<sub>2</sub> and LOX/RP models are implemented as external Fortran code, there are no equations under the numbers in the cells as would be expected in a spreadsheet. Because the same piece of spreadsheet "real estate" (i.e., the same cells) are used for both the LOX/H<sub>2</sub> and the LOX/RP models, the Calculate button in the upper left side of the screen must be pressed to produce numbers for the weights, lengths and performance. The independent variables, and the ranges through which each can be varied and remain within the validity of the model, are shown in the upper part of the screen on the yellow background. To examine a new case, change any or all of these independent variables and then press the calculate button. New values for the results will appear in the cells.

Pressing the "English Units" button changes the button name to "Metric Units" and changes the results (only) to metric units. Pressing the button a second time reverses the process. The Print (Report) button sets up for printing the page (without buttons) in portrait mode and stripped of color. The Print (Briefing) button sets up for printing the page in landscape mode and stripped of color. These buttons work the same on other screens. The page setup dialog box will always come up because Resolve script does not have a means to specify landscape versus portrait mode, so the user must click the appropriate icon. The model can be used to generate parametric data and produce a table and selected graphs of that data. To do so, press the Graphs button and the parametric generation screen of Figure 6 will appear. This screen shows the variables which can be used for parametrics as titles within yellow buttons. The parametrics possible are one dimensional, only one variable can be varied at a time. To make a parametric run using one of the independent variables that are shown on the yellow buttons, choose a range of the variable to vary. Input its starting value and its ending value in the column "Variable to Change" (within the limits that are shown under each yellow button), along with the number of discrete points (11 maximum) to calculate (the variable values must be evenly spaced throughout the range which is why only the number of points, as opposed to the actual values, is input).

The column "Other Independent Variables" shows the values that will be used during the parametric run for the variables other than the one being varied. Use this column to change these values to those desired for the parametric run. These values start as the values from the previous screen, but they will change as parametrics are generated taking on the last value of the range used if they have been used in a previous parametric run. They should always be checked. When satisfied that the input is as desired, then press the yellow button that has the name of the variable that was chosen to vary. Pressing that button actually replaces the chosen independent variable in the screen of Figure 5, reads out the results, places them into a table and graphs, changes the variable again, reads out the results again, etc.

After the yellow button is pressed to generate the parametric run, a portion of Figure 7 appears. This table can be printed (Figure 8) and graphs can be individually accessed by pressing the yellow Weight, Lengths, and Performance buttons. Examples of the graphs are shown as Figure 9-11 and an overview of the table and graphs is shown in Figure 12.

The route for the Solid Fuels goes back to Figure 2 and when the Solid Fuels button is pressed, Figure 13 is seen. These four buttons invoke the different models used for the different solid rocket boosters. They actually use a script and rewrite the

equations in the cells shown in Figure 14. The same piece of spreadsheet "real estate" is used for each model (except the Medium Motor model) but with new equations, titles and words for each different model. Because the solids use spreadsheet models, when an input is changed in Figure 14 the result changes immediately and there is no "Calculate" button. The "English Units" button changes to "Metric Units" when pressed and changes the output (only) to metric. It reverts to "English Units" when pressed again.

If the Graphs button is pressed, Figure 15 appears. This screen allows the user to generate parametric tables and graphs by varying any of the independent variables as was described for the LOX/H<sub>2</sub> and the LOX/RP models. The results of the parametric run appear after pressing the yellow button with the title of the variables chosen and are seen as a portion of Figure 16. The table can be printed as shown in Figure 17, and the graphs are accessed, individually, by pressing the Weights, Lengths, Mass Fraction, or Performance buttons. They can be printed when accessed as shown in Figures 18-21. Figure 22 shows an overview of the table and graphs.

The route of the hybrid rocket booster model goes back through Figure 2 where pressing the Hybrid RB button brings up Figure 23. The buttons on Figure 23 work the same as those described for the other models. Pressing the Graphs button brings up Figure 24 where parametric runs can be made as described for the other models. After generating a parametric run a portion of Figure 25 appears. The table can be printed or the graphs of Figure 26 accessed and printed as shown in Figures 27-31.

Tracing the Nuclear Thermal button, pressing it brings up Figure 32 where only the Solid Core button is currently active. Pressing Solid Core goes to Figure 33 where only the Prismatic Fuel button is active. Pressing it goes to the model for the NERVA derived nuclear thermal rocket (Figure 34). This model uses an external Fortran code and thus there are no equations under the numbers in the cells. Instead the user changes the inputs as desired and then presses the "Calculate" button to produce changes in the output.

#### **Individual Models**

#### Solid Fuel Models

The design equations are the result of a multivariate regression of a matrix of designs produced by Thiokol's Solid Rocket Motor Automated Design Program (ADP). The results of these equations produce solid rocket motor preliminary design data within the ranges over which the regression was performed. There are a number of assumptions underlying the motor equations. These are factors which were held fixed during the creation of the database upon which the design equations are based.

These equations assume T650 graphite epoxy filament wound cases. The web fraction, or proportion of the case diameter filled with propellant, was held constant at 0.75. Also held constant were the burn rate exponents, propellant densities, and the ratio of throat to port diameters for the respective propellant types. Nozzle submergence (defined as the nose to boss distance divided by the nose to nozzle exit distance) varied from 5 percent to 30 percent. The nozzle length reported in the design equations is from the aft case boss interface to the end of the nozzle, i.e., external nozzle length. A finocyl grain design was used for all propellant types. The finocyl design has a finned grain (typical of the Shuttle Solid Rocket Motor) for part of the port length and a simple cylindrical port for the remainder of the port length. Silica filled EPDM internal case insulation was used. The booster elements were divided into six categories: nose cone, external insulation, forward skirt and attachment, aft skirt and attachment, separation system, and miscellaneous which includes electronics, instrumentation, raceway, thrust vector control system, etc.

The motors were all designed to a thrust trace similar to that of Figure 35 (which is that of the current space shuttle solid rocket boosters).

The parametric design equations were formulated as follows:

• A proprietary Thiokol design program called ADP (Automated Design Program) was used to generate a matrix of designs based on a set of input data spanning predetermined parameter ranges. • The ADP determined a design for each set of the input parameters by using the in-house design codes for the case, insulation, nozzle and ballistics and the NASA-LEWIS thermochemical program.

• Once the matrix of designs was created the Number Cruncher statistics package was used to do a multivariate regression on the independent and dependent variables.

The generation of the parametric equations followed two steps. First, the logarithms of each independent variable and the dependent variables were taken. A regression was performed on the logarithms resulting in a factor with terms to various powers. This factor was used in a linear regression along with other terms to give an expression for the dependent variable in terms of the independent variables. Regression variables were based upon the physics of the problems plus input from Number Cruncher as to what the most meaningful variables would be.

ASRM Propellant. The ASRM (ANB3652) type propellant utilizes aluminum as the primary fuel with an ammonium perchlorate (AP) oxidizer. The normal formulation for ASRM propellant is shown in Figure 36. The predominant exhaust species produced by this propellant at the nozzle exit plane are shown in Figure 37. This propellant is non-neutralizing with an exhaust containing approximately 21% hydrogen chloride. Figures 38 and 39 show sample model outputs, Figure 40 shows the equations used, and Figure 41 shows the script used to implement the model.

Neutralized Mg Propellant. The DL-H435 propellant is a clean propellant utilizing magnesium instead of aluminum as the primary fuel in order to reduce or eliminate the hydrogen chloride (HCl). Reference 1 contains a full discussion of this propellant. Reference 1 also shows, by means of small motor test results, that this propellant will fully neutralize the HCl byproduct (see Reference 1, Table IV) in the exhaust plume. The nominal formulation for DL-H435 magnesium clean propellant is shown in Figure 42. The predominant exhaust species produced by the DL-H435 propellant at the nozzle exit plane are shown in Figure 43. Most of the neutralizing reaction occurs in the plume. The amount of the neutralization is a function of ambient conditions and mission parameters. The species at the nozzle exit plane, however, represents a minimum estimate of total neutralization of HCl. Figures 44 and 45 show sample model outputs, Figure 46 shows the equations used, and Figure 47 shows the script used to implement the model.

Earlier in the contract a preliminary set of equations was generated using a different set of data and different input ranges. Although the new equations replace the old ones and the new model breaks the weights into different sets of components, the old model went to a lower thrust level. Consequently, the lower thrust results are also included in the parametric database as the "Medium Motor" button for the neutralized Mg propellent which is the one case where they are available. Figures 48 and 49 show sample outputs and Figure 50 shows the script used to implement the equations.

Non-Chlorine Propellant. The non-chlorine (PGN/AN/AL) propellant substitutes ammonium nitrate for ammonium perchlorate as the primary oxidizer in order to eliminate the halogen byproducts of combustion associated with the use of ammonium perchlorate (AP) oxidizer and uses PGN (PolyGlycidalNitrate), an energetic binder, to achieve performance close to the current RSRM propellant. This propellant is in the development stage. Thiokol has overcome the major impediment to using PGN binder in large motors, but this type of clean propellant is still developmental. The nominal formulation for non-chlorine propellant is shown in Figure 51. The predominant species produced by the non-chlorine propellant at the nozzle exit plane are shown in Figure 52. Figures 53 and 54 show sample model outputs, Figure 55 shows the equations used, and Figure 56 shows the script used to implement the equations.

#### Hybrid Rocket Booster Model

The hybrid model used included a T650 graphite epoxy filament wound case for the fuel grain and an aluminum 2219 oxidizer tank with a pressure feed system. The fuel is a combination of HTPB polymer and escorez. The escorez is used to increase the fuel's density. The propellants are shown in Figure 57. Figure 58 shows the mass fractions of the exhaust species at the nozzle exit for both a mixture ratio (O/F) of 1.8 and 2.8. One major advantage of a hybrid system can be seen from the figure: there are no chlorine or chlorine compounds in the exhaust. This alleviates many of the environmental concerns normally associated with solid rocket motors. The hybrid system can also be readily shut down and restarted.

The regression process described for the solid models was also used by Thiokol for the hybrid designs, although the variables in some cases were different. One notable difference was that case diameter was a dependent variable in the hybrid model, whereas it was an independent variable in the solid models. A special grain design must be used in the hybrid designs. This grain was driven by the performance requirements and required a specific diameter just to fit the grain geometry. Two new independent variables were added: the maximum oxidizer flux and the mixture ratio (oxidizer to fuel ratio). In a solid rocket motor there is no oxidizer flux and the oxidizer/fuel ratio is invariant, fixed by the propellant formulation.

The hybrid model was simpler than the solid models in that all of the subcomponent weights and lengths were not calculated. However, the nozzle, total tank/case, motor, and stage lengths, as well as  $O_2$  and fuel used weights were calculated. The motor mass fraction was also calculated empirically, allowing the calculation of total motor weight. The same stage component weight relations were used for both the solid and hybrid models. Figures 59 and 60 show sample model outputs, Figure 61 shows the equations used, and Figure 62 shows the script used to implement the equations.

#### Liquid and Nuclear Models

Performance. The LOX/H<sub>2</sub>, LOX/RP, and Nuclear Thermal models all use the same approach for performance prediction. These models employ the JANNAF Simplified Performance Prediction Methodology detailed in CPIA Publication 246. Starting from ODE (one-dimensional equilibrium) thermochemical codes, tables of theoretical specific impulse and C-star are prepared versus chamber pressure, mixture ratio, area ratio and inlet propellant enthalpy. When the system is modeled, a table-look-up is used to obtain the theoretical  $I_{sp}$  and C-star values. The chamber temperature is used in place of mixture ratio for cases where there is no mixture ratio (e.g., H<sub>2</sub> in the nuclear model).

Performance efficiency terms are then used to represent the various loss mechanisms present within the engine system. The method uses the following efficiency terms:

- C-star: A measure of the combustion and mixing efficiency in the combustor. How much of the propellant's chemical energy is actually available for heat.
- Divergence: A measure of the geometric losses associated with a finite nozzle having a finite turning angle. How much of the exhaust momentum is lost by not being turned parallel to the nozzle axis.
- Boundary Layer: A measure of the drag momentum loss caused by the viscous boundary layer within the thrust chamber.

Kinetic: A measure of kinetic losses during the expansion process.

Rocketdyne uses a table-look-up to compute kinetic losses based on chamber pressure ( $P_c$ ), mixture ratio, throat area, and area ratio. The tables used are the results of detailed ODK (one-dimensional kinetic) code runs for the particular propellant combination (or heated H<sub>2</sub>) being studied. For divergence losses, a curvefit correlation is used which relates divergence efficiency to  $P_c$ , nozzle percent length, thrust, and area ratio. The boundary layer losses are estimated by curve fits of the results of rigorous boundary-layer codes (such as BLIMP or TBL). The C-star losses are input based on the results of detailed cycle balances.

The other effects of the thermodynamic cycle is input by using detailed cycle balances and then using the resulting thrust chamber mixture ratio instead of the engine mixture ratio.

For the specific LOX/H<sub>2</sub>, LOX/RP, and Nuclear Thermal performance models used here, the further effect effects of the thermodynamic cycle throughout the range of variables was accounted for by forcing the result at a single design point through a known value (e.g., SSME, F-1A), then using a factor on the delivered specific impulse at other conditions.

<u>Weight.</u> The weight for the LOX/H<sub>2</sub> model is based on the reference SSME design point. The individual component weights are then scaled with flows, thrust,  $P_c$ , area ratio, etc. The scaling methodology is based on engineering parameters and physical quantities. It employes neither point designs nor curve fits. The weight for the LOX/RP model is based on the reference F-1A design point. The individual component weights are then scaled with flows, thrust,  $P_c$ , area ratio, etc. The scaling methodology is based on engineering parameters and physical quantities. It employes neither point designs nor curve fits.

The weights for the nuclear thermal model are based on four design points (at 25K, 50K, 75K, and 100K) for the reactor and additional components. These points were then incorporated into a table lookup and interpolation routine.

Liquid Models. A model of a LOX/H<sub>2</sub> engine using a staged combustion cycle was made based on SSME experience, and scaling a set of weights based on a SSME baseline. Figures 63 and 64 show examples of model output.

A model of a LOX/RP engine using a gas generator cycle was made based on F-1 and F-1A experience, and scaling a set of weights based on F-1/F-1A weights. Figures 65 and 66 show examples of the model output.

Nuclear Thermal Rocket Model. The design work done at Rocketdyne and Westinghouse over the past few years, including work for NASA/LeRC during the last year, has produced a series of detailed conceptual designs for nuclear thermal rockets based on the NERVA experience base. Those design results were included in a table and combined with performance data to produce a model for a NERVA derived nuclear thermal rocket. The model is based on using a prismatic fuel form. Because this is a concept derived from a specific reactor design and using one fuel type (graphite matrix with UC<sub>2</sub> beads with ZrC protective fuel element coating), temperature is fixed. Only thrust, chamber pressure, and nozzle area ratio are variable. Also the thrust range is limited from 25,000 to 100,000 lbf. Figure 67 shows a sample output of the model.

#### Changing the Worksheet Script

The worksheet script is a collection of functions which are called by other scripts. It is essentially a library. To make changes to the worksheet script, even temporarily, requires that the file "Library" be modified. The procedure is:

- 1.
- Select any spreadsheet cell Go to the "Script" item in the menu bar and select "Unload Script" 2. and "Library"
  - If "Unload Script" is grayed in the menu bar then skip this step
- Go to the "Script" item in the menu bar and select "Open Script..." 3.
- Use the resulting dialog box to find and open the file "Library" 4.
- Make the desired changes 5.
- Go to the "File" item in the menu bar and select "Save" 6.
- Go to the "File" item in the menu bar and select "Close" 7.
- Go to the "Script" item in the menu bar and select "Worksheet 8. Script"
- Highlight the following four lines with the cursor: 9.

**On Activate** Attach Script "Library" Get Script "Library" **End Activate** 

- 10.
- Go to the "Edit" item in the menu bar and select "Copy" Go to the "Edit" item in the menu bar and select "Select All" 11.
- Press "Delete" key 12.
- Go to the "Edit" item in the menu bar and select "Paste" 13.
- Go to the "File" item in the menu bar and select "Close" 14.
- Press any active button which forces the program to attach the file 15. "Library" and make it the current "Worksheet Script".

## **Propulsion System Database**

The propulsion system database was developed using the Macintosh database FileMaker Pro, version 2.0v1 (published by Claris). It was developed on a Macintosh II fx running system 7 with the tuneup kit and using an Apple 13 inch color monitor.

The propulsion system database consists of two files: "Prop System DB" and "Prop System DB-Pictures". They can be placed anywhere. The names of the two files must not be changed since the first is used as a look-up file by the second, and the second is referenced by name in scripts in the first. "Prop System DB" is the main file which contains all the data except two picture fields for each record. The two picture fields were separated because they are often scanned images using significant amounts of memory, and also by having two files, even when many more propulsion systems are included in the database, the FileMaker limit of 32 Meg per individual file should be avoidable.

The engine systems currently included in the propulsion system database are:

Space Transportation Main Engine (STME) F-1 F-1A J-2 J-2S SSME RD-170 Integrated Modular Engine (IME) Space Shuttle Redesigned Solid Rocket Motor (RSRM) NERVA Derived NTR

To run the propulsion system database double-click on the file "Prop System DB". The opening screen of Figure 68 will appear. Press Continue and Figure 69 will appear. Pressing on any button will find all propulsion systems of the type represented by the button. For example, pressing "Cryogenic" will find only the cryogenic engines, pressing "Chemical" will find the cryogenics plus the solids, plus the hybrids, etc. Pressing "Propulsion Systems" will find all the records in the database. If the user presses a button for which there are no records of that type, a dialog box will appear and if Continue or Cancel is pressed, <u>all</u> records will be found instead of the null set of zero records expected. This is a quirk of FileMaker Pro.

#### Code Structure and Output

The code is broken into five general classes of propulsion systems based on needing different reports for each kind of propulsion system: Liquids, Solids, Hybrids, Nuclear, and Exotic. The layouts for Liquids must be different from those for Solids since many parameters of one have no meaning for the other (e.g., mixture ratio, grain design). This structure is transparent to the user if the buttons supplied on every screen for navigation are used. In other words, when a liquid engine is selected and the Data Entry button is pressed, the user will go to the liquid data entry screen, not the ones available for solids, hybrids, etc. (which are different). Nonetheless, the actual internal structure is fairly complex and extensive because of the need for different report and entry formats. There are 160 layouts and 71 scripts used.

The result of pressing "Propulsion Systems" in the Main Menu (Figure 69) is shown in Figure 70 which is also the list of all currently available propulsion systems. An example of using the code is to select one of the propulsion systems from the figure (i.e., click on the engine name) and then press one of the five buttons across the top of the screen. The Print button simply prints the page (and works the same on all other layouts where it is present), the More Data button shows two additional lines of information for each propulsion system (thrust, specific impulse, weight, length, width, etc.) and is intended as a short technical summary of the systems in the database. The button with the "org chart" icon returns to the Main Menu (Figure 69). The Data Entry button goes to a set of layouts specifically designed to make data entry easy by gathering all the fields of data for one system in one place and eliminating any that are calculated from other data.

The Reports button goes to a screen like Figure 71. This screen shows the individual reports (layouts) available for each propulsion system. The reports are arranged into two sets – each containing the same information, but with some differences in arrangement – with one set structured for portrait mode presentation and called

"Reports", and the other structured for landscape mode presentation and called "Briefing Charts".

Typical use of the code would be to go to the Main Menu screen (Figure 69), press "Propulsion Systems", choose an engine from the resulting Summary screen (Figure 70), press the Reports button and then use Figure 71 to look at the data (and print any of interest) by pressing individual reports. For example, pressing "Engine Performance 1" brings up the layout in Figure 72 (for a STME as an example). From this (or any other) report the user can print the report, return to the Reports screen, or return to the Main Menu.

After examining the various reports, the user might return to the Summary screen (Figure 70) and select another propulsion system and then look at its reports, and so on.

Figures 73-82 present the output for each of the currently available systems.

Figure 83 shows the field definitions for all fields in the file "Prop System DB". Figure 84 shows the field definitions for all fields in "Prop System DB-Pictures". Note that all of the fields in "Prop System DB-Pictures" except "Engine Name" and two picture fields are look-up fields using the data from "Prop System DB" through the field "Engine Name". It is important to remember to force a relook-up in "Prop System DB-Pictures" if changes are made to the file "Prop System DB" since relookups are not automatic in FileMaker Pro.

## References

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1. AIAA-91-2560 "Magnesium Neutralized Clean Propellant", Daniel Doll and Gary Lund, Thiokol Corporation, 24 June 1991.

# Parametric Propulsion Database Figures



Figure 1. Parametric Database Opening Screen



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Figure 2. Main Navigation Screen





Figure 3. Current Cryogenic Models





Figure 4. Current Hydrocarbon Models

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CALCULATE IN OXALLY			Graphs
biquid Bugines	LOX/H2	28 January 1993	
Independent Terms	Value	Valid Range	
Major Variables			ga san an a
Vacuum Thrust, klbf	512.845	100 to 2.000	
Chamber Pressure, psia	3,277.0	1,000 to 5,000	
Mixture Ratio, O/F	6.011	4 to 8	n an the state of the second sec
Maximum Area Ratio	77.0	10 to 400	
Parameters			
Area Ratio of Nozzle Attachment	5.0		
Nozzle Percent Length, %	80.0	70 to 140	n da ser en tradición de la composición
Gimbal Angle, degrees	11.0	0 to 15	
C* Efficiency	0.98450	0.85 to 0.999	
Fuel Inlet Enthalpy, kcal/mole	-1.270	-2.154 to 1.856	
			Value
Performance		Throat Diameter in	10.3
Vacuum Thrust, klbf	152.083	Throat Area in^2	83.2
Vacuum Isp, sec-lbi/lbm	432,303	Chamber Length, in	12.3
SL Thrust, kibi	369 891	Nozzle Exit Diameter, in	90.3
SL Isp, sec-ibi/ibm	7 753 620	Engine Diameter, in	96.0
ODE C-Star, n/sec	30,399	Nozzle Length, in	119.5
L-Star, III	468.923	Engine Length, in	168.0
DE ISP, Sec-IDI/IDII	0.984		
Ellergy Release Elliciency	1,000	Weights, Ibm	Value
Diversion of Fficiency	0.993	Turbomachinery	1,725.0
Boundary Lover Efficiency	0,989	Preburners	229.0
Endine Efficiency	0.967	PB Hot Gas Manifold	558.0
Eligine Eliciency		Thrust Chamber	859.0
		Nozzle	1,250.0
	· TRANSPORT	Gimbal Bearing	105.0
		Valves and Controls	722.0
		Controller and Mount	85.0
		POGO System	94.0
and the second difference of the second s	a de la companya de l	Propellant Ducts	867.
		Pressurization System	89.0
	Constant of the second	Other Engine Systems	228.0
	and a second		
		Total Dry Weight	6.811.
		Total Dry Weight	L

Figure 5. Input/Output Table for Liquid Models

Liquid Engines LOX/IE	2 		
Parametric Variable: Imput	Starting Value, Endi	ng Value, Inst	ructions)
			na (entri la ples
Vacuum Thrust, klb(	Variable to Change Starting Value	Modify as NeedCo Mac //Drust = Chamber Press	612.845 3,277
Chamber Pressure, pela	Ending Value 7.5	Area Ratio	6.011 77,0 5.0
1,000 10 5,000	(10.04.00) 8	Nos & Length Gimbal Angle =	80.0 11.0 0.98450
Mixture Ratio, O/F		Fuel in Enthalpy -	-1.270
Maximum Area Ratio			
10 18 400			
Nozzle Percent Length	. <u>*</u>		
Fuel Inlet Enthalpy, kcal,	/mole		
•2.154 to 1.858	in a state and in the state of the	alang a lang sing sing a sing sing sing sing sing sing sing sing	
	Return	raphs	

Figure 6. Parametric Data Generation Screen – Liquid Engines

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| Weight )             | Longths               |                   | erforma                                  | nce                 |                           |                   | C             | Print                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----------------------|-----------------------|-------------------|------------------------------------------|---------------------|---------------------------|-------------------|---------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Return               |                       |                   | Use the to See                           | e Yellow<br>the Gra | Buttons<br>phs            |                   | _             |                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| independent Varia    | bles L                | OX/H2             | -Liquid                                  | mainers             |                           |                   |               |                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Vacuum Thrust, lbf - | 512.845               | 512.845           | 512.845                                  | 512,845             | 512.845                   | 512.845           | 512.845       | 812.840              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Chamber Press, pai-  | 3,277                 | 3,277             | 3.277                                    | 3.277               | 3,277                     | 3,277             | 3,2//         | 7 500                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Mixture Ratio, O/F = | 4.000                 | 4.500             | 5.000                                    | 5.500               | 0.000                     | 0.200<br>77 A     | 77.0          | 77.0                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Max Area Ratio =     | 77.0                  | 77.0              | 50                                       |                     | 5.0                       | 5.0               | 5.0           | 5.0                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Noz Attach AR .      | 5.0                   | 0.0               | 80.0                                     | 80.0                | 80.0                      | 80.0              | 80.0          | 80.0                 | 월년(1월) 전체인 전문), 1910년 1월 1917년 1월 1917년<br>1월 1917년 1월 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Nozzie S Lengon .    | 110                   | 11.0              | 11.0                                     | 11.0                | 11.0                      | 11.0              | 11.0          | 11.0                 | 推动的 机动动物 医白色的 医白白白白白白白白白白白白白白白白白白白白白白白白白白白白白白白白白                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                      | 0.98450               | 0.98450           | 0.98450                                  | 0.98450             | 0.98450                   | 0.98450           | 0.98450       | 0.98450              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Fuel H. kcal/mole .  | -1.270                | -1.270            | -1.270                                   | -1.270              | -1.270                    | -1.270            | -1.270        | <u>-1.270</u>        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Weights, Ibm         |                       | tiga mere e       |                                          | i in add            | <b>er kan sut</b> telet i | 17 <b>1 - 1</b> 1 | Ser Star Star | <b>Distriction</b> D |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Turbomachinery =     | 2,092.9               | 1,978.6           | 1,881.6                                  | 1,798.6             | 1,726.5                   | 1,662.5           | 1,605.9       | 1.515.6              | 建碱和加加 化乙基乙酸乙酯                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Preburners           | 383.3                 | 329.4             | 288.0                                    | 255.5               | 229.5                     | 208.3             | 190.7         | 104.7                | · · · · · · · · · · · · · · · · · · ·                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| PB Hot Gas Man .     | 660.7                 | 627.4             | 600.1                                    | 577.5               | 558.4                     | 041.0             | 027.0         | 70K A                | 2014년 - 1919년 -<br>1919년 - 1919년 - 1919년<br>- 1919년 - 1919년                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Thrust Chamber =     | 988.9                 | 945.9             | 911.3                                    | 883.2               | 80¥.2                     | 1 720 4           | 1 220 1       | 1.214 5              | and a second                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Nozzle =             | 1,295.1               | 1,285.1           | 1,272.7                                  | 1,201.2             | 1,250.2                   | 1.239.4           | 105 0         | 105.0                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Gimbal Bearing =     | 105.0                 | 105.0             | 105.0                                    | 100.0               | 100.0<br>707 9            | 709.9             | 698.7         | 681.7                | ski u postalni si palikusi si i                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Valves & Cont =      | 789.6                 | 109.1             | 101.3                                    | 85.0                | 85.0                      | 85.0              | 85.0          | 85.0                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Cont & Mount =       | 60.V                  | 04.7              | Q4 6                                     | 94.3                | 94.0                      | 93.6              | 93.1          | 92.5                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| POGO System -        | 11165                 | 1 037.0           | 971.1                                    | 915.9               | 868.7                     | 827.5             | 791.6         | 735.5                | ala a nganasan ing taon na sa taon<br>An                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Prop Ducus           | 93.6                  | 92.3              | 91.1                                     | 90.0                | 89.0                      | 88.0              | 87.1          | 85.7                 | 방법은 사람이 있는 것 같아요. 이 가 있는 것 같아요. 이 이 이 가 있는 것 같아요. 이 이 이 이 이 이 이 이 이 이 이 이 이 이 이 이 이 이 이                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Other Engine Sva     | 278.7                 | 261.6             | 248.7                                    | 237.8               | 228.2                     | 219.7             | 212.2         | 200.1                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Total Dry Weight     | 7,984.7               | 7, <u>611.</u> 1  | 7,300.5                                  | 7,039.9             | 6,816.3                   | 6,619.4           | 6,446.2       | 6,180.6              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Dimensions           | i i chen de la com    | i finite (politic | i an | hain ingi           |                           |                   | - filler Fehr | MIG ICAN             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Throat Dia in        | 10.5                  | 10.5              | 10.4                                     | 10.3                | 10.3                      | 10.2              | 10.2          | 10.1                 | na shekara na kata kata ka shekara shekara s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Thread Area in A?    | 85.8                  | 85.8              | 84.9                                     | 84.1                | 83.2                      | 82.4              | 81.7          | 80.6                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Imost Area, m a      | 10.0                  | 12 4              | 12 4                                     | 12.3                | 12.3                      | 12.2              | 12.2          | 12.1                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Chamber Len, m       | 14.0                  | 01.7              | 01.7                                     | 90.6                | 90.3                      | 89.9              | 89.5          | 88.9                 | See an                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Noz Exit Dia, m =    | 6 - 1 - <b>74.2</b> . | er::¥1./:<br>     |                                          | 00.0                | 04.0                      | 08.0              | 96.0          | 96.0                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Engine Dia, in -     | 96.0                  | 90.0              | 90.V                                     | 90.0                | 110 8                     | 110 0             | 118.4         | 1176                 | 철말은 것이 가장할 것 같아요. 그는 것이 같아요.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Noz Length. in       | 122.0                 | 121,3             | 120.7                                    | 120.1               | 179-2                     | 110.0             | 110.4         | 165.4                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Engine Length, in    | 171.4                 | 170.5             | 169.6                                    | 165.8               | 168.0                     | 107.2             | 100.0         | 100.4                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Performance          | a production of the   | 1. N              |                                          |                     |                           | or on here        |               |                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| SL Thrust, kibi      | 414.74                | 415.82            | 416.87                                   | 417.83              | 418.75                    | 419.66            | 420.53        | 421.75               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| V Thrust kibf        | 512.84                | 512.84            | 512.84                                   | 512.84              | 512.84                    | 512.84            | 512.84        | 512.84               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| St ten sec. Ihf/ihm  | 366.75                | 369.26            | 370.35                                   | 370.47              | 369.91                    | 368.28            | 365.84        | 358.85               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| If Inn and the the   | AKG RA                | 455 49            | 455.62                                   | 454.71              | 453.03                    | 450.06            | 446.15        | 436.36               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| v isp, sec-int/ind   |                       | 100.48            | 7 054                                    | 7.861               | 7.756                     | 7.631             | 7.495         | 7,233                | na an a                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| ODE C", R/MCC        | 8,093                 | 8,038             | 7,800                                    | 40 E                | <b>N</b>                  | 20.2              | 50.5          | 30.1                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| L-Star, in           | . 30.7                | 30.6              | 30.0                                     | 30.0                |                           | 402.00            | 401 07        | 489.94               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| ODE lap              | 469.44                | 471.42            | 471.62                                   | 470.69              | 408.97                    |                   |               | 0.08480              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Energy Rel Eff       | 0.98450               | 0.98450           | 0.98450                                  | 0.98450             | 0.98450                   | 0.95450           | U.98450       | 0.20400              | and a state of the       |
| Kinetic Eff          | 0.99999               | 0.99999           | 0.99999                                  | 0.99999             | 0.99994                   | 0,99986           | 0.99968       | 0,99060              | Manazar and Araba and Araba and Araba.<br>An anna an ann an Araba                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Divergence Eff       | 0.99283               | 0.99283           | 0.99283                                  | 0.99283             | 0.99283                   | 0.99283           | 0.99283       | 0.99253              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| BL Eff               | 0.98904               | 0.98904           | 0.98904                                  | 0.98904             | 0.98904                   | 0.98904           | 0.98904       | 0.98904              | Constant Company and Constant Cons<br>Constant Constant Const<br>Constant Constant Const<br>Constan |
| Engine Eff           | 0.96672               | 0.96672           | 0.96672                                  | 0.96672             | 0.96668                   | 0.96658           | 0.96642       | 0.96344              | la sufficienda se en                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

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Figure 7. Parametric Results Table – Liquid Engines

| Indenendent Varis    | hire             | CH/X01         | Lionid 1         | Cndince       |                 |                |         |                |
|----------------------|------------------|----------------|------------------|---------------|-----------------|----------------|---------|----------------|
| IIIUCPCHUCHE Val     | E10 DAA          | E10 BAA        | E10 844          | 517 BA4       | 512 844         | 512 844        | 512.844 | 512.844        |
| Vacuum Inrust, ibi   | ++0.71C          | 012.044        | 5 077            | 220.210       | 220.210         | 3 277          | 3.277   | 3.277          |
| Unamber Press, psi - | 5.212<br>A 000   | 3.211<br>4.500 | 5.2.5            | 5,500         | 6.000           | 6.500          | 7.000   | 7.500          |
| May Area Ratio       | 77.0             | 77.0           | 77.0             | 77.0          | 77.0            | 77.0           | 77.0    | 77.0           |
| Noz Attach AR        | 5.0              | 5.0            | 5.0              | 5.0           | 5.0             | 5.0            | 5.0     | 5.0            |
| Nozzle % Length      | . 80.0           | 80.0           | 80.0             | 80.0          | 80.0            | 80.0           | 80.0    | 80.0           |
| Gimbal Ang, deg      | . 11.0           | 0.11.0         | 11.0             | 11.0          | 11.0            | 11.0           | 11.0    | 11.0           |
| C• Eff               | 0.98450          | 0.98450        | 0.98450          | 0.98450       | 0.98450         | 0.98450        | 0.98450 | 0.98450        |
| Fuel H, kcal/mole    | -1.270           | -1.270         | -1.270           | -1.270        | -1.270          | -1.270         | -1.2/0  | -1.2/0         |
| Weights, Ibm         |                  |                |                  |               |                 | 2000           |         | 1 E1E E        |
| Turbomachinery       | 2,092.8          | 1,978.6        | 1,881.6          | 1,798.6       | 1,726.5         | 1,662.5        | 1.605.  | 0.010,1        |
| Preburners           | - 383.3          | 329.4          | 288.0            | 255.5         | C.622           | 208.3          | 1.061   | 104.7<br>Fof 3 |
| PB Hot Gas Man       | . 660.7          | 627.4          | 600.1            | 577.5         | 4.900<br>4.9010 | 0.140          | 0.120   | 200.3<br>706 0 |
| Thrust Chamber       | - 988.5          | 945.9          | 911.3<br>· 220 - | 883.1         | 859.5           | 838.8          | 8-079 I | 1 2 1 4 5      |
| Nozzle               | = 1,298.1        | 1.285.1        | 1,272.7          | 1,261.2       | 1,250.2         | 1.239.4        | 1.229.1 | 1.414.0        |
| Gimbal Bearing       | - 105.0          | 105.0          | 105.0            | 105.0         | 105.0           | 105.0          | 100.0   | 0.601          |
| Valves & Cont        | - 789.6          | 5 769.1        | 751.3            | 735.9         | 722.3           | 9.80/          | 020.7   | 001.7<br>05.0  |
| Cont & Mount         | = 85.0           | 85.0           | 85.0             | 85.0          | 0.00            | 00.00          | 0.00    | 2000<br>2 A    |
| POGO System          | - A4.            | 1.4R           | 0.45             | 0.40          | 0.40            | 0.06<br>7 7 60 | 791.6   | 0.50<br>7.37 R |
| Prop Ducts           | - I.110.         | 0.160,1        | 1.178            | 8.018<br>0.00 | 80.0            | 0.440          | 87 1    | 85.7           |
| Pres bys             |                  | 7 961.6        | 2487             | 237.8         | 228.2           | 219.7          | 212.2   | 200.1          |
|                      |                  |                |                  |               | 1               |                |         |                |
|                      |                  |                |                  |               |                 |                |         |                |
|                      |                  |                |                  |               |                 |                |         |                |
|                      | . 11             |                |                  |               |                 |                |         |                |
|                      |                  |                |                  |               |                 |                |         |                |
| Total Dry Weight     | - 7,984.         | 7 7,611.1      | 7,300.5          | 7,039.9       | 6,816.3         | 6,619.3        | 6,446.2 | 6,180.6        |
| Dimensions           |                  |                | ×.               | XX            |                 |                |         |                |
| Throat Dia. in       | = 10.            | 5 10.5         | 10.4             | 10.3          | 10.3            | 10.2           | 10.2    | 10.1           |
| Throat Area. in 2    | =<br>86.1        | 82.8           | 84.9             | 84.1          | 83.2            | 82.4           | 81.7    | 80.6           |
| Chamber Len. in      | - 12.            | 5 12.4         | 12.4             | 12.3          | 12.3            | 12.2           | 12.2    | 12.1           |
| Noz Extt Dia, in     | - 92.            | 2 91.7         | 91.2             | 90.8          | 90.3            | 89.9           | 89.5    | 88.9           |
| Fudire Dia in        | 9                | 0.96.0         | 96.0             | 96.0          | 96.0            | 96.0           | 96.0    | 96.0           |
| Nor Length In        | - 122            | 0 121.3        | 120.7            | 120.1         | 119.5           | 118.9          | 118.4   | 117.6          |
| Fudine Length in     | = 171            | 4 170.5        | 169.6            | 168.8         | 168.0           | 167.2          | 166.5   | 165.4          |
| Performance          |                  |                |                  |               |                 |                |         |                |
| SI. Thrust. klbf     | = 414.7          | 4 415.82       | 416.87           | 417.83        | 418.75          | 419.66         | 420.52  | 421.75         |
| V Thrust. klbf       | - 512.8          | 4 512.84       | 512.84           | 512.84        | 512.84          | 512.84         | 512.84  | 512.84         |
| SL Isp. sec-lbf/lbm  | <b>-</b> 366.7   | 5 369.26       | 370.35           | 370.47        | 369.91          | 368.28         | 365.84  | 358.85         |
| V Isn. sec-lbf/lbm   | - 453.5          | 0 455.42       | 455.62           | 454.71        | 453.03          | 450.06         | 446.15  | 436.36         |
| ODF.C. ft/sec        | <b>-</b> 8.09    | 5 8.039        | 7,956            | 7,861         | 7.756           | 7,631          | 7,495   | 7,233          |
| L-Star. In           | =<br>30.         | 7 30.6         | 30.6             | 30.5          | 30.4            | 30.3           | 30.3    | 30.2           |
| ODF. Isn             | 469.4            | 4 471.42       | 471.62           | 470.69        | 468.97          | 465.93         | 461.97  | 453.24         |
| Fnerøv Rel Eff       | - 0 9845         | 0 0.98450      | 0.98450          | 0.98450       | 0.98450         | 0.98450        | 0.98450 | 0.98450        |
| Eucity Net Eur       |                  |                | 0 00000          |               | 0.99994         | 0.99986        | 0.99968 | 0.99660        |
|                      |                  | 0,0000         | 000000           | 0.00000       | 0.000           | 0.000.03       | 0 00083 | 0 00383        |
| Divergence Eff       | = 0.9928         | 3 0.99283      | 0.99283          | 0.99283       | 0.99283         | 0.99203        | 0000000 | 0.99203        |
| BL Eff               | <b>- 0.989</b> 0 | 4 0.98904      | 0.98904          | 0.98904       | 0.98904         | 0.98904        | 0.98904 | 0.0001         |
| Engine Eff           | = 0.9667         | 2 0.96672      | 0.96672          | 0.96672       | 0.96666         | 0.96659        | 0.96642 | 0.96344        |
|                      |                  |                |                  |               |                 |                |         |                |

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Figure 10. Printed Version of Lengths Chart - Liquid Models



Figure 11. Printed Version of Performance Chart – Liquid Models

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Th           |                                  |                          |                            |                | <b>E</b> C)              |                                                                                                                                                                                                                                     |                    |
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| Numeric Development         March Print B         March P         March P <th></th> <th>n ( mysuus (</th> <th>11 E</th> <th>uomo:</th> <th></th> <th></th> <th></th> <th></th> <th>NEXTERNAL</th>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | n ( mysuus (     | 11 E                             | uomo:                    |                            |                |                          |                                                                                                                                                                                                                                     | NEXTERNAL          |
| Total Balance         Total                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 8.877            | 8.8TT 8.3TT                      | A17 A1                   | 7 A.877                    | 1.177          | 1.007<br>7.000           | al an                                                                                                                                                                                           | Y#1                |
| Terme Schurzen - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 1995 - 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| C M                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    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| TRUM Can have - 60.7 60.7 60.7 60.7 60.7 60.7 60.7 60.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                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| Texture         -         Links         Links         Texts         T                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | PB Hot Gas Mass                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                  | 687.4 688.1<br>946.8 941.5       | 077.5                    |                            | 10010          | 786.0                    | a da se de la composición de la composi<br>La composición de la c | 88.3               |
| Ten Los III - 100 / 2011 / 2010 / 2010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 010 - 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| <pre> transform tailing tailin</pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Caset & Monate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                  | -                                |                          |                            |                |                          | , sasak X                                                                                                                                                                                                                           | 344                |
| Conc Bager (n. 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| Total Dr. Y         Total J. January J. Janua                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Colum Baylow Nys                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                  |                                  |                          |                            |                |                          |                                                                                                                                                                                                                                     |                    |
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| Sciences                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Has Joseph. In                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | * 100.0<br>171.4 | 101.0 100.0                      | 1 100.1 11<br>1 100.0 10 | 646 11648<br>649 1973      | 110.4          | 108.4                    |                                                                                                                                                                                                                                     |                    |
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M<br>Ingino Id                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                  | 0.00015 0.0000<br>0.00072 0.0007 | 2 0.00072 0.00           |                            |                |                          |                                                                                                                                                                                                                                     |                    |

Heturn (1993)

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Figure 12. Parametric Data Available - Liquid Engines



Figure 13. Solid Fuel Models Available
Return



Print (Report)



REPORT

Graphs

| Large Motors                                                                                                     | ASRM ANES          | 8652) Propell                            | ani: A part in                                                                                                  |                            |                                                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------|--------------------|------------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4 January 1993                                                                                                   |                    |                                          |                                                                                                                 |                            |                                                                                                                                                                                                                                    |
| Independent Terms                                                                                                |                    | Range                                    | Results                                                                                                         |                            | KMSE                                                                                                                                                                                                                               |
| Meop, psia                                                                                                       | <b>.</b> 1,000     | 200 To 2000                              | Rbo, in/sec                                                                                                     | - 0.530                    | 0.002                                                                                                                                                                                                                              |
| initial Area Ratio, Ei                                                                                           | - 7.0              | - 5 To 19                                | (Isp)sl. sec-lbf/lbm                                                                                            | - 246.54                   | N/A                                                                                                                                                                                                                                |
| Favg)vac, lbf                                                                                                    | . 2,590,000        | 320 K To 8.9 M                           | (Isp)vac, sec-lbf/lbm                                                                                           | - 269.57                   | N/A                                                                                                                                                                                                                                |
| Burn Time, Tb. seconds                                                                                           | - 111              | 60 To 178                                | (A throat)avg, in 2                                                                                             | - 2,243.0                  | 10.7                                                                                                                                                                                                                               |
| Dcase, in                                                                                                        | - 146              | 80 To 255                                | (R throat)avg, in                                                                                               | - 20.7                     | N/A                                                                                                                                                                                                                                |
| Push Weight, lbm                                                                                                 | - 1,000,000        |                                          | (Favg)sl, lbf                                                                                                   | - 2,368,679                | N/A<br>N/A                                                                                                                                                                                                                         |
| iose Cone L/D                                                                                                    | <u> </u>           | 1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1. | (Favg)vac, Ibf                                                                                                  | - 2,590,000                | N/A                                                                                                                                                                                                                                |
| Dependent Terms                                                                                                  |                    |                                          | L case, in                                                                                                      | = 1,187.9<br>P 14          | D.J<br>Note 1                                                                                                                                                                                                                      |
|                                                                                                                  |                    | <b>Linesia kunan ta</b> tata             | L/D case                                                                                                        | .14<br>107 E               | NOLE I                                                                                                                                                                                                                             |
| Note Is                                                                                                          | Cases with L/D     | greater than 5.6                         | L nozzle, in                                                                                                    | = 107.5                    | 3.0                                                                                                                                                                                                                                |
|                                                                                                                  | are difficult to w | vind w/o joints.                         | Nozzle Exdt O.D., in                                                                                            | - 138.D                    | N/A                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | Total Length, in                                                                                                | • 1,545.5                  | N/A<br>Note A                                                                                                                                                                                                                      |
| Note 2:                                                                                                          | MG propellant t    | ourn rates                               | W propellant, lbm                                                                                               | • 1,066,400                | Note 4                                                                                                                                                                                                                             |
|                                                                                                                  | (Rbo) are tallora  | able between                             | W nozzle, lbm                                                                                                   | • 12,500.2                 | 1.025                                                                                                                                                                                                                              |
|                                                                                                                  | 0.334 and 0.80     | 8 ips                                    | W insulation, lbm                                                                                               | • 6,716.0                  | 105                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | W case, lbm                                                                                                     | - 20,124.3                 | 933                                                                                                                                                                                                                                |
| Note 3                                                                                                           | Data is being ex   | drapolated                               | Wigniter, Ibm                                                                                                   | - 633.0                    | 28                                                                                                                                                                                                                                 |
|                                                                                                                  | below range of     | regression.                              | W nose cone, lbm                                                                                                | = 3,/42.3                  | N/A                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | W ext insul, lbm                                                                                                | • 763.5                    | N/A                                                                                                                                                                                                                                |
| Note 4                                                                                                           | Data is being e    | drapolated                               | W fwd skirt, lbm                                                                                                | • 2,965.U                  | N/A                                                                                                                                                                                                                                |
| The second s   | above range of     | regression.                              | Waft skirt, lbm                                                                                                 | - 14,659.7                 | N/A                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | W separation, lbm                                                                                               | - 1,246.8                  | N/A                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | W misc, lbm                                                                                                     | • 980.4                    | N/A                                                                                                                                                                                                                                |
| a series de la series |                    | n is ar haddadbad                        | W SRM, Ibm                                                                                                      | - 1.112E+06                |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          | W stage, lbm                                                                                                    | = 2.436E+04                |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          | W SRB, Iom                                                                                                      | = 1.137E+00                | N/A                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | Videal, n/sec                                                                                                   | = 0.9972400                | N/A                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | Mass Fraction                                                                                                   | 9.3312-01                  | N/R                                                                                                                                                                                                                                |
|                                                                                                                  |                    |                                          | (Impulse)si, ini-sec                                                                                            | 2.025E+00                  |                                                                                                                                                                                                                                    |
| ter fin i der standense dage bester der bester                                                                   |                    |                                          | (impulse)vac, ior-sec                                                                                           | - 2.070E+00                |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          |                                                                                                                 |                            |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          | an a                                                                        |                            |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          | A                                                                                                               |                            |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          |                                                                                                                 |                            |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          |                                                                                                                 |                            |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          |                                                                                                                 |                            |                                                                                                                                                                                                                                    |
| and the second |                    |                                          |                                                                                                                 |                            |                                                                                                                                                                                                                                    |
|                                                                                                                  |                    |                                          | in the second | an nan kurut bisi sa shi s | en an an an Arrange an<br>Arrange an Arrange an Ar |

Figure 14. Solid Motor Model



Figure 15. Parametric Generation Screen - Solid Boosters

| Walanis                 |                                                                                                                                     | Length                                      |                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Pri                | nt                                                                                                             |                                                                                                                 |                   |                  |                                       |                                                                                                                                                                                                                                   |                     |
|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-------------------|------------------|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Mass Praction           | R                                                                                                                                   | erforme                                     | nce                   | _                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                    |                                                                                                                |                                                                                                                 |                   |                  |                                       |                                                                                                                                                                                                                                   |                     |
|                         |                                                                                                                                     | (Denz                                       |                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | use the Ye         | Constraints                                                                                                    |                                                                                                                 |                   | 100              | 5 P. P. P. P.                         | C. C                                                                                                                                                                                          |                     |
| Return                  |                                                                                                                                     | California de                               | 23-12-14<br>23-12-142 | l ž                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Children and Canad | filmt fat. Continue                                                                                            |                                                                                                                 |                   |                  | w y 246-6-62                          | CARAGERS                                                                                                                                                                                                                          |                     |
|                         |                                                                                                                                     |                                             |                       | DORAL D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                    | Arms Matte                                                                                                     |                                                                                                                 |                   |                  |                                       | a fantation                                                                                                                                                                                                                       |                     |
| dependent Variable      |                                                                                                                                     | 1 000                                       | NSKUR UNIK            | 1.000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1.000              | 1.000                                                                                                          | 1,000                                                                                                           | 1,000             | 900.[            | 1,000                                 | NA STATES                                                                                                                                                                                                                         | e ga ja             |
| -Milet Arres Wedde . 11 | s <b>e</b> is e<br>Stati                                                                                                            |                                             | 7.                    | 7.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 4 <b>7.0</b>       | 7.0                                                                                                            | 7.4                                                                                                             | 7.0               |                  | · · · · · · · · · · · · · · · · · · · |                                                                                                                                                                                                                                   | a                   |
|                         | • • • • • •                                                                                                                         | 1 000 000                                   | 1 100 000             | 3 000 000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 3 500.000          | 3.000.000                                                                                                      | 3.500,000                                                                                                       | 4,000.000         | 4,500.000        | 5,000.000                             |                                                                                                                                                                                                                                   | 3                   |
| PROFILER, INC.          | e <b>e</b> 1933.<br>A 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 - 1945 | [,000,000                                   |                       | 111 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 111.0              | مدرر                                                                                                           | 111.0                                                                                                           | 1114.             | 111.0            | 111.4                                 |                                                                                                                                                                                                                                   | Ç.                  |
| " burn, seconds         | •,                                                                                                                                  | 111.0                                       | 111.4                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 140.0              | 144.0                                                                                                          | 148.0                                                                                                           | 146.0             | 146.0            | 146.8                                 |                                                                                                                                                                                                                                   |                     |
| ) case, in              |                                                                                                                                     | 146.9                                       | 140.9                 | 100.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                    |                                                                                                                | 1 000 000                                                                                                       | 1 000 000         | 1.000.000        | 1.000.000                             |                                                                                                                                                                                                                                   |                     |
| rush Weight, Ibm        |                                                                                                                                     | 1,000,000                                   | 1,000.909             | 1,000,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 1,000,000          | 1,000,000                                                                                                      | 1.000,000                                                                                                       |                   |                  | 1.1                                   | ann a stàitean a' stàitean                                                                                                                    |                     |
| ices Cons L/D           | •                                                                                                                                   | <b>E</b> 1                                  | 1.3                   | 1.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 1.3                |                                                                                                                | <u>.</u>                                                                                                        |                   |                  |                                       | menninger er bisseriet mit det in                                                                                                                                                                                                 |                     |
| dente, iben antikken    | i Niji                                                                                                                              | een oor oo |                       | te pienenstate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                    |                                                                                                                | Configuration of the second |                   |                  |                                       |                                                                                                                                                                                                                                   | Silicitais.         |
| locale                  |                                                                                                                                     | 4,731.2                                     | 7,108.0               | 9,545.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 12.045.9           | 14,500.8                                                                                                       | 17.174.8                                                                                                        | 18,791.8          |                  |                                       |                                                                                                                                                                                                                                   |                     |
| nsulation               | •                                                                                                                                   | 4,005.6                                     | 4,994.9               | 5,859.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 6,589.8            | 7.270.9                                                                                                        | 7,901.3                                                                                                         |                   | 3,040.6          |                                       | 100 Y 10 11 11 11 11                                                                                                                                                                                                              |                     |
| <b>.</b>                | •                                                                                                                                   | 10,803.8                                    | 15,819.0              | 20,614.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 35.291.8           | 29,884.7                                                                                                       | 34.408.8                                                                                                        | 36,874.3          | . 6,200.7        | 47,00 kit                             |                                                                                                                                                                                                                                   |                     |
| dniter                  | ` <b>_</b> ``                                                                                                                       | 301.9                                       | \$25.7                | 461.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 8.808              | 759.8                                                                                                          |                                                                                                                 | 1.006.2           | 1,259.0          | 1,436.0                               |                                                                                                                                                                                                                                   | •                   |
| annellent               | 8 <u>8</u> (                                                                                                                        | 413.609                                     | 619.233               | 824.527                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1.029.579          | 1,234,436                                                                                                      | 1,439,138                                                                                                       | 1,643,691         | 3,648,139        | 3,063,440                             |                                                                                                                                                                                                                                   |                     |
| TODEMIN                 | 8 <b>.</b> (                                                                                                                        |                                             | \$ 749 \$             | 8.749.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 3.742.3            | 8.741.9                                                                                                        | 3,742.3                                                                                                         | 3.743.3           | 3.742.3          | 3,743.5                               |                                                                                                                                                                                                                                   |                     |
|                         | <b>.</b>                                                                                                                            |                                             |                       | 763 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 784.6              | 763.5                                                                                                          | 765.5                                                                                                           | 763.5             | 761.5            | 763.5                                 |                                                                                                                                                                                                                                   |                     |
| ht insulation           | •                                                                                                                                   | 701.0                                       | 700.0                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | + 945 A            | 1 665 6                                                                                                        | 9.965.0                                                                                                         | 3.000.0           | 2.965.0          | 3,905.0                               |                                                                                                                                                                                                                                   |                     |
| Pwd Skirt               |                                                                                                                                     | 3,966.6                                     | 7,000.0               | 3,909.9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                    |                                                                                                                | 34 454 5                                                                                                        | 14 658 7          | 14.656.7         | 14.658.7                              |                                                                                                                                                                                                                                   |                     |
| AftSkirt                | •                                                                                                                                   | 14.686.7                                    | 14,060.7              | 14.659.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 14,699.7           | 14.000.7                                                                                                       | 14,000,7                                                                                                        |                   | • 184.4          |                                       |                                                                                                                                                                                                                                   |                     |
| Separation System       |                                                                                                                                     | 485.5                                       | 725.7                 | 965.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | [,208.9            | 1,442.4                                                                                                        | 1.000.7                                                                                                         | 1,010.7           | 1.000.0          | a 006.4                               |                                                                                                                                                                                                                                   | e ni                |
| Miec                    | •                                                                                                                                   | 137.5                                       | 418.8                 | 669.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 996.9              | 1,170.7                                                                                                        | 1,416.5                                                                                                         | 1,847.5           | 1,573.5          | 2,000.4                               |                                                                                                                                                                                                                                   |                     |
| SRM                     |                                                                                                                                     | 435.441                                     | 647.486               | 860.966                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1.074.111          | 1,206.949                                                                                                      | 1,499,537                                                                                                       | 1,711.994         | 1,924,143        | 2.138.348                             | e di kana da san da<br>San da san da | 1355<br>1256 (1894) |
| Stade                   |                                                                                                                                     | 23,754                                      | 29.276                | 23.779                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 24.370             | 24.753                                                                                                         | 25,228                                                                                                          | 25,807            | <b>36</b> , 16 l | 26.620                                |                                                                                                                                                                                                                                   |                     |
| Total (BRB)             |                                                                                                                                     | 456.195                                     | 670.750               | 884.767                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1.098.383          | 1.311.696                                                                                                      | 1.524.765                                                                                                       | 1.737.631         | 1.960.323        | 2,102,868                             |                                                                                                                                                                                                                                   |                     |
| mathe in                | in Dadi                                                                                                                             | a a suidhe lad                              |                       | ingen and a general                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | en de sindere      | in a sur |                                                                                                                 |                   | en Miritha (†    |                                       |                                                                                                                                                                                                                                   |                     |
| Cana                    |                                                                                                                                     | 475.9                                       | 708.4                 | 929.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1,148.3            | 1.304.5                                                                                                        | 1.567.0                                                                                                         | 1,804.6           | 2,021.1          | 2,236.6                               |                                                                                                                                                                                                                                   |                     |
| Nozzle                  |                                                                                                                                     |                                             | 129.9                 | 146.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 164.5              | 101.7                                                                                                          | ) <b>96.</b> 0'                                                                                                 | 318.5             | 227.5            | 241.3                                 |                                                                                                                                                                                                                                   |                     |
| /D Cast                 | 1 <b>-</b> 1                                                                                                                        | * * * * *                                   |                       | e a la caractería de la car                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 7.9                | 94                                                                                                             | <b>10.9</b>                                                                                                     | 13.4              | 18.5             | 15.3                                  |                                                                                                                                                                                                                                   |                     |
| Total                   |                                                                                                                                     | 784.6                                       | 1,018.2               | 1,381.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1,502.3            | 1,739.9                                                                                                        | 1,974.0                                                                                                         | 2.207.6           | 2,438.5          | 3,007.8                               |                                                                                                                                                                                                                                   |                     |
| lise Results            | na bilin                                                                                                                            | atyja                                       |                       | in the specific section of the secti |                    | and the second second                                                                                          |                                                                                                                 | AND ALC: NO. OF A |                  |                                       |                                                                                                                                                                                                                                   |                     |
| Rbo, in/sec             | . •                                                                                                                                 | 0.639                                       | 0.530                 | 0.530                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                    | 0.530                                                                                                          | 0.530                                                                                                           | 0.630             | 0.039            | 4 971 9                               | a ar a tha that a the second                                                                                                                  | 1 . M               |
| (A throat)avg.m*2       | •                                                                                                                                   | 2.000                                       | 1,917.7               | 1,748.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 2,100.9            | 2,500.8                                                                                                        | 3,011.5                                                                                                         | 3,431.5           | 7.5 WR.6         |                                       | 소 문화 영영 주변                                                                                                                                                                                                                        |                     |
| (R throat)avg, in       | •                                                                                                                                   | 10-0                                        | <b>10.1</b>           | <b>. 33</b> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <b>36.3</b>        | 99.7                                                                                                           | 31.0                                                                                                            | <b>77.</b> ]      | بروني<br>ه مور   | 196 6                                 |                                                                                                                                                                                                                                   |                     |
| Noezie Exit Die, in     | •                                                                                                                                   | <b></b> .                                   | 108.6                 | 181.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 136.0              | 149.9                                                                                                          | 100.9                                                                                                           | 172.U<br>مدم ج    |                  |                                       |                                                                                                                                                                                                                                   |                     |
| Mass Fraction           | ° 🔶 -                                                                                                                               | 4.907                                       | 0.923                 | 0.833                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 0.937              | 0.941                                                                                                          |                                                                                                                 | 9 244 218         | A 118 104        | 4.571.630                             |                                                                                                                                                                                                                                   |                     |
| (Favg)al, ibf           |                                                                                                                                     | 914.397                                     | 1,371.061             | 1,828.993                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 2,296,351          | 3,743,741                                                                                                      | 3,201,108                                                                                                       | 1.000.000         | 4 500,000        | 5.000.000                             |                                                                                                                                                                                                                                   |                     |
| (Pavg)vac, Ibf          |                                                                                                                                     | 1.000,000                                   | 1,500,000             | 2.000,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 3,800,000          | 9.000,000                                                                                                      | 348 91                                                                                                          | 547 M             | 247.91           | 247.35                                |                                                                                                                                                                                                                                   | esti i              |
| (Isp)el, ecc-lb//lbm    | •                                                                                                                                   | 248.50                                      | <b>148.89</b>         | 246.23                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 245.49             | 244.73                                                                                                         |                                                                                                                 | 270.19            | \$70.97          | 278.41                                |                                                                                                                                                                                                                                   | 1.0                 |
| (lap)vac, sec-lb//lbm   |                                                                                                                                     | 306.87                                      | 268.84                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                    | NAL REE 04-1                                                                                                   | 355 329.100                                                                                                     | 404.108.571       | 456.867.827      | 507.671.836                           |                                                                                                                                                                                                                                   | - 10                |
| (Impulse)sl, lbf-sec    |                                                                                                                                     | 101,491,444                                 | 133,354,419           | 203,018,303                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                    | 111 000 000                                                                                                    | 385,500,000                                                                                                     | 444.000.000       | 499,500,000      | \$55,000,000                          |                                                                                                                                                                                                                                   |                     |
| (impulse)vac, ibi-sec   | •                                                                                                                                   | 111.000.000                                 | 100.509,000           | 222,000,000<br>222,000,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 2/ 7,000,000       | 6.A11                                                                                                          | 7,991                                                                                                           | 7,974             | 8,564            | 9,109                                 | 19월 504일 전문원                                                                                                                                                                                                                      |                     |
| V ideal, fl/sec         |                                                                                                                                     | 7.000                                       | 4,000                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                    |                                                                                                                | Mar Maria                                                                                                       |                   |                  | (* <u>1</u> 68) (* 4)                 | 다. 같을 다 없는 것 . 것은 것 같아. 것 같아.                                                                                                                                                                                                     | 1993                |

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Figure 16. Parametric Results Table - Solid Boosters

| Indenendent Variabilea   |      | SA.         | RM (ANBS   | 652) Prop   | ellant - L  | arge Moto   | 81          |             |             |                               |
|--------------------------|------|-------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------------------------|
| Meon. psia               |      | 1,000       | 1.000      | 1,000       | 1,000       | 1,000       | 1,000       | 1,000       | 1,000       | 1.000                         |
| Initial Arca Ratio. Ei - |      | 7.0         | 7.0        | 7.0         | 7.0         | 7.0         | 7.0         | 7.0         | 7.0         | 7.0                           |
| (Favolvac, Ibf           |      | 000.000     | 1,500,000  | 2,000,000   | 2,500,000   | 3.000,000   | 3,500,000   | 4,000,000   | 4.500,000   | 5.000.000                     |
| T burn. seconds          |      | 0.111       | 111.0      | 0.111       | 111.0       | 111.0       | 0.111       | 111.0       | 0.111       | 111.0                         |
| D case, in               |      | 146.0       | 146.0      | 146.0       | 146.0       | 146.0       | 146.0       | 146.0       | 146.0       | 146.0                         |
| Push Weight. Ibm         | -    | 000'000     | 1,000,000  | 1,000.000   | 1,000.000   | 1,000,000   | 1.000.000   | 1,000.000   | 1,000,000   | 1.000,000                     |
| Nose Cone L/D            |      | 1.3         | 1.3        | 1.3         | 1.3         | 1.3         | 1.3         | 1.3         | 1.3         | 1.3                           |
| Weights. Ibm             |      |             |            |             |             |             |             |             |             |                               |
| Nozzle                   |      | 4,731.3     | 7,102.0    | 9.545.6     | 12,045.2    | 14.590.5    | 17,174.3    | 19.791.8    | 22,439.0    | 25,112.9                      |
| Insulation               |      | 4,005.6     | 4,994.9    | 5,839.0     | 6,588.8     | 7,270.9     | 2,901.3     | 8,490.3     | 9,045.4     | 9,571.9                       |
| Case                     |      | 0,893.6     | 15,829.0   | 20,614.6    | 25,291.8    | 29,884.7    | 34,408.6    | 38,874.3    | 43,289.7    | 47.661.1                      |
| Igniter                  |      | 201.9       | 325.7      | 461.4       | 606.6       | 759.8       | 920.1       | 1,086.7     | 1,259.0     | 1,436.6                       |
| Propellant               |      | 413,609     | 619,232    | 824.527     | 1.029.579   | 1.234,436   | 1,439,133   | 1,643,691   | 1,848,129   | 2.052.460                     |
| Nose Cone                |      | 3,742.3     | 3,742.3    | 3,742.3     | 3,742.3     | 3,742.3     | 3,742.3     | 3,742.3     | 3,742.3     | 3,742.3                       |
| Ext Insulation           |      | 763.5       | 763.5      | 763.5       | 763.5       | 763.5       | 763.5       | 763.5       | 763.5       | 763.5                         |
| Fwd Skirt                |      | 2,965.0     | 2,965.0    | 2,965.0     | 2,965.0     | 2,965.0     | 2,965.0     | 2,965.0     | 2,965.0     | 2,965.0                       |
| AftSkirt                 |      | 14,659.7    | 14,659.7   | 14.659.7    | 14,659.7    | 14,659.7    | 14,659.7    | 14,659.7    | 14,659.7    | 14,659.7                      |
| Separation System        |      | 485.8       | 725.7      | 965.0       | 1,203.9     | 1,442.4     | 1,680.7     | 1,918.7     | 2,156.6     | 2,394.3                       |
| Misc                     |      | 679.2       | 960.5      | 1,224.9     | 1,477.6     | 1.721.4     | 1,958.2     | 2,189.2     | 2,415.3     | 2,637.1                       |
| SRM                      | ,    | 433,441     | 647,484    | 860,988     | 1.074.111   | 1.286.942   | 1,499,537   | 1,711,934   | 1.924.162   | 2,136,243                     |
| Stage                    |      | 23,296      | 23,817     | 24,320      | 24,812      | 25,294      | 25,769      | 26,238      | 26.702      | 27.162                        |
| Total (SRB)              |      | 456,737     | 671,301    | 885,308     | 1.098.923   | 1.312.237   | 1.525,306   | 1,738,173   | 1.950.865   | 2,163,405                     |
| Lengths, in              |      |             |            |             |             |             |             |             |             |                               |
| Case                     | n    | 475.6       | 702.4      | 926.4       | 1,148.2     | 1,368.3     | 1,587.0     | 1,804.6     | 2,021.1     | 2,230.0                       |
| Nozzle                   | Ħ    | 99.3        | 123.9      | 145.2       | 164.3       | 181.7       | 198.0       | 213.2       | 227.0       | 241.0                         |
| L/D Case                 | 11   | 3.3         | 4.8        | 6.3         | 7.9         | 9.4         | 10.9        | 12.4        | 10.01       | 10.01<br>10.02 10<br>10.02 10 |
| Total                    | H    | 764.6       | 1,016.2    | 1.261.4     | 1.502.3     | 1.739.9     | 1,974.8     | 2.207.6     | 2,430.0     | 2.001.2                       |
| Die Je / con             | 1    | 0 530       | 0.530      | 0.530       | 0.530       | 0.530       | 0.530       | 0.530       | 0.530       | 0.530                         |
| KUU, μι/ Sou             | 1 11 | 890.2       | 1.317.7    | 1,743.0     | 2,166.9     | 2,569.5     | 3,011.1     | 3,431.9     | 3,851.9     | 4,271.2                       |
| (R throat avg. In        | 11   | 16.8        | 20.5       | 23.6        | 26.3        | 28.7        | 31.0        | 33.1        | 35.0        | 36.9                          |
| Nozzle Exit Dia, in      | H    | 86.1        | 105.4      | 121.7       | 136.0       | 149.0       | 160.9       | 172.0       | 182.3       | 192.2                         |
| Mass Fraction            |      | 0.906       | 0.922      | 0.931       | 0.937       | 0.941       | 0.944       | 0.946       | 0.947       | 0.949                         |
| (Favg)sl. lbf            |      | 914.337     | 1.371.661  | 1,828,993   | 2,286.351   | 2.743.741   | 3,201,163   | 3,658,618   | 4,116,104   | 4.573.620                     |
| (Favg)vac, Ibf           | "    | 000'000'    | 1,500,000  | 2.000,000   | 2,500,000   | 3,000,000   | 3,500,000   | 4.000,000   | 4,500,000   | 5,000,000                     |
| (Isp)sl, sec-lbf/lbm     | H    | 245.38      | 245.88     | 246.22      | 246.49      | 248.72      | 246.91      | 247.07      | 247.22      | 247.35                        |
| (Isp)vac. sec-lbf/lbm    | ŧI   | 268.37      | 268.88     | 269.25      | 269.53      | 269.76      | 269.95      | 270.12      | 270.27      | 270.41                        |
| (Impulse)sl, lbf-sec     | = 10 | 491,445 1   | 52,254,419 | 203.018.262 | 253,784,994 | 304,555,227 | 355,329,100 | 406,106,572 | 456,887,527 | 507,671,826                   |
| (Impulse)vac, Ibf-sec    | =    | 1,000,000,1 | 66,500,000 | 222,000.000 | 277,500,000 | 333,000,000 | 388,500,000 | 444,000,000 | 488,500,000 |                               |
| V ideal, ft/sec          | 11   | 2,884       | 4,005      | 4,983       | 5,849       | 6.626       | 7,329       | 179.7       | 100'8       | 8,100                         |
|                          |      |             |            |             |             |             |             |             |             |                               |

Figure 17. Printed Output of Parametric Results - Solid Motors

-



## Figure 18. Printed Version of Weights Chart - Solid Rocket Boosters



# Figure 19. Printed Version of Lengths Chart - Solid Rocket Boosters



Figure 20. Printed Version of Mass Fraction Chart - Solid Rocket Boosters



Figure 21. Printed Version of Performance Chart - Solid Rocket Boosters



Figure 22. Parametric Results Available - Solid Rocket Boosters





Print (Report)



HERE BOWER

Graphs

and the particular

| idependent Terms                                                                                                 |                                                                                                                 | Rande         | Destrike with a                                                                                                                                                                                                                  |                                         | <b>H. M. S. K</b> .      |
|------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|--------------------------|
| eop. psia                                                                                                        | A VALUE AND A V |               | Results                                                                                                                                                                                                                          |                                         |                          |
| THE REAL PROPERTY OF THE STANDARD AND AND AND AND AND AND AND AND AND AN                                         | 500                                                                                                             | 500 To 1500   | D nozzle exit, in                                                                                                                                                                                                                | - 132.8                                 | N/A                      |
| itial Arca Ratio, Ei                                                                                             | 8                                                                                                               | 8 To 20       | (Isp)sl, sec-lbf/lbm                                                                                                                                                                                                             | - 238.76                                | N/A                      |
| avglvac, lbf                                                                                                     | 1,267,506                                                                                                       | 280 K To 21 M | (Isp)vac, sec-lbf/lbm                                                                                                                                                                                                            | - 284.48                                | 1.9                      |
| urn Time, Tb, seconds -                                                                                          | 45                                                                                                              | 45 To 200     | (A throat)avg. in^2                                                                                                                                                                                                              | - 1,765.4                               | N/A                      |
| e Cone L/D                                                                                                       | 1.3                                                                                                             | 0.5 To 3.0    | (R throat)avg. in                                                                                                                                                                                                                | - 23,7                                  | 0.9                      |
| x Ox Flux, Ibm/s-in^2                                                                                            | 0.2                                                                                                             | 0.2 To 1.0    | (Favg)al, Ibf                                                                                                                                                                                                                    | . 1,063,817                             | N/A                      |
| rg MR. O/F                                                                                                       | 1.8                                                                                                             | 1.8 To 2.8    | (Favg)vac, lbf                                                                                                                                                                                                                   | = 1,207,500                             | N/A                      |
| ush Weight, Ibm                                                                                                  | 1,000,000                                                                                                       |               | L tank & case, in                                                                                                                                                                                                                | <ul> <li>803.5</li> <li>4.01</li> </ul> | /1<br>N/A                |
|                                                                                                                  |                                                                                                                 |               | L/D case                                                                                                                                                                                                                         | - 9.81<br>105 7                         | RJ<br>N/A                |
| ependent Terms                                                                                                   |                                                                                                                 |               | L nozzie, in                                                                                                                                                                                                                     | = 120.7<br>109 E                        | 03                       |
|                                                                                                                  | i in the second states                                                                                          |               | D motor. in                                                                                                                                                                                                                      | . 103.0                                 | J<br>N/A                 |
|                                                                                                                  |                                                                                                                 |               | Total Length, in                                                                                                                                                                                                                 | = 1,141,8                               | 17/A                     |
| Note 1:                                                                                                          | Data is being ex                                                                                                | trapolated    | W oxidizer, IDm                                                                                                                                                                                                                  | • 140,404<br>71 969                     | N/A<br>N/A               |
|                                                                                                                  | below range of                                                                                                  | regression.   | w fuel, iom                                                                                                                                                                                                                      | 100 819                                 | N/A                      |
|                                                                                                                  |                                                                                                                 |               | W propellant, ibm                                                                                                                                                                                                                | - 199,010<br>                           | N/A                      |
| NOIC 24                                                                                                          | Data is being o                                                                                                 | drapolated    | W nose cone, lom                                                                                                                                                                                                                 | - 0,307.4<br>001 F                      | N/A                      |
|                                                                                                                  | above range of                                                                                                  | regression.   | Wext insul. Ibm                                                                                                                                                                                                                  | - 921.3                                 | N/A                      |
|                                                                                                                  |                                                                                                                 |               | W fwd skirt, lom                                                                                                                                                                                                                 | - 4./44                                 | N/A                      |
|                                                                                                                  |                                                                                                                 |               | Walt Skirt, IDm                                                                                                                                                                                                                  | • 23,240<br>981                         | N/A                      |
|                                                                                                                  |                                                                                                                 |               | W separation, 10m                                                                                                                                                                                                                | - 201<br>1 868                          | N/A                      |
|                                                                                                                  |                                                                                                                 |               | W misc, lom                                                                                                                                                                                                                      | = 1,000                                 |                          |
|                                                                                                                  |                                                                                                                 |               | W HRM. IDM                                                                                                                                                                                                                       | a 712F10A                               | - 18 (A) (C)<br>- 18 (A) |
|                                                                                                                  |                                                                                                                 |               | W stage, iom                                                                                                                                                                                                                     | 2 RORF105                               | ******                   |
|                                                                                                                  |                                                                                                                 |               | W HRB, 10m                                                                                                                                                                                                                       | 1 569F109                               | N/A                      |
|                                                                                                                  |                                                                                                                 |               | V Ideal, IT/sec                                                                                                                                                                                                                  | = 1.300E703                             | 0.012                    |
| and the second |                                                                                                                 |               | Mass Fraction                                                                                                                                                                                                                    | - 0.3946-VI                             | N/A                      |
|                                                                                                                  |                                                                                                                 |               | (Impulse)si, IDI-sec                                                                                                                                                                                                             | 5 704E+07                               | N/A                      |
|                                                                                                                  |                                                                                                                 |               | (impulse/vac, ini-sec                                                                                                                                                                                                            | • J./041570/                            | M/A                      |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  |                                         | ¢e N                     |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  |                                         | M. 1971                  |
|                                                                                                                  |                                                                                                                 |               | a da serva de serva<br>Esta de serva de serv |                                         |                          |
|                                                                                                                  |                                                                                                                 |               | Contraction of the second s                                                                                                                  |                                         |                          |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  | 1000 SG 👬 🖉                             | 199                      |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  |                                         | <b>.</b>                 |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  |                                         | 121912                   |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  |                                         |                          |
|                                                                                                                  |                                                                                                                 |               |                                                                                                                                                                                                                                  |                                         |                          |

Figure 23. Input/Output Table for Hybrid Rocket Booster Model



Figure 24. Parametric Data Generation Screen - Hybrid Motors

| El S 236276)                  |              |                  | Dom                 |                | to See the       |                    |                                              |                            |                | etra no                                          |                          |                    |
|-------------------------------|--------------|------------------|---------------------|----------------|------------------|--------------------|----------------------------------------------|----------------------------|----------------|--------------------------------------------------|--------------------------|--------------------|
| undernin koma 🖉 - inna ar e i |              | 1                | yorid Prop          | ellanta 🛶      | Large Moto       | rs                 | n nin an |                            |                |                                                  |                          |                    |
| oon, neis                     |              | 500              | 500                 | 600            | 500              |                    | 500                                          | 109                        | <u>, 504</u>   | 808                                              |                          | 500                |
| Itial Ares Ratio, B           | 20           |                  |                     |                |                  |                    |                                              | 8.6                        |                |                                                  |                          | . <b></b>          |
| and M                         | × 3,03       | 1 247 508        | 1.967.506           | 1.267.306      | 1.267.506        | 1,367.506          | 1,267,506                                    | 1,387,508                  | 1,267,806      | 1,307,508                                        | 1,267.508                | 1,267,505          |
|                               | •            | 45.0             | 45.0                | م مه           | 46.0             | 48.0               | 48.0                                         |                            | 45.0           | ( <b>1.</b> )                                    | 45.0                     | - 45.0             |
|                               |              | 1.00             | 1 10                | 1.30           | 05.1             |                    |                                              |                            | 1.20           |                                                  | 1.30                     | 1,30               |
|                               |              |                  |                     |                | B 30             | 0.30               | 6.90                                         |                            |                | 6.56                                             | 0.90                     | 0.30               |
|                               |              |                  |                     | • 00           | 9 10             | 1.94               | 1.30                                         | 2.45                       | 1.00           | 2.00                                             | 1.70                     | 2.80               |
| NE MIL O/F                    | * <b>*</b>   | 1.89             |                     |                | 1 000 000        | 1 000 000          | 1 000 000                                    | 1 000 000                  | 1.000.000      | 1.000.000                                        | 1.000.000                | 1.000,000          |
| ash Weight, Ibm               |              | 1,000,000        | 1.000.000           | 1,000.000      | 1.000.000        |                    |                                              |                            |                |                                                  |                          |                    |
| ighte, Den                    |              |                  |                     |                |                  |                    |                                              | a succession of the second |                |                                                  |                          |                    |
| a second datas                | •••          | 1.4.6            | icie i de Algeicale | gaph nga kabum | 1                |                    | 104 344                                      |                            | 134            | 104 575                                          | 137.100                  | 197.751            |
| xidiser 🕺                     | . • .        | 129.454          | 139.645             | ]3],]49        | 122,239          | 122,287            | 194,999                                      |                            | 84 4FF         |                                                  | 50.019                   | 49.107             |
|                               | •            | 71,565           |                     | 65,584         | <b>\$9,010</b> . | 90,617             | 00,357                                       |                            |                |                                                  |                          | 4.507              |
| oes Cone                      |              | 6.307            | 6,307               | 8,307          | 6,307            | 6,307              | 8,307                                        | 6,307                      | 4,367          |                                                  | 0.007                    |                    |
| d Inculation                  | -            | <b>661.5</b>     |                     | 681.5          | <b>B</b> 1.3     | <b>1.1</b>         | • • • • • • • • •                            | <b></b>                    | . <b></b>      |                                                  | ·····                    |                    |
| rd Skirt                      |              | 4.734            | 4,734               | 4.724          | 4.734            | 4,724              | 4.724                                        | oge 4,784                  | 4,734          | 4.724                                            | 4,734                    | 6,734              |
| nSkirt.                       |              | 33,240           | \$3,340             | 23.240         | \$3,240          | 95,240             | 23.249                                       | 23,340                     | 23.240         | 29.340                                           | 23.240                   | 23,340             |
| eneration System              |              | 941              | 259                 | 257            | 256              | 264                | 253                                          |                            | 350            | 249                                              |                          | 247                |
|                               | <u>.</u>     | 1 000            | 1.623               | 1.565          | 1.346            | 1.511              | 1,478                                        | 1,448                      | 1,419          | 1,305                                            | 1.300                    | 1,341              |
|                               |              | 999 614          | 991.004             | 229.673        | 228.203          | 226,893            | 226,637                                      | 224,439                    | 123,275        | 223.143                                          | 221,069                  | 320.054            |
|                               |              |                  | 37 075              | 87 034         | 54.944           | 36.954             | 36,935                                       | 36,895                     | 28.86          | 30,894                                           | 38,807                   | 36,761             |
| nda                           |              | ••••••           |                     |                |                  | 31011 Maret 40     | i in arca                                    | 407 N 199                  | 1999 (P. 1997) | 10 M 10                                          | (* 1 × 1 × 1 × 1 × 1     | Section 1999       |
|                               |              |                  |                     |                | 945 108          | 263 851            | 261.562                                      | 261.326                    | 260,138        | 258.998                                          | \$57.896                 | 256.035            |
| otal (HKB)                    |              | 200.034          | 300,003             | 200,007        |                  | inter at states in | and a second second se                       | sike wskied                | i enit pa 1.19 | n sala si ka | alan se biya a           | a National Andreas |
| ngths, in                     |              |                  |                     |                |                  |                    | 796.0                                        | 721.5                      | 7104           | 700.0                                            |                          | 680.8              |
| ank à Case                    | :<br>::::    | 901. <b>)</b>    | 767.4               | 7724           | /06.4            |                    | 195.7                                        | 198 7                      | 195.7          | 196.7                                            | 125.7                    | 128.7              |
| ozzie                         | 8 <b>*</b> 1 | 196.7            |                     | 1267           | * * * * * * * *  |                    |                                              |                            |                | 49                                               | 44                       | 4.9                |
| /D (Tank & Case)              |              | . <b></b>        |                     | 47             |                  |                    | 4.8<br>7 A71 -                               | 1 140 4                    | 1 048 7        | 1.058.5                                          | 1.028.5                  | 1.019.2            |
| lato                          | 100 E.       | 1,141.9          | 1,125.7             | 1,110.7        | 1.000.7          | 1,003.0            | 1,071.4                                      | P. I. S. S. BURK           |                |                                                  | H NAMES                  |                    |
| SC Results                    | 161 S.J.     | anan minini kata |                     | 1 744          | 1.744            | 1.744              | 1.765                                        | 1,765                      | 1,768          | 1,765                                            | 1,766                    | 1,765              |
| threather f                   |              | 3.700            |                     | 93 7           | <u>91</u> 7.     | 1.7                | 21.7                                         | 33.7                       | 21.7           | S.7                                              | 92.7                     | 23.7               |
| Curdelavy, E                  |              | 149.2            | 141 5               | 161.5          | 143.5            | 189.5              | 163.5                                        | (68.5                      | 169.5          |                                                  | 163.5                    | 163.5              |
| ionale Exit Dia, in           |              | 132.4            | 132.8               | 132.8          | 133.8            | 122.8              | 132.6                                        | 132.0                      | 192,8          | 122.5                                            | 132.5                    | 192.8              |
| ana Fraction                  | ÷.           | 0.869            | 0.868               | 0.657          | 0.865            | 9.856              | 0.854                                        | 0.855                      | 0.662          | 0.851                                            | 0.860                    | 0.860              |
| avelal. Ibi                   |              | 1.063.817        | 1.053,817           | 1,065.817      | 1,063,817        | 1,063,817          | 1,083,817                                    | 1,045,817                  | 1.063,817      | 1,063.817                                        | 1,065.817                | 1,063,817          |
| avg)vac, lbf                  | ÷.           | 1,307,500        | 1,267,506           | 1,267,506      | 1,267.506        | 1,267,506          | 1,267,508                                    | 1,267,506                  | 1,367,506      | 1,267,506                                        | 1,357,506                | 1,267,805          |
| ap)al, sec-lbf/lbm            |              | 238.76           | 340.06              | 242.44         | 244.25           | 245.90             | 247.61                                       | 249.23                     | 250.77         | 265.29                                           | 783.76                   | 200.20             |
| sp)vac, sec-lb(/lbm           |              | 384.48           | 206.73              | 206.91         | 291.01           | 293.05             | 296.03                                       | 296.93                     | 296.78         | 390,69                                           | 303.30                   |                    |
| impulacial, ibf-aec           |              | 47.871.761       | 47,871.761          | 47.871.761     | 47.871,761       | 47.871.761         | 47.871.761                                   | 47.871.741                 | 47,871,761     | 47,871,781                                       | 9/,8/1,/0[<br>E7 017 790 | 87 097 770         |
| impulae)vac, ibf-sec          |              | 67,037,770       | \$7,037,770         | \$7,037,770    | \$7,037,770      | 57.037,770         | 87.037.770                                   | 57,037,779                 | a7,037.770     | 97,U37,(79                                       | 1 1.75                   | 1.579              |
| ideal, fl/sec                 |              | 1.568            | 1,569               | 1.570          | 1,579            | 1.571              | 1,573                                        | 1,573                      |                | L.#/*                                            |                          | •••••              |

Figure 25. Parametric Results Table – Hybrid Rocket Boosters



Figure 26. Parametric Data Available - Hybrid Rocket Boosters

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Mcop, psia Initial Arra Ratio. El												
Initial Area Ratio, El .	50	0 500	500	500	500	500	500	500	500	500	500	
	đ	.0 8.0	6.0	8.0	<b>5</b> .0	8.0	8.0	8.0	8.0	8.0	8.0	
(Favgyvac, Ihf	. 1.267.50	36 1,267,508	1,267,506	1,267,506	1,267,506	1.267.506	1,267,506	1,267,506	1,267,506	1,267,506	1,267,506	
T burn, seconds	. 45.	.0 45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	
Nose Cone L/D	. 1.3	30 1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	-
Max Ox Flux, Ibf/e-in^2 .	. 0.2	20 0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
Avg MR, O/F	. 1.6	30 1.90	2.00	2.10	2.20	2.30	3.40	2.50	2.60	2.70	2.80	
Push Weight, Ibm	1.000.00	000.000	1,000,000	1.000.000	1.000.000	1.000,000	1.000.000	1,000,000	1.000.000	1.000.000	1.000.000	
Weights, Ibm												
-	-											
Oxidizer	. 128.45	54 129,885	131,168	132,320	133,357	134.290	135,132	135,890	136,575	137,193	137.751	
Fuel .	. 71.36	53 68,361	65,584	63.010	60,617	58,387	56,305	54,356	52,529	50,812	49,197	
Nose Cone	• 6.30	07 6.307	6,307	6.307	6,307	6.307	6,307	6,307	6.307	6.307	6,307	
Ext Insulation	. 921	.5 921.5	921.5	921.5	921.5	921.5	921.5	921.5	921.5	921.5	921.5	
Fwd Skirt	. 4.72	24 4.724	4.724	4.724	4,724	4.724	4.724	4.724	4.724	4,734	4,724	
AftSkirt	. 23,24	10 23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	
Separation System	. 36	31 259	257	256	254	253	252	250	240	248	247	
Misc	. 1.66	36 1,623	1.583	1.548	1.511	1.478	1,448	1.419	1.392	1.366	1,341	
HRM	- 232,51	14 231,008	229,573	228,203	226,893	225.637	224.433	223,275	222,162	221,089	220,054	
Stage	- 37.11	20 37.075	37,034	36,995	36,959	36,925	36,893	36,863	36,834	36,807	36,781	
Total (HRB)	- 269.6	34 268.083	266,607	265.198	263,851	262,562	261.326	260.138	258,996	257.896	256.835	
		1 197 1	A 077	758.4	745.0	737 0	7913	7104	200.0	690.2	ARD D	
North	- 1000 	- 101 C	125.7	125.7	195.7	125.7	125.7	125.7	125.7	125.7	125.7	
I /D (Tank & Cam)		A A A	4.7	4.6	4.6	1.54 1.5				5	42	
Total		9 1 125 7	1.110.7	1.096.7	1.083.6	1.071.2	1.059.6	1.048.7	1.038.3	1.028.5	1.019.2	
Misc Results												
(A throat)avg.in^2	= 1.7(	85 1.765	1,765	1,765	1.765	1.765	1.765	1.765	1,765	1,765	1.765	
(R throat)avg, in	33	3.7 23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	
Motor Dia, in	= 163	1.5 163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	
Nozzle Exdt Dia, in	= 132	1.8 132.8	132.8	132.6	132.8	132.8	132.8	132.8	132.8	132.8	132.8	
Mass Fraction	≡ 0.8	59 0.858	0.857	0.856	0.855	0.854	0.853	0.852	0.851	0.850	0.850	
(Favg)al, lbf	= 1,063,8	17 1,063,817	1,063,817	1,063.817	1,063,817	1,063,817	1,063,817	1,063,817	1,063,817	1,063,817	1,063,817	
(Favg)vac. lbf	<ul><li>1.267.50</li></ul>	06 1,267,506	1,267,506	1.267.506	1,267,506	1,267,506	1,267,506	1.267.506	1,267,506	1.267.506	1,267,506	
(Isp)sl, sec-lbf/lbm	= 238.	76 240.66	242.48	244.25	245.96	247.61	249.22	250.77	252.29	253.76	255.20	
(lsp)vac, sec-lbf/lbm	= 284.	48 286.73	288.91	291.01	293.05	295.02	296.93	298.79	300.60	302.35	304.06	
(Impulse)sl, lbf-sec	= 47.871.7	61 47,871,761	47,871,761	47.871.761	47.871.761	47,871,761	47,871,761	47,871,761	47,871,761	47.871.761	47.871.761	
(Impulse)vac, Ibf-sec	= 57,037,7	70 57,037,770	57,037,770	57,037,770	57,037,770	57,037,770	57,037.770	57,037,770	57.037.770	57,037,770	57,037,770	
V Ideal, II/ sec	n. -	68 I, 569	0/6.1	0/0.1	1/0'1	7/c'I	c/c'1	1,0,1	• / 0' 1	C/C'1	0/0'1	

Figure 27. Printed Version of Parametric Results Chart - Hybrid Boosters



Figure 28. Printed Version of Weights Chart - Hybrid Rocket Motors



Figure 29. Printed Version of Lengths Chart – Hybrid Rocket Motors







Figure 31. Printed Version of Performance Chart – Hybrid Rocket Motors



### Figure 32. Reactor Choices



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### Figure 33. Fuel Form Choices

	na da serie de la composición de la com Esta de la composición	2	1045417.440)	aivei	) Contraction (d	64.40C)		n finita Malakistan Malakistan	n Spake Maria	
	14. <b>-</b>				OUTP	UTWIND	WOO		di di di	
input	input	. Ryac	Ţç.	Pc	Epsilon	<b>%L</b>	Del Isp sec	Total Wt Ibm	Envel Dia in	Envel L in
Parameter Fyac, Kibf	50.000	50.000	2,450	784	200	110	849.6	9,524.0	96.4	<u>324.9</u>
25 to 100 Tc. *K	2,450	narust/We	ight Ratio							
Pc, psia	784							an a		
(500 to 2,000)	200				ande legitime : Mai la la c					
100 to 700	200			e ne ne der Bis gester						

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Figure 34. Nuclear Thermal Rocket Model

Return





Vacuum Thrust (percent)

TA3-0420Fig

Ingredient	Weight Percent
AI	19.0
AP	68.86
HP*	12.0
Fe2O3**	0.14

\* varied for mechanical property control \*\* varied for burn rate control

Figure 36. Nominal	Composition of	ASRM Propel	lant
--------------------	----------------	-------------	------

Exhaust Product	Mass Fraction
CO (g)	0.2081
CO2 (g)	0.02786
CL (g)	0.00285
HCI (g)	0.2093
FeCl2 (g)	0.0021
H (g)	0.00019
H2 (g)	0.01972
H2O (g)	0.08455
Al2O3 (s & l)	0.3587
N2 (g)	0.08582

Figure 37. Theoretical Exhaust Products at 1,000 psi Chamber Pressure Expanded to 14.7 psi ASRM Propellant

Large Motors	ASRM (ANB3	(652) Propell	ant		
14 January 1993	TRANSPORT		Panilla		RMSE
Independent Terms		kange	Pho in /sec	- 0.530	0.002
Meop, psia	1,000	200 To 2000	(len)el sec.lhf/lhm	246.54	N/A
Initial Area Ratio, Ei	7.0	5 TO 19	(Isp)si, scc-ibi/ibii (Isp)yac_sec_lbf/lbm	269.57	N/A
(Favg)vac. lbf	. 2,590,000	320 K TO 8.9 M	(A throat)ave in^?	- 2.243.0	10.7
Burn Time, Tb, seconds -		00 10 1/8	(R throat)ave in	. 26.7	N/A
Dcase, in		60 10 255	(Four)el lbf	. 2.368.679	N/A
Push Weight, lbm	1 20		(Favolvac, lbf	- 2,590.000	N/A
Nose Cone L/D	• 1.30		L case, in	<b>1.187.9</b>	5.3
Dependent lerms			L/D case	. 8.14	Note 1
State 1.	Cases with I /D	greater than 5.6	L nozzle, in	- 167.5	3.6
Note 1:	are difficult to u	rind $w/o$ loints.	Nozzle Exit O.D., in	<b>1</b> 38.5	N/A
	as anicult to w		Total Length, in	<b>1,545.3</b>	N/A
Note 9.	MG propellant h	urn rates	W propellant, lbm	<b>1,066,466</b>	Note 4
MOLE 2:	(Rbo) are tailora	ble between	W nozzle, lbm	- 12,500.2	1,025
	0.334 and 0.806	ips.	W insulation. lbm	- 6,716.0	105
		-	W case, lbm	<b>26,124.3</b>	933
Note 3:	Data is being ex	trapolated	W igniter, lbm	<b>-</b> 633.6	29
	below range of a	regression.	W nose cone, lbm	- 3,742.3	N/A
		-	W ext insul. lbm	- 763.5	N/A
Note 4:	Data is being ex	trapolated	W fwd skirt, lbm	- 2,965.0	N/A
	above range of r	egression.	W aft skirt, lbm	<b>-</b> 14,659.7	N/A
	5	-	W separation, lbm	- 1.246.8	N/A
			W misc, lbm	<b>1,522.1</b>	N/A
			W SRM, lbm	- 1.112E+06	
			W stage, lbm	- 2.490E+04	
			W SRB, lbm	- 1.137E+06	
			V ideal, ft/sec	- 5.995E+03	N/A
			Mass Fraction	<b>9.377E-01</b>	N/A
			(Impulse)sl, lbf-sec	- 2.629E+08	6
			(Impulse)vac, lbf-sec	- 2.875E+08	6

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Figure 38. Printed Output- "Report" - English Units

Large Motors ASRM (ANB3	3652) Propella	nt			
14 January 1993					
Independent Terms	Range	Results			RMSE
Mcop, psta - 1,000	200 To 2000	Rbo, cm/sec	•	1.345 (	0.00508
Initial Area Ratio, El - 7.0	5 To 19	(Isp)sl, scc-N/kg		2.417.70	N/A
(Favg)vac, lbf - 2.590,000	320 K To 8.9 M	(Isp)vac. sec-N/kg		2.643.60	N/A
Burn Time, Tb, seconds - 111	60 To 178	(A throat)avg, cm^2		14,471.2	69.0321
Dcase, in 146	80 To 255	(R throat)avg. cm		67.9	N/A
Push Weight. lbm = 1,000,000		(Favg)sl, N		10.535.884	N/A
Nose Cone L/D - 1.30		(Favg)vac, N	•	11.520.320	N/N
Dependent Terms		L case, cm		3.017.4	13.462
		L/D case	,	8.14	Note 1
Note 1: Cases with L/D	greater than 5.6	L nozzle. cm		425.6	9.144
are difficult to w	vind w/o joints.	Nozzle Extt O.D., cm		351.7	N/A
	<b>.</b>	Total Length. cm		3,925.0	N/A
Note 2: MG propellant t	ourn rates	W propellant, kg		483.643	Note 4
(Rbo) are tailor	able between	W nozzle, kg	•	5,668.9	464.838
0.334 and 0.800	6 ips.	W insulation, kg		3,045.7	47.6175
	•	W case. kg		11.847.4	423.116
Note 3: Data is being ex	ctrapolated	W igniter, kg		287.3	13.1515
below range of	regression.	W nose cone, kg		1,697.1	N/A
0	0	W ext insul, kg	•	346.2	N/A
Note 4: Data is being ex	ktrapolated	W fwd skirt, kg	1	1,344.6	N/A
above range of	regression.	W aft skirt, kg	•	6,648.2	N/A
0	0	W separation. kg	۲	565.4	N/A
		W misc. kg		690.3	N/A
		W SRM, kg	۲	5.045E+05	
		W stage, kg	•	1.129E+04	
		W SRB, kg	•	5.158E+05	
		V ideal, m/sec		1.827E+03	N/A
		<b>Mass Fraction</b>		9.377E-01	N/A
		(Impulse)sl, N-sec	I	1.169E+09	
		(Impulse)vac, N-sec	•	1.279E+09	

### Figure 40. Equations for ASRM Propellant Model

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### **Equations for Stage Components**

### Variable to beCalculatedEquation

Nose Cone Weight, lbm

 $W_{Nose\ Cone} = 3395 - 2098 N_{I/d} - 0.4705 (D_c/2)^2 + 2.533 x 10^{-5} \{ (D_c/2) \sqrt{(D_c/2)^2 + (N_{I/d}D_c)^2} \}^2$ 

External Insulation Weight, lbm

 $W_{ExtInsulation} = 87 + 0.7243D_c + 0.1071(D_c/2)^2$ 

Fwd Skirt and Attach Weight, lbm

 $W_{FwdSkint} = e^{(2.095 + 0.05276D_c - 0.0000846D_c^2)}$ 

Aft Skirt and Attach Weight, lbm

 $W_{AftSkirt} = e^{(2.89+0.06343D_c - 0.00012D_c^2)}$ 

Separation System Weight, lbm

 $W_{Separation} = 0.0011208 W_{srm}$ 

Misc Weight, lbm

 $W_{misc} = -1039 - 0.00204W_{srm} + 2.854L_{case & nozzle} + 0.07885(D_c/2)^2$ 

TA3-0321

### Large Motor Equations for ASRM Propellant

		Method
Variable to be Calculated	Equation	& Range
Burning Rate @ 1000 psia, ips	$Rbo = 4.633 (D_c/T_b)^{0.9794} Meop^{-0.3528}$	RMSE = 0.002 (0.334-0.806)
Propellant Weight, Ibm	$W_p = 0.004530 \overline{F}_v^{+0.9953} T_b^{1.0024} E_t^{-0.07282}$	RMSE = 2,809 (198k-3.01M)
Vacuum specific Impulse,	$Isp_{v} = \frac{\bar{F}_{v}T_{b}}{\bar{W}_{c}}$	Analytical Equation
bf-sec/lbm Average Nozzle Throat Area,	$\overline{A}_{t} = -14.5 + 172.8 W_{p}^{0.9902} Meop^{-0.9551} T_{b}^{-0.9776} + 1.039 E - 5 \overline{F}_{*} + 0.3131 T_{b}$	RMSE = 10.7 (315-6830)
n <sup>2</sup> Average Nozzle Throat	$\overline{R}_t = \sqrt{\frac{\overline{A_t}}{\overline{x}}}$	Analytical Equation
Radius, in Diameter of Nozzle @ Exit, in	$D_n = 2\sqrt{(\bar{R}_i - 0.005T_b)^2 E_i}$	Analytical Equation
Average Sea Level Thrust, lbf	$\overline{F}_{sl} = \overline{F}_{v} - 3.675\pi D_{n}^{2}$	Analytical Equation
Sea Level Specific Impulse,	$Isp_{vsl} = \frac{Isp_v \bar{F}_{cl}}{\bar{F}_v}$	Analytical Equation
Boss-Boss Case Length, in	$L_c = 26.26 W_p^{0.9665} D_c^{-1.914} T_b^{-0.01366}$	RMSE = 5.3 (443-1,640)
Nozzle Length (Aft Case Boss	$L_n = 1.096 \overline{A}_t^{+0.5665} E_i^{0.3385}$	RMSE = 3.6 (52-373)
Case length to Diameter Ratio,	$L/D_c = \frac{L_c}{D_c}$	Analytical Equation
Booster Total Length, in	$L_{total} = L_c + L_n + N_{iid}D_c$	Analytical Equation
Igniter Weight, Ibm	$W_{ign} = 19.1 + 164.3 M^{+1.273} Meop^{-1.076} D_c^{-0.5851} - 0.07182 \overline{A}_t^{+0.5124}$	RMSE = 29 (77-1,748)
Nozzle Weight, lbm	$W_n = 400.6 + 0.02310 \sqrt{\overline{A_t}} (1 + E_t) L_n + 0.1004 \overline{A_t}^{+0.6699} W_p^{0.4374} E_i^{0.1699}$	RMSE = 1,025 (1,880-46,900)
Internal Case Insulation, Ibm	$W_i = -18.3 + 0.2467 W_p^{0.7199} T_b^{0.3134} L_c^{-0.1737} - 0.07211 \overline{A_i}$	RMSE = 105 (1,690-16,800)
Empty Case Weight, Ibm	$W_{c} = -183.1 + 4.795e - 4\overline{F}_{*} + 6.142e - 6L_{c}^{0.3219}Meop^{0.7691}\overline{F}_{*}^{+0.1140}D_{c}^{1.369}$	RMSE = 933 (2,650-107k)
Total Rocket Motor Weight,	$W_{srm} = W_p + W_n + W_i + W_c + W_{ign}$	Analytical Equation
Total Stage Component Weight Ibm	$W_{sig} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$	Analytical Eq. (4,200-193K)
Total Booster weight, lbm	$W_{srb} = W_{srm} + W_{sig}$	Analytical Equation
Booster Ideal Velocity, fl/sec	$V_{ideal} = Isp_{v} \ln\left(\frac{W_{puch} + W_{irb}}{W_{puch} + W_{irb} - W_{prop}}\right) 32.18$	Analytical Equation
Booster Mass Fraction, dim	$Mf_{srb} = \frac{W_p}{W_{srb}}$	Analytical Equation
Total Impulse Sea Level, lbf.sec	$I_{sl} = \overline{F}_{sl} T_b$	Analytical Eq. (45M-728M)
Total Impulse vacuum,	$I_{v} = \overline{F}_{v} T_{b}$	Analytical Eq (51M-865M)

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1/14/93

## Figure 41. Script for ASRM Propellant Model

27 March 1993 05:48:54 PM Parametric Database/Object 39 script

Invalidate On Manual Recalc Select Range A116 Window Scale 65%

{Titles and dates} Put " Large Motors" Into A123 Put "ASRM (ANB3652) Propellant" Into C123 Put "14 January 1993" Into A124

{Initial Independent Variable Setup}

Put 1000 Into C126{Meop, psia}Put 7 Into C127{Initial Area Ratio, Ei}Put 2590000 Into C128{(Favg)vac, lbf}Put 111 Into C129{Burn Time, Tb, seconds}Put 146 Into C130{Dcase, in}Put 1000000 Into C131{Push Weight, lbm}Put 1.3 Into C132{Nose Cone Length/Diameter}

{Load Range Information}

Put "200 To 2000" Into D126 Put "5 To 19" Into D127 Put "320 K To 8.9 M" Into D128 Put "60 To 178" Into D129 Put "80 To 255" Into D130

{Load Range Limit Checks}

Put "=If (C126<200, 1,0)" Into K126 Put "=If (C126>2000, 1,0)" Into K127 Put "=If (C127<5, 1,0)" Into K128 Put "=If (C127>19, 1,0)" Into K129 Put "=If (C128<320000, 1,0)" Into K130 Put "=If (C128>8900000, 1,0)" Into K131 Put "=If (C129<60, 1,0)" Into K132 Put "=If (C129>178, 1,0)" Into K133 Put "=If (C130<80, 1,0)" Into K134 Put "=If (C130>255, 1,0)" Into K135

{Load Results Formulas, RMSE and correlation limits, and percent error}

{Rbo} Put "=( $4.633^{(C130/C129)^{0.9794}}^{(C126^{-0.3528})}$ L122" Into G126 Put "=[ $f(G126<0.334^{L122}$ .""Note 3"",If(G126>0.806\*L122,""Note 4"",0.002\*L122))" Into H126 Put "" Into I126

{(Isp)sl} Put "=G128\*G131/(C128\*L126)" Into G127 Put "N/A" Into H127 Put "" Into I127 27 March 1993 05:48:55 PM Parametric Database/Object 39 script

```
{(Isp)vac}
Put "=(C128*C129/(G138/L123))*L125" Into G128
Put "N/A" Into H128
Put "" Into I128
Put "=(-14.5+172.8*((G138/L123)^0.9902)*(C126^(-0.9551))*(C129^(-0.9776))
     +(1.039E-5)*C128+0.3131*C129)*L122*L122" Into G129
Put "=If(G129<315*L122*L122,""Note 3"",If(G129>6830*L122*L122,""Note 4"",10.7*L122*L122))" Into H
Put "" Into I129
{(R throat)avg}
Put "=SqRt(G129/3.141593)" Into G130
Put "N/A" Into H130
Put "" Into 1130
{(Favg)sl}
Put "=(C128-11.54535*G136*G136/(L122*L122))*L126" Into G131
Put "N/A" Into H131
Put "" Into I131
 {(Favg)vac}
 Put "=C128*L126" Into G132
 Put "N/A" Into H132
 Put "" Into 1132
 Put "=(26.26*((G138/L123)^0.9665)*(C130^(-1.914))*(C129^(-0.01366)))*L122" Into G133
 Put "=If(G133<443*L122, ""Note 3"", If(G133>1640*L122, ""Note 4"", 5.3*L122))" Into H133
 Put "" Into I133
 \{L/D \text{ case}\}
 Put "=G133/(C130*L122)" Into G134
 Put "=If(G134>5.6,""Note 1"",""N/A"")" Into H134
 Put "" Into I134
 Put "=(1.096*(C127^0.3385)*((G129/(L122*L122))^0.5665))*L122" Into G135
 Put "=If(G135<52*L122,""Note 3"",If(G135>373*L122,""Note 4"",3.6*L122))" Into H135
 Put "" Into I135
 Put "=(2*SqRt(((G130/L122-0.005*C129)^2)*C127))*L122" Into G136
  {Nozzle Exit Dia}
  Put "N/A" Into H136
  Put "" Into I136
  {Total Length}
  Put "=G133+G135+(C132*C130)*L122" Into G137
  Put "N/A" Into H137
  Put "" Into I137
  Put "=((0.004530*C128^0.9953)*(C129^1.0024)*(C127^(-0.07282)))*L123" Into G138
  {W propellant}
  Put "=If(G138>198000*L123,""Note 4"",If(G138<3010000*L123,""Note 3"",2809*L123))" Into H138
  Put "" Into 1138
```

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{W nozzle} Put "=(400.6+0.02310\*SqRt(G129/(L122\*L122))\*(1+C127)\*(G135/L122) +0.1004\*((G129/(L122\*L122))^0.6699)\*((G138/L123)^0.4374)\*(C127^0.1699))\*L123" Into G139 Put "=If(G139<1880\*L123,""Note 3"", If(G139>46900\*L123,""Note 4"", 1025\*L123))" Into H139 Put "" Into I139 {W case insulation} Put "=(-18.3+0.2467\*((G138/L123)^0.7199)\*(C129^0.3134)\*((G133/L122)^(-0.1737)) -0.07211\*(G129/(L122\*L122)))\*L123" Into G140 Put "=If(G140<1690\*L123, ""Note 3"", If(G140>16800\*L123, ""Note 4"", 105\*L123))" Into H140 Put "" Into I140 {W case} Put "=(-183.1+(4.795E-4)\*C128+ (6.142E-6)\*((G133/L122)^0.8219)\*(C126^0.7691)\*(C128^0.1140)\*(C130^1.869))\*L123" Into G141 Put "=If(G141<2650\*L123,""Note 3"",If(G141>107000\*L123,""Note 4"",933\*L123))" Into H141 Put "" Into I141 Put "=(19.1+(164.3\*(G138/(C129\*L123))^1.273)\*(C126^(-1.076))\*(C130^(-0.5851)) {W igniter} -0.07182\*(G129/(L122\*L122))^0.5124)\*L123" Into G142 Put "=If(G142<77\*L123,""Note 3"",If(G142>1748\*L123,""Note 4"",29\*L123))" Into H142 Put "" Into I142 {W nose cone} Put "=(3395-2098\*C132-0.4705\*((C130/2)^2) +(2.533E-5)\*(((C130/2)\*SqRt(((C130/2)^2)+((C132\*C130)^2)))^2))\*L123\* Into G143 Put "N/A" Into H143 Put "" Into I143 {W external Insulation} Put "=(87+0.7243\*C130+0.1071\*((C130/2)^2))\*L123" Into G144 Put "N/A" Into H144 Put "" Into I144 {W fwd skirt & attach} Put "=(Exp(2.095+0.05276\*C130-0.0000846\*C130\*C130))\*L123" Into G145 Put "N/A" Into H145 Put "" Into I145 {W aft skirt & attach} Put "=(Exp(2.89+0.06343\*C130-0.00012\*C130\*C130))\*L123" Into G146 Put "N/A" Into H146 Put "" Into I146 {W separation system} Put "=0.0011208\*G149" Into G147 Put "N/A" Into H147 Put "" Into I147 Put "=(-1039-0.00204\*(G149/L123)+2.854\*((G133+G135)/L122)+0.07885\*((C130/2)^2))\*L123" Into G14 Put "N/A" Into H148 Put "" Into 1148 {W SRM}

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Put "=Sum(G138..G142)" Into G149 Put "" Into H149 Put "" Into I149 {W stage} Put "=Sum(G143..G148)" Into G150 Put "=If(G150<4200\*L123,""Note 3"",If(G150>193000\*L123,""Note 4"",""""))" Into H150 Put "" Into 1150 {W SRB} Put "=G149+G150" Into G151 Put "" Into H151 Put "" Into I151 Put "=(32.18\*(G128/L125)\*Ln((C131+(G151/L123))/(C131+(G151/L123)-(G138/L123))))\*L124" Into G152 Put "N/A" Into H152 Put "" Into I152 {Mass Fraction} Put "=G138/G151" Into G153 Put "N/A" Into H153 Put "" Into 1153 {(Impulse)sl} Put "=G131\*C129" Into G154 Put "=If(G154<45000000\*L126, ""Note 3"", If(G154>728000000\*L126, ""Note 4"", """"))" Into H154 Put "" Into 1154 {(Impulse)vac} Put "=C128\*C129\*L126" Into G155 Put "=If(G155<51000000\*L126,""Note 3"",If(G155>865000000\*L126,""Note 4"",""""))" Into H155 Put "" Into 1155 {Load Notes} Put "Note 1:" Into A135 Put "Cases with L/D greater than 5.6" Into C135 Put "are difficult to wind w/o joints." Into C136 Put "Note 2:" Into A138 Put "MG propellant burn rates" Into C138 Put "(Rbo) are tailorable between" Into C139 Put "0.334 and 0.806 ips." Into C140 Put "Note 3:" Into A142 Put "Data is being extrapolated" Into C142 Put "below range of regression." Into C143 Put "Note 4:" Into A145 Put "Data is being extrapolated" Into C145 Put "above range of regression." Into C146 Automatic Recalc Invalidate Off

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| Ingredient         | Weight Percent |
|--------------------|----------------|
| R-45M (1% A02246)* | 13.83          |
| IPDI*              | 0.86           |
| HX-752             | 0.30           |
| ТРВ                | 0.01           |
| Mg                 | 22.0           |
| AP**               | 62.80          |
| Fe2O3**            | 0.20           |
|                    |                |

\* varied for mechanical property control \*\* varied for burn rate control

| Figure 42. Nominal Composi | tion of Magnesium | Clean Propellant |
|----------------------------|-------------------|------------------|
|----------------------------|-------------------|------------------|

| Exhaust Product | Mass Fraction |
|-----------------|---------------|
| CO (g)          | 0.2860        |
| CO2 (g)         | 0.0162        |
| CL (g)          | 0.0002        |
| HCI (g)         | 0.1505        |
| FeCl2 (g)       | 0.0032        |
| MgCl2 (g)       | 0.052         |
| H (g)           | Insignificant |
| H2 (g)          | 0.0289        |
| H2O (g)         | 0.0415        |
| MgO (s)         | 0.3412        |
| N2 (g)          | 0.0766        |
| Other           | 0.0005        |

Figure 43. Theoretical Exhaust Products at 1,000 psi Chamber Pressure Expanded to 14.7 psi Magnesium Clean Propellant

TA3-0323

| Large Motors               | Neutralizing       | Mg (DL-H43        | 5) Propellant         |                  |        |
|----------------------------|--------------------|-------------------|-----------------------|------------------|--------|
| 4 January 1993             | y 1961.25          |                   | Docile                |                  | RMSE   |
| Independent Terms          |                    | Kange             | Pho in /sec           | . 0.534          | 0.002  |
| Meop. psia                 | 1,000              | 200 To 2000       | (len)el sec_lhf/lhm   | 243.05           | N/A    |
| Initial Area Ratio, Ei 🛛 - | 7.0                | 5 TO 19           | (Isp)si, sec.lbf/lbm  | . 266.17         | N/A    |
| (Favg)vac, lbf             | 2,590,000          | 320 K TO 8.9 M    | (A throat)ave, in^2   | . 2,278.9        | 11     |
| Burn Time, Tb, seconds -   | . 111              | 60 TO 178         | (R throat)ave. in     | <b>_</b> 26.9    | N/A    |
| Dcase, in                  | . 146              | 80 10 255         | (Favo)sl. lbf         | . 2,365,069      | N/A    |
| Push Weight, lbm           | 1,000,000          |                   | (Favgivac, lbf        | . 2,590,000      | N/A    |
| Nose Cone L/D              | . 1.30             |                   | L case, in            | . 1,337.3        | 5      |
| Dependent Terms            |                    |                   | L/D case              | . 9.16           | Note 1 |
|                            |                    | menter than 5 A   | L nozzle, in          | . 169.7          | 3      |
| Note 1:                    | Cases with L/D     | greater utan 5.0  | Nozzie Exit O.D., in  | . 139.6          | N/A    |
|                            | are difficult to v | vina w/o jointas. | Total Length, in      | . 1,696.8        | N/A    |
| · ·                        |                    | um rates          | W propellant. lbm     | . 1,080,110      | Note 4 |
| Note 2:                    | MG propenant t     | ble between       | W nozzie. lbm         | - 12,648.0       | 1,184  |
|                            | (RDO) are tailor   | ADIC DELACCII     | W insulation. Ibm     | . 7,128.9        | 107    |
|                            | 0.34 and 0.81 ij   |                   | W case. Ibm           | - 28,823.5       | 1,066  |
|                            | Data is being a    | drapolated        | W igniter. lbm        | . 630.7          | 28     |
| Note 3:                    | Data is being e    | redression        | W nose cone, lbm      | . 3,742.3        | N/A    |
|                            | Delow range of     | ICR COSION.       | W ext insul. lbm      | - 763.5          | N/A    |
| \$7_4 - <b>4</b>           | Data le beind et   | rtrapolated       | W fwd skirt, lbm      | <b>2,</b> 965.0  | N/A    |
| Note 4:                    | Data is being e    | regression        | W aft skirt, lbm      | <b>14,659.7</b>  | N/A    |
|                            | above range of     | regression.       | W separation, lbm     | - 1,265.8        | N/A    |
|                            |                    |                   | W misc, lbm           | <b>.</b> 1,920.0 | ) N/A  |
|                            |                    |                   | W SRM. Ibm            | - 1.129E+06      | 5      |
|                            |                    |                   | W stage, Ibm          | - 2.532E+04      | Ł      |
|                            |                    |                   | W SRB, lbm            | = 1.155E+06      | 3      |
|                            |                    |                   | V ideal, ft/sec       | . 5.959E+03      | 3 N/A  |
|                            |                    |                   | Mass Fraction         | - 9.354E-0       | l N/A  |
|                            |                    |                   | (Impulse)sl, lbf-sec  | - 2.625E+08      | 3      |
|                            |                    |                   | (Impulse)vac. lbf-sec | - 2.875E+08      | 3      |
|                            |                    |                   | (                     |                  |        |
|                            |                    |                   |                       |                  |        |
|                            |                    |                   |                       |                  |        |
|                            |                    |                   |                       |                  |        |
|                            |                    |                   |                       |                  |        |
|                            |                    |                   |                       |                  |        |
|                            |                    |                   |                       |                  |        |
|                            |                    |                   |                       |                  |        |

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Figure 44. Printed Output - "Report" - English Units

| 4 January 1993           |                    | Range                 | Results              |   | R           | MSE     |   |
|--------------------------|--------------------|-----------------------|----------------------|---|-------------|---------|---|
| Independent Lettus       | -                  |                       | Rho cm/sec           | . | 1.356 0.    | 00508   |   |
| Meop. psia               | 1,000              | z 10 z 2000           | (tents) sec-N/kg     |   | 2,383.53    | N/A     |   |
| Initial Area Ratio. El   |                    | 900 T 0 19            | (Isnbac, sec-N/kg    | • | 2,610.21    | N/A     |   |
| (Favg)vac. lbf           |                    | 070 TO 170            | (A threatlave cm^2   | • | 14.702.3 70 | 0.9676  |   |
| Burn Time, Tb, seconds - | 111                | 00 10 1/0<br>00 m 056 | (D throatland cm     | • | 68.4        | V/N     | _ |
| Dcase. in                | 146                | ecz 01 09             |                      | • | 10 519 828  | N/A     |   |
| Push Weight, Ibm -       | 1,000.000          |                       | (Favg)si, N          | • | 10,010,040  |         |   |
| Nose Cone L/D            | 1.30               |                       | (Favgvac, N          | • | 070,020,11  | V/N     |   |
| Dependent Terms          |                    |                       | L case, cm           | • | 3,396.6     | 12.7    |   |
|                          |                    |                       | L/D case             | ١ | 9.16 1      | Note 1  |   |
|                          | Cases with L/D     | preater than 5.6      | L nozzle, cm         | ٠ | 431.2       | 7.62    |   |
|                          | are difficult to w | and w/o toints.       | Nozzle Exit O.D., cm | • | 354.5       | V/V     |   |
|                          |                    |                       | Total Length, cm     | • | 4.309.9     | V/N     |   |
| Mote 9.                  | MC provellant h    | nm rates              | W propellant, kg     | 1 | 489,830     | Note 4  |   |
| NOIG 7.                  | (Bhn) are tailors  | hle between           | W nozzle, kg         | • | 5,735.9 5   | 36.944  |   |
|                          | 0 34 and 0 81 tr   | đ                     | W insulation, kg     |   | 3,233.0 4   | 8.5245  |   |
|                          |                    | į                     | W case. kg           | ٩ | 13.071.5 4  | 183.431 |   |
|                          | Dote te heind ev   | tranolated            | W igniter. kg        | • | 286.0       | 12.698  |   |
| NOIG OF                  | Palata is mange of | adreedon              | W nose cone. kg      | • | 1,697.1     | N/N     |   |
|                          | DOION TAURO OF     | regression.           | W ext insul. kg      | • | 346.2       | N/A     |   |
|                          | Note to beind av   | translated            | W fwd skirt. kg      | ١ | 1,344.6     | N/N     |   |
| NOIC 4:                  | Data is build of   | edression -           | W aft skirt. ke      | • | 6.648.2     | N/A     |   |
|                          | above failing of a | chircenou.            | W senaration. kg     |   | 574.0       | N/A     |   |
|                          |                    |                       | W misc kd            | • | 870.7       | N/A     |   |
|                          |                    |                       | W HILSO, AG          |   | 5.122E+05   | •       |   |
|                          |                    |                       |                      |   | 1 1485-04   |         |   |
|                          |                    |                       | W stage, Kg          | • |             |         |   |
|                          |                    |                       | W SRB. kg            | 4 | D.236E+UD   |         |   |
|                          |                    |                       | V ideal, m/sec       | • | 1.816E+03   | V/N     |   |
|                          |                    |                       | Mass Fraction        |   | 9.354E-01   | N/A     |   |
|                          |                    |                       | (Impulse)sl, N-sec   | 1 | 1.168E+09   |         |   |
|                          |                    |                       | (Impulse)vac, N-sec  | • | 1.279E+09   |         |   |
|                          |                    |                       |                      |   |             |         |   |
|                          |                    |                       |                      |   |             |         |   |
|                          |                    |                       |                      |   |             |         |   |
|                          |                    |                       |                      |   |             |         |   |
|                          |                    |                       |                      |   |             |         |   |
|                          |                    |                       |                      |   |             |         |   |
|                          |                    |                       |                      |   |             |         |   |

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Figure 45. Printed Output - "Briefing" - Metric Units
Figure 46. Equations for Mg Clean Propellant Model

#### **Equations for Stage Components**

## Variable to beCalculatedEquation

Nose Cone Weight, lbm

 $W_{Nose \ Cone} = 3395 - 2098 N_{I/d} - 0.4705 (D_c/2)^2 + 2.533 x 10^{-5} \{ (D_c/2) \sqrt{(D_c/2)^2 + (N_{I/d} D_c)^2} \}^2$ 

External Insulation Weight, lbm

 $W_{ExtInsulation} = 87 + 0.7243D_c + 0.1071(D_c/2)^2$ 

Fwd Skirt and Attach Weight, lbm

 $W_{FwdSkint} = e^{(2.095+0.05276D_c - 0.0000846D_c^2)}$ 

Aft Skirt and Attach Weight, lbm

 $W_{AfiSkin} = e^{(2.89+0.06343D_c - 0.00012D_c^2)}$ 

Separation System Weight, lbm

 $W_{Separation} = 0.0011208W_{srm}$ 

Misc Weight, lbm

 $W_{misc} = -1039 - 0.00204W_{srm} + 2.854L_{case & nozzle} + 0.07885(D_c/2)^2$ 

TA3-0321

# Large Motor Equations for Magnesium Based Propellant

| Variable to be<br>Calculated                | Equation                                                                                                                      | Method<br>& Range              |
|---------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| burning Rate @ 1000 psia, ips               | $Rbo = 4.957 (D_c/T_b)^{0.9788} Meop^{-0.3614}$                                                                               | RMSE = 0.002<br>(0.34-0.81)    |
| ropellant Weight, Ibm                       | $W_{p} = 0.005028 \overline{F}_{v}^{+0.9953} T_{b}^{1.0027} E_{i}^{-0.05843} Meop^{-0.01470}$                                 | RMSE = 3,466<br>(198k-3.01M)   |
| acuum specific Impulse,                     | $Isp_{*} = \frac{\bar{F}_{*}T_{b}}{W_{p}}$                                                                                    | Analytical<br>Equation         |
| Average Nozzle Throat Area,                 | $\overline{A}_{t} = -15.2 + 157.4 W_{p}^{0.9899} Meop^{-0.9404} T_{b}^{-0.9776} + 1.027E - 5\overline{F}_{*} + 0.3134 T_{b}$  | RMSE = 11<br>(329-6,820)       |
| n<br>Average Nozzle Throat                  | $\overline{R}_t = \sqrt{\frac{\overline{A_t}}{\pi}}$                                                                          | Analytical<br>Equation         |
| Radius, in<br>Diameter of Nozzle @ Exit, in | $D_n = 2\sqrt{(\overline{R}_t - 0.005T_b)^2 E_i}$                                                                             | Analytical<br>Equation         |
| Average Sea Level Thrust, lbf               | $\overline{F}_{sl} = \overline{F}_v - 3.675\pi D_n^2$                                                                         | Analytical<br>Equation         |
| Sea Level Specific Impulse,<br>lbf-sec/lbm  | $Isp_{vsl} = \frac{Isp_{v}\bar{F}_{cl}}{\bar{F}_{v}}$                                                                         | Analytical<br>Equation         |
| Boss-Boss Case Length, in                   | $L_{c} = -0.3 + 28.23 \left[ \frac{W_{p}}{D_{c}^{2}} \right]^{0.9794} + 8.696E - 4 \frac{\bullet}{M} + 0.009766Meop$          | RMSE = 5<br>(492-1,825)        |
| Nozzle Length (Aft Case Boss                | $L_n = -14.87 + 1.8468E_i^{0.2966}\overline{A}_t^{+0.5225} - 0.002486Meop + 0.4242E_i - 0.02445T_b$                           | RMSE = 3<br>(46-374)           |
| Case length to Diameter Ratio,              | $L/D_c = \frac{L_c}{D_c}$                                                                                                     | Analytical<br>Equation         |
| Booster Total Length, in                    | $L_{total} = L_c + L_n + N_{l/d}D_c$                                                                                          | Analytical<br>Equation         |
| Igniter Weight, Ibm                         | $W_{ign} = 21.0 + 0.2218Meop^{0.1277}\overline{A}_{i}^{+1.3314}D_{c}^{-0.6535}$                                               | RMSE =28<br>(76-1,754)         |
| Nozzle Weight, Ibm                          | $W_n = 588.7 + 0.02444 \sqrt{\overline{A_t}} (1 + E_t) L_n + 0.06048 \overline{A_t}^{+0.6750} W_p^{0.4703} E_t^{0.1592}$      | RMSE = 1184<br>(1,944-47,600)  |
| Internal Case Insulation, Ibm               | $W_{i} = -19.5 + 0.2395 W_{p}^{0.7022} T_{b}^{0.3056} L_{c}^{-0.1211} - 0.06024 \overline{A}_{i}$                             | RMSE = 107<br>(1,830-17,200)   |
| Empty Case Weight, lbm                      | $W_{c} = -277.8 + 5.822E - 4\overline{F}_{v} + 6.142E - 6L_{c}^{0.8298}Meop^{0.7754}\overline{F}_{v}^{+0.1110}D_{c}^{1.8575}$ | RMSE = 1,066<br>(2,840-117k)   |
| Total Rocket Motor Weight,                  | $W_{srm} = W_p + W_n + W_i + W_c + W_{ign}$                                                                                   | Analytical<br>Equation         |
| Total Stage Component                       | $W_{sig} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$                        | Analytical Eq.<br>(4,300-193K) |
| Total Booster weight, lbm                   | $W_{srb} = W_{srm} + W_{stg}$                                                                                                 | Analytical<br>Equation         |
| Booster Ideal Velocity, fl/sec              | $V_{ideal} = Isp_{\nu} \ln \left( \frac{W_{push} + W_{rb}}{W_{push} + W_{rb} - W_{prop}} \right) 32.18$                       | Analytical<br>Equation         |
| Booster Mass Fraction, dim                  | $Mf_{srb} = \frac{W_p}{W_{rb}}$                                                                                               | Analytical<br>Equation         |
| Total Impulse Sea Level,                    | $I_{sl} = \overline{F}_{sl} T_b$                                                                                              | Analytical Eq.<br>(44M-716M)   |
| Total Impulse vacuum,                       | $I_{v} = \overline{F}_{v} T_{b}$                                                                                              | Analytical Eq.<br>(51M-854M)   |
| lbm-sec                                     |                                                                                                                               | 1/14                           |

Figure 47. Script for Mg Clean Propellant Model (Large Motors) Invalidate On Manual Recalc Select Range A116 Window Scale 65%

{Titles and dates} Put " Large Motors" Into A123 Put "Neutralizing Mg (DL-H435) Propellant" Into C123 Put "14 January 1993" Into A124

{Initial Independent Variable Setup}

Put 1000 Into C126{Meop. psia}Put 7 Into C127{Initial Area Ratio, Ei}Put 2590000 Into C128{(Favg)vac, lbf}Put 111 Into C129{Burn Time, Tb, seconds}Put 146 Into C130{Dcase, in}Put 1000000 Into C131{Push Weight, lbm}Put 1.3 Into C132{Nose Cone Length/Diameter}

{Load Range Information}

Put "200 To 2000" Into D126 Put "5 To 19" Into D127 Put "320 K To 8.9 M" Into D128 Put "60 To 178" Into D129 Put "80 To 255" Into D130

{Load Range Limit Checks}

```
Put "=If (C126<200, 1,0)" Into K126

Put "=If (C126>2000, 1,0)" Into K127

Put "=If (C127<5, 1,0)" Into K128

Put "=If (C127>19, 1,0)" Into K129

Put "=If (C128>320000, 1,0)" Into K130

Put "=If (C128>8900000, 1,0)" Into K131

Put "=If (C129<60, 1,0)" Into K132

Put "=If (C129>178, 1,0)" Into K133

Put "=If (C130<80, 1,0)" Into K134

Put "=If (C130>255, 1,0)" Into K135
```

{Load Results Formulas, RMSE and correlation limits, and percent error}

```
{Rbo}
Put "=(4.957*((C130/C129)^0.9788)*(C126^(-0.3614)))*L122" Into G126
Put "=If(G126<0.34*L122, ""Note 3"", If(G126>0.81*L122, ""Note 4"", 0.002*L122))" Into H126
Put "" Into I126
{(Isp)sl}
Put "=G128*G131/(C128*L126)" Into G127
```

```
Put "=G128*G131/(C128*L126)" Into G127
Put "N/A" Into H127
Put "" Into I127
```

```
{(Isp)vac}
Put "=(C128*C129/(G138/L123))*L125" Into G128
```

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```
Put "N/A" Into H128
Put "" Into I128
{(A throat)avg}
Put "=(-15.2+157.4*((G138/L123)^0.9899)*(C126^(-0.9404))*(C129^(-0.9776))
     +(1.027E-5)*C128+0.3134*C129)*L122*L122" Into G129
Put "=If(G129<329*L122*L122,""Note 3"",If(G129>6820*L122*L122,""Note 4"",11*L122*L122))" Into H12
Put "" Into I129
{(R throat)avg}
Put "=SqRt(G129/3.141593)" Into G130
Put "N/A" Into H130
Put "" Into I130
{(Favg)sl}
Put "=(C128-11.54535*G136*G136/(L122*L122))*L126" Into G131
Put "N/A" Into H131
Put "" Into I131
{(Favg)vac}
Put "=C128*L126" Into G132
Put "N/A" Into H132
Put "" Into I132
{L case}
Put "=(-0.3+28.23*((G138/L123)/(C130*C130))^0.9794+(8.696E-4)
     *(G138/L123)/C129+0.009766*C126)*L122" Into G133
Put "=If(G133<492*L122,""Note 3"",If(G133>1825*L122,""Note 4"",5*L122))" Into H133
Put "" Into I133
\{L/D \text{ case}\}
Put "=G133/(C130*L122)" Into G134
Put "=If(G134>5.6,""Note 1"",""N/A"")" Into H134
Put "" Into I134
{L nozzle}
Put "=(-14.87+1.8468*(C127^0.2966)*((G129/(L122*L122))^0.5225)
     -0.002486*C126+0.4242*C127-0.02445*C129)*L122" Into G135
Put "=If(G135<46*L122,""Note 3"",If(G135>374*L122,""Note 4"",3*L122))" Into H135
Put "" Into I135
{Nozzle Exit Dia}
Put "=(2*SqRt(((G130/L122-0.005*C129)*2)*C127))*L122" Into G136
Put "N/A" Into H136
Put "" Into I136
{Total Length}
Put "=G133+G135+(C132*C130)*L122" Into G137
Put "N/A" Into H137
Put "" Into I137
{W propellant}
Put"=((0.005028*C128^0.9953)*(C129^1.0027)*(C127^(-0.06843))*(C126^(-0.01470)))*L123" Into G138
Put "=If(G138>198000*L123,""Note 4"",If(G138<3010000*L123,""Note 3"",3466*L123))" Into H138
Put "" Into I138
```

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{W nozzle} Put "=(588.7+0.02444\*SqRt(G129/(L122\*L122))\*(1+C127)\*(G135/L122) +0.06048\*((G129/(L122\*L122))^0.6750)\*((G138/L123)^0.4703)\*(C127^0.1592))\*L123" Into G139 Put "=If(G139<1944\*L123,""Note 3"",If(G139>47600\*L123,""Note 4"",1184\*L123))" Into H139 Put "" Into I139 {W case insulation} Put "=(-19.5+0.2395\*((G138/L123)^0.7022)\*(C129^0.3056)\*((G133/L122)^(-0.1211)) -0.06024\*(G129/(L122\*L122)))\*L123" Into G140 Put "=If(G140<1830\*L123,""Note 3"",If(G140>17200\*L123,""Note 4"",107\*L123))" Into H140 Put "" Into I140 {W case} Put "=(-277.8+(5.822E-4)\*C128+ (6.142E-6)\*((G133/L122)\*0.8298)\*(C126\*0.7754)\*(C128\*0.1110)\*(C130\*1.8575))\*L123" Into G141 Put "=If(G141<2840\*L123, ""Note 3"", If(G141>117000\*L123, ""Note 4"", 1066\*L123))" Into H141 Put "" Into I141 Put "=(21.0+0.2218\*(C126^0.1277)\*((G129/(L122\*L122))^1.3314)\*(C130^(-0.6535)))\*L123" Into G142 Put "=If(G142<76\*L123,""Note 3"",If(G142>1754\*L123,""Note 4"",28\*L123))" Into H142 Put "" Into I142 {W nose cone} Put "=(3395-2098\*C132-0.4705\*((C130/2)^2) +(2.533E-5)\*(((C130/2)\*SqRt(((C130/2)^2)+((C132\*C130)^2)))^2))\*L123" Into G143 Put "N/A" Into H143 Put "" Into I143 {W external Insulation} Put "=(87+0.7243\*C130+0.1071\*((C130/2)\*2))\*L123" Into G144 Put "N/A" Into H144 Put "" Into I144 {W fwd skirt & attach} Put "=(Exp(2.095+0.05276\*C130-0.0000846\*C130\*C130))\*L123" Into G145 Put "N/A" Into H145 Put "" Into I145 {W aft skirt & attach} Put "=(Exp(2.89+0.06343\*C130-0.00012\*C130\*C130))\*L123" Into G146 Put "N/A" Into H146 Put "" Into I146 {W separation system} Put "=0.0011208\*G149" Into G147 Put "N/A" Into H147 Put "" Into I147 Put "=(-1039-0.00204\*(G149/L123)+2.854\*((G133+G135)/L122)+0.07885\*((C130/2)\*2))\*L123" Into G14 Put "N/A" Into H148 Put "" Into I148 {W SRM} Put "=Sum(G138..G142)" Into G149

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Put "" Into H149 Put "" Into I149 {W stage} Put "=Sum(G143..G148)" Into G150 Put "=If(G150<4300\*L123,""Note 3"",If(G150>193000\*L123,""Note 4"",""""))" Into H150 Put "" Into 1150 {W SRB} Put "=G149+G150" Into G151 Put "" Into H151 Put "" Into I151 Put "=(32.18\*(G128/L125)\*Ln((C131+(G151/L123))/(C131+(G151/L123)-(G138/L123))))\*L124" Into G152 Put "N/A" Into H152 Put "" Into I152 {Mass Fraction} Put "=G138/G151" Into G153 Put "N/A" Into H153 Put "" Into I153 {(Impulse)sl} Put "=G131\*C129" Into G154 Put "=If(G154<44000000\*L126,""Note 3"",If(G154>716000000\*L126,""Note 4"",""""))" Into H154 Put "" Into I154 {(Impulse)vac} Put "=C128\*C129\*L126" Into G155 Put "=If(G155<51000000\*L126,""Note 3"",If(G155>854000000\*L126,""Note 4"",""""))" Into H155 Put "" Into 1155 {Load Notes} Put "Note 1:" Into A135 Put "Cases with L/D greater than 5.6" Into C135 Put "are difficult to wind w/o joints." Into C136 Put "Note 2:" Into A138 Put "MG propellant burn rates" Into C138 Put "(Rbo) are tailorable between" Into C139 Put "0.34 and 0.81 ips." Into C140 Put "Note 3:" Into A142 Put "Data is being extrapolated" Into C142 Put "below range of regression." Into C143 Put "Note 4:" Into A145 Put "Data is being extrapolated" Into C145 Put "above range of regression." Into C146 Automatic Recalc Invalidate Off

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| Medium Motors          | Neutralizing       | Mg (    | DL-        | H43   | 5) Propellant         |   |           |        |       |
|------------------------|--------------------|---------|------------|-------|-----------------------|---|-----------|--------|-------|
| 18 August 1992         |                    | C C     | end        |       | Results               |   |           | RMSE   |       |
| Independent Lerms      | 3 000              | 000     | To         | 2000  | Rbo. in/sec           | - | 0.573     | Note 4 | 2.995 |
| Meop, psia =           | 2,000              | 7       | То         | 19    | (Isp)sl. sec-lbf/lbm  | - | 253.43    | N/A    | N/A   |
| initial Area Ratio, El | 250 000            | 62K     | to         | 328K  | (Isp)vac, sec-lbf/lbm | - | 271.88    | 0.595  | 0.217 |
| (Favgivac, IDI         | 40                 | 30      | To         | 105   | (A throat)avg, in^2   | - | 115.4     | 1.57   | 0.872 |
| Burn lime, 10, seconds | 70                 | 30      | То         | 105   | (R throat)avg, in     | - | 6.1       | N/A    | N/A   |
| Dease, III             | 200.000            |         |            |       | (Favg)sl, lbf         | - | 233,035   | N/A    | N/A   |
| Push weight, ibin      | 200,000            |         |            |       | (Favg)vac, lbf        | - | 250,000   | N/A    | N/A   |
|                        |                    |         |            |       | L case, in            | - | 217.5     | 1.519  | 0.466 |
| Dependente texat       |                    |         |            |       | L/D case              | - | 3.11      | N/A    | N/A   |
| Note 1                 | Cases with L/D     | greater | tha        | n 5.6 | L nozzle, in          | - | 24.7      | 0.94   | 2.282 |
| NOTE 1:                | are difficult to w | find w  | /0 10      | ints. | Nozzle Exit O.D., in  | - | 38.3      | N/A    | N/A   |
|                        | are difficult to " |         | , <b>.</b> |       | Total Length, in      | - | 347.2     | N/A    | N/A   |
| Note 2.                | MC propellant h    | urn ra  | tes        |       | W propellant, lbm     | = | 36,781    | N/A    | N/A   |
| Note 2.                | (Pho) are tailors  | hle be  | twee       | en.   | W nozzle, lbm         | - | 540.7     | 21     | 2.358 |
|                        | 0.34 and 0.81 in   | 1910 00 |            |       | W insulation, lbm     | - | 567.2     | 13.42  | 1.33  |
|                        | 0.04 and 0.01 ip   |         |            |       | W case, lbm           | = | 403.5     | 66.95  | 2.64  |
| Note 3.                | Data is heing ex   | tranola | ated       |       | W igniter, lbm        | - | 24.3      | 2.9    | 5.74  |
| NOIE 3:                | below range of i   | regress | sion.      |       | W SRM, lbm            | - | 38,317    | 71.7   |       |
|                        | Delow Tange of A   | - Groot |            |       | W stage, lbm          | - | 1,556     | 94.8   | 4.3   |
| Note di                | Data is heing ex   | trapola | ated       |       | W SRB, lbm            | - | 39,873    | 121.5  |       |
| Note 4.                | above range of t   | egress  | ilon.      |       | V ideal, ft/sec       | = | 1,456     | N/A    | N/A   |
|                        | above range or .   | -9.000  |            |       | Mass Fraction         | - | 0.922     | N/A    | N/A   |
|                        |                    |         |            |       | (Impulse)sl, lbf-sec  | = | 9.321E+06 | N/A    | N/A   |
|                        |                    |         |            |       | (Impulse)vac, lbf-sec | - | 1.000E+07 | N/A    | N/A   |
|                        |                    |         |            |       |                       |   |           |        |       |

Figure 48. Printed Output - "Report" - English Units

| E1       2.000       700       700       700       700       700       700       700       700       700       700       710       200       62X       00       52X       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00       00                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | El       2.000       70 10 50 00       62K to 328K (159) acc-N/kg       2.485.28 N/A       N/A         ceonds       40       30 70 105 (150) (150) (150) (150) (150) (120) 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       037 100 00       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       046       <                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | E1       2.000       700       100       700       100       700       100       700       0.201         conds       40       30       70       105       (R throatlavg, cm <sup>-2</sup> )       744.6       10.128       0.87         conds       70       30       70       105       (R throatlavg, cm <sup>-2</sup> )       744.6       10.128       0.87         700       30       70       105       (R throatlavg, cm <sup>-2</sup> )       1036.540       NA       NA         700       30       70       105       (R throatlavg, cm <sup>-2</sup> )       11.12.000       NA       NA         700       10       105       (R throatlavg, cm <sup>-2</sup> )       11.12.000       NA       NA         700       10       10.10       10.10       10.10       10.10       NA         700       10.10       10.10       10.10       10.10       NA       NA         Reavelyse, N       11.12.000       NA       NA       NA       NA       NA         Note 1:       Cases with L/D greater than 5.6       Locase, cm       11.112.000       NA       NA         Note 2:       MG propellant burn rates       Nozel, kg       1.002.6       10.10       NA       NA     <                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | E1       2.000       700       10       700       10       700       2.466.28       N/A       N/A         conds       40       30       70       105       10       00       021       5.83466       021         conds       40       30       70       105       10       10       07       10       07       00       021       10       07       03       07       07       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087       087                                                                                                                                                                                                                                                                                                      | ust 1992<br>indent Terms |                    | Range            | Results                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |   | 1.454 Note 4    | 2.99    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------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| E1       100       501 to 328k       (isphae: sec:N/kg       7446       10.129       0.877         conds       70       30 To 105       (R throatlavg, cm <sup>-2</sup> )       15.4 N/A       N/A       N/A         200.000       30 To 105       (R throatlavg, cm <sup>-2</sup> )       15.4 N/A       N/A       N/A         200.000       30 To 105       (R throatlavg, cm <sup>-2</sup> )       15.4 N/A       N/A         200.000       200       (isphae: sec:N/kg)       1.036.540       N/A       N/A         Rote 1:       200.000       20 to 105       (R throatlavg, cm <sup>-2</sup> )       1.036.540       N/A       N/A         Note 1:       Cases with L/D greater than 5.6       Locase       0.46       1.112.000       N/A       N/A         Note 1:       Cases with L/D greater than 5.6       Locase       0.21       552.5       3.85636       0.46         Note 2:       MG propellant, tw       L/D case       case       572.5       3.876       2.93         Note 2:       MG propellant, kg       1.0.0.1.4kg       16.083       N/A       N/A         Note 3:       Data is being extrapolated       W propellant, kg       2.45.2       9.32516       3.44         Note 3:       Data is being extrapolated       W sRM, kg </th <th>E1       250.000       621 to 328t       (isphwe. sec.N/kg       744.6       10.23       0.87.         conds       70       30       70       105       R throatlavg. cm       15.4       N/A       N/A         conds       70       30       70       105       R throatlavg. cm       15.4       N/A       N/A         200.000       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         200.000       30       70       105       R throatlavg. cm       1.035.540       N/A       N/A         200.000       30       70       105       R throatlavg. cm       1.035.540       N/A       N/A         Note 1:       Zases with L/D greater than 5.6       Locsec. cm       5.1       N/A       N/A         Note 2:       MG propellant burn rates       N/D case       Cm       62.8       23876       238       0.44         Note 2:       MG propellant burn rates       Note 2:       82.0       10.01.46       11.0       13515       5.7       0.33618       2.6       244       136       245       2.95       238       0.36       2.66       2.66557       3.5156       2.66557       3.5156       2.6       &lt;</th> <th>E1       250.000       62.K to 328K       (isphwe. sec.Nkg       744.6       10.23       0.87         conds       70       30       70       105       R throatlavg. cm       15.4       N/A       N/A         conds       70       30       70       105       R throatlavg. cm       15.5.8346       0.87         70       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         70       200.000       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         ms       200.000       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         ms       1200.000       105       R throatlavg. cm       1.036.540       N/A       N/A         Mote 1:       Zases with L/D greater than 5.6       L nozzle. cm       3.11       N/A       N/A         Note 2:       MG propellant burn rates       Nozzle Exit O.D cm       97.4       N/A       N/A         Note 3:       Data is being extrapolated       W insulation, kg       16.6633       N/A       N/A         Note 3:       Data is being extrapolated       W insulation, kg       13.030.301       3.351.0</th> <th>E1       250,000       624 to 328h (ispbac, secon/kg cm 2       744.6       10.129       0.877         conds       70       30 To 105       R throatlavg, cm 2       154.6       NA       NA         n       200.000       624 to 105       R throatlavg, cm 2       1536.54       NA       NA         n       200.000       624 to 105       R throatlavg, cm 2       1.036.540       NA       NA         n       200.000       80 To 105       R throatlavg, cm 2       1.036.540       NA       NA         n       200.000       80 To 105       R throatlavg, cm 2       1.036.540       NA       NA         Note 1:       200.000       624 to 1015       Lease, cm 2       3.11 NA       NA         Note 1:       Cases with L/D greater than 5.6       Locase, cm 2       97.4 NA       NA         Note 2:       MG propellant burn rates       Norzele, cm 2       97.4 NA       NA         Note 3:       Data is being extrapolated       Winsulation, kg 2       2.452.9 3535       2.454         Note 3:       Data is being extrapolated       Winsulation, kg 2       17.379       2.9535       2.444 NA         Note 4:       Data is being extrapolated       Winsulatio, MK, kg 2       1.166.683       1.13</th> <th>•</th> <th>2.000</th> <th>900 To 2000</th> <th>Rbo, cm/sec<br/>//en/el_sec_N/kg</th> <th></th> <th>1.435.28 N/A</th> <th>W/N</th>                                                                                                                                                                 | E1       250.000       621 to 328t       (isphwe. sec.N/kg       744.6       10.23       0.87.         conds       70       30       70       105       R throatlavg. cm       15.4       N/A       N/A         conds       70       30       70       105       R throatlavg. cm       15.4       N/A       N/A         200.000       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         200.000       30       70       105       R throatlavg. cm       1.035.540       N/A       N/A         200.000       30       70       105       R throatlavg. cm       1.035.540       N/A       N/A         Note 1:       Zases with L/D greater than 5.6       Locsec. cm       5.1       N/A       N/A         Note 2:       MG propellant burn rates       N/D case       Cm       62.8       23876       238       0.44         Note 2:       MG propellant burn rates       Note 2:       82.0       10.01.46       11.0       13515       5.7       0.33618       2.6       244       136       245       2.95       238       0.36       2.66       2.66557       3.5156       2.66557       3.5156       2.6       <                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | E1       250.000       62.K to 328K       (isphwe. sec.Nkg       744.6       10.23       0.87         conds       70       30       70       105       R throatlavg. cm       15.4       N/A       N/A         conds       70       30       70       105       R throatlavg. cm       15.5.8346       0.87         70       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         70       200.000       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         ms       200.000       30       70       105       R throatlavg. cm       1.036.540       N/A       N/A         ms       1200.000       105       R throatlavg. cm       1.036.540       N/A       N/A         Mote 1:       Zases with L/D greater than 5.6       L nozzle. cm       3.11       N/A       N/A         Note 2:       MG propellant burn rates       Nozzle Exit O.D cm       97.4       N/A       N/A         Note 3:       Data is being extrapolated       W insulation, kg       16.6633       N/A       N/A         Note 3:       Data is being extrapolated       W insulation, kg       13.030.301       3.351.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | E1       250,000       624 to 328h (ispbac, secon/kg cm 2       744.6       10.129       0.877         conds       70       30 To 105       R throatlavg, cm 2       154.6       NA       NA         n       200.000       624 to 105       R throatlavg, cm 2       1536.54       NA       NA         n       200.000       624 to 105       R throatlavg, cm 2       1.036.540       NA       NA         n       200.000       80 To 105       R throatlavg, cm 2       1.036.540       NA       NA         n       200.000       80 To 105       R throatlavg, cm 2       1.036.540       NA       NA         Note 1:       200.000       624 to 1015       Lease, cm 2       3.11 NA       NA         Note 1:       Cases with L/D greater than 5.6       Locase, cm 2       97.4 NA       NA         Note 2:       MG propellant burn rates       Norzele, cm 2       97.4 NA       NA         Note 3:       Data is being extrapolated       Winsulation, kg 2       2.452.9 3535       2.454         Note 3:       Data is being extrapolated       Winsulation, kg 2       17.379       2.9535       2.444 NA         Note 4:       Data is being extrapolated       Winsulatio, MK, kg 2       1.166.683       1.13                                                                                                                                                          | •                        | 2.000              | 900 To 2000      | Rbo, cm/sec<br>//en/el_sec_N/kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |   | 1.435.28 N/A    | W/N     |
| conds         400         30         70         105         R throatlave, cm         7         74.6         10.129         0.877           70         30         70         105         R throatlave, cm         1         15.4         N/A         N/A           70         30         70         105         R throatlave, cm         1         1036.540         N/A         N/A           70         30         70         105         R throatlave, cm         1         112.000         N/A         N/A           Note         1:         Cases with L/D greater than 5.6         Locase, cm         532.5         355826         0.46           are difficult to wind w/o joints.         L/D case         0.24         N/A         N/A           Note 2:         MG propellant burn rates         U/D case         62.8         3.3676         2.36           Note 2:         MG propellant, kg         16.683         N/A         N/A         N/A           Note 3:         Data is being extrapolated         W issulation. kg         16.683         N/A         N/A           Note 4:         Data is being extrapolated         W issulation. kg         17.379         32.516         3.73           Note 4:         D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | conds.       40       30       To       105       (A throat)avg, cm <sup>2</sup> 744.6       10.129       0.87.         70       30       To       105       (A throat)avg, cm       1036.540       NA       NA         70       30       To       105       (R throat)avg, cm       1.1036.540       NA       NA         80       200.000       R throat)avg, cm       1.112.000       NA       NA         Note       1.       Lease, cm       3.11       NA       NA         Vote       1.       Cases with L/D greater than 5.6       Locase, cm       3.11       NA       NA         Vote       1.       Cases with L/D greater than 5.6       Locase, cm       3.11       NA       NA         Vote       1.       Cases with L/D greater than 5.6       Locase, cm       3.11       NA       NA         Note       2.       MG propellant wind w/o joints.       Nozzle Exit O.D cm       97.4       NA       NA         Note       3.       MG propellant burn rates       W propellant, kg       16.683       NA       NA         Note       3.       Data is being extrapolated       W prozelle Exit o.D.       97.444       NA       NA         Note<                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | conds         40         30         70         105         R throatlave, cm         744.6         10.29         0.87.           70         30         70         105         R throatlave, cm         15.4         N/A         N/A           200.000         30         70         105         R throatlave, cm         1.112.000         N/A         N/A           200.000         30         70         105         R throatlave, cm         3.11         N/A         N/A           200.000         30         70         105         R throatlave, cm         3.11         N/A         N/A           with         L/D case         Locate, cm         3.11         N/A         N/A         N/A           wote         1:         Cases with L/D greater than 5.6         Locate, cm         3.11         N/A         N/A           wote         2:         Mod         Not         2:         3.28         0.46         1/A           wote         2:         Case         Locate, cm         3.11         N/A         1/A           wote         2:         Mod         Not         2:         2:         2:         2:         2:         2:         2:         2:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | conds         40         30         70         105         R throatlavg, cm         74.6         10.129         0.877           70         30         70         105         R throatlavg, cm         1         155.54         N/A         N/A           70         30         70         105         R throatlavg, cm         1         155.53         35.858         0.46           70         30         10         Ditts         Lcase, cm         3.11         N/A         N/A           81         N/A         N/A         N/A         N/A         N/A         N/A           Note 1:         Cases with L/D greater than 5.6         Lcase, cm         3.11         N/A         N/A           Note 2:         MG propellant to wind w/o joints.         Nozzle. Exit 0.D. cm         97.4         N/A         N/A           Note 2:         MG propellant burn rates         Norezle. Kg         16.683         N/A         N/A           Note 3:         Data is being extrapolated         W groter, kg         130.03.03018         2.44         N/A           Note 3:         Data is being extrapolated         W groter, kg         11.0         1.33.03.030318         2.444         N/A           Note 4:         Dat                                                                                                                                                   | •<br>ទ                   | 250.000            | 62K to 328K      | (Isp)vac, sec-N/kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |   | 2,666.21 5.8349 | 6 0.21  |
| 70         30         To         105         15.4         N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 70         30         70         105         16.4         N/A         N/A           -         200.000         Favgyst, N         -         1.036.540         N/A         N/A           ms         -         200.000         Favgyst, N         -         1.036.540         N/A         N/A           ms         -         200.000         Favgyst, N         -         1.112.000         N/A         N/A           tote 1:         Cases with L/D greater than 5.6         L case, cm         -         3.11         N/A         N/A           tote 1:         Cases with L/D greater than 5.6         L case, cm         -         3.11         N/A         N/A           dote 2:         MG propellant burn rates         U         Nozale Ext O.D. cm         882.0         N/A         N/A           dote 2:         MG propellant burn rates         W prozellant kg         -         16.683         N/A         N/A           dote 3:         Data lebing extrepolated         W moztle, kg         -         11.0         1315.5         5.7           Note 3:         Data ls being extrapolated         W faulter, kg         -         11.0         1315.5         5.7           Note 4:         Data ls being extrapolated                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 70         30         70         105         1036.54         N/A         N/A           -         200.000         Favgyust, N         -         1036.540         N/A         N/A           -         200.000         Favgyust, N         -         1.112.000         N/A         N/A           olde         1:         Cases with L/D greater than 5.6         L/D case         -         552.5 3.858.80         0.46           olde         1:         Cases with L/D greater than 5.6         Locas, cm         -         3.11         N/A         N/A           dole         1:         Cases with L/D greater than 5.6         Locas, cm         -         97.4         N/A         N/A           dole         2:         MG propellant burn rates         Noracle, kg         -         16.683         N/A         N/A           dole         3:         Data tailorable between         W propellant, kg         -         16.683         N/A         N/A           dole         0.34 and 0.81 ips.         W propellant, kg         -         257.2         6.06505         13.55         5.7           Note         3:         Data is being extrapolated         W igniter, kg         -         17.05         251.003         9.3<                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 70         30         To         105         R throatlave         11         1036.540         N/A         N/A         N/A           ms         200.000         Favglst, N         1,112,000         N/A         N/A         N/A           teast         L cases, cm         552.53.85626         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.46         0.                                                                                                                                                  | - spuos                  | 40                 | 30 To 105        | (A throat)avg. cm <sup>2</sup> 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |   | 744.6 10.129    | 9 0.87  |
| -     200.000     If Pavgysl, N     -     1.036.540     N/A     N/A       ms     -     200.000     N/A     N/A     N/A       not     1.112.000     N/A     N/A     N/A       lote 1:     Cases with L/D greater than 5.6     L nozzle. cm     552.5 3.85826     0.46       lote 1:     Cases with L/D greater than 5.6     L nozzle. cm     572.8     2.38     2.38       lote 2:     MG propellant to wind w/o joints.     Vozzle. kg     1.112.000     N/A     N/A       lote 2:     MG propellant burn rates     W propellant, kg     1.66.683     N/A     N/A       lote 3:     Data tailorable between     W propellant, kg     1.882.0     N/A     N/A       lote 3:     Data is being extrapolated     W igniter, kg     133.0     30.3018     2.45       wote 4:     Data is being extrapolated     W igniter, kg     17,379     2.516     4.44       wote 4:     Data is being extrapolated     W sRM, kg     17,379     2.510     3.03       wote 4:     Data is being extrapolated     W sRM, kg     17,379     2.65     3.03       wote 4:     Data is being extrapolated     W srage, kg     17,379     3.2516     4.44       wote 4:     Data is being extrapolated     W srage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | -       200.000       If Pavgysl, N       -       1.036.540       N/A       N/A         ms       Favgyvac, N       -       1.036.540       N/A       N/A         not       Favgyvac, N       -       1.112.000       N/A       N/A         lote 1:       Cases with L/D greater than 5.6       L nozzle, cm       552.5 3.85926       0.46         lote 2:       MG propellant burn rates       U/O case       52.8 2.387       2.28         lote 2:       MG propellant burn rates       W propellant, kg       -       52.5 3.6593       N/A       N/A         lote 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         lote 3:       Data tailorable between       0.34 and 0.81 ips.       -       166.683       N/A       N/A         lote 3:       Data is being extrapolated       W igniter, kg       -       133.0       30.3018       2.45         lote 4:       Data is being extrapolated       W igniter, kg       -       17.379       32.5103         lote 4:       Data is being extrapolated       W igniter, kg       -       17.379       32.5103         lote 4:       Data is being extrapolated       W stage, kg       -       17.379<                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | -     200.000     IPavgsl, N     -     1.036.540     N/A     N/A       Interpretation     Interpretation     1.112.000     N/A     N/A       Interpretation     Notation     Interpretation     1.112.000     N/A     N/A       Interpretation     Notation     Notation     N/A     N/A     N/A       Interpretation     Notation     Notation     N/A     N/A     N/A       Interpretation     Notation     Notation     N/A     N/A       Interpretation     Notation     Notation     N/A     N/A       Interpretation     Notation     Notation     N/A     N/A       Interpretation     Notation     N/A     N/A     N/A       Interpretation     Notation     N/A     N/A     N/A       Interpretation     N     Notation     N/A     N/A       Interpretation     N     N     N/A       Interpretation <td>-     200.000     IFavgsl, N     -     1.036.540     NA     NA       Interpret     Interpret     1.036.540     NA     NA       Interpret     Locae, cm     -     55.25     3.85826     0.46       Interpret     Locae, cm     -     55.25     3.85826     0.46       Interpret     Locae, cm     -     51.112.000     NA     NA       Interpret     Locae, cm     -     51.2     3.85826     0.46       Interpret     Locae, cm     -     51.2     3.8526     0.46       Interpret     Locae, cm     -     51.4     NA     NA       Interpret     Nozie     Extrapolated, weight, cm     97.4     NA     NA       Interpret     Nozie     Locae, kg     -     10.6     3.3     NA       Interpret     Nozie     Nozie     16.683     NA     NA       Interpret     Winsulation, kg     -     16.683     NA     NA       Interpret     Winsulation, kg     -     11.0     1315.5     5.74       Interpret     Winsulation, kg     -     16.683     NA     NA       Vote 4:     Data is being extrapolated     Winsulation, kg     -     17.379     32.516</td> <td></td> <th>20</th> <td>30 To 105</td> <td>(R throat)avg, cm</td> <td></td> <td>15.4 N/A</td> <td>N/N</td> | -     200.000     IFavgsl, N     -     1.036.540     NA     NA       Interpret     Interpret     1.036.540     NA     NA       Interpret     Locae, cm     -     55.25     3.85826     0.46       Interpret     Locae, cm     -     55.25     3.85826     0.46       Interpret     Locae, cm     -     51.112.000     NA     NA       Interpret     Locae, cm     -     51.2     3.85826     0.46       Interpret     Locae, cm     -     51.2     3.8526     0.46       Interpret     Locae, cm     -     51.4     NA     NA       Interpret     Nozie     Extrapolated, weight, cm     97.4     NA     NA       Interpret     Nozie     Locae, kg     -     10.6     3.3     NA       Interpret     Nozie     Nozie     16.683     NA     NA       Interpret     Winsulation, kg     -     16.683     NA     NA       Interpret     Winsulation, kg     -     11.0     1315.5     5.74       Interpret     Winsulation, kg     -     16.683     NA     NA       Vote 4:     Data is being extrapolated     Winsulation, kg     -     17.379     32.516                                                                                                                                                                                                                                                                                                                              |                          | 20                 | 30 To 105        | (R throat)avg, cm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |   | 15.4 N/A        | N/N     |
| ms       (Favg)vac, N       1,112,000       N/A       N/A         note 1:       Cases with L/D greater than 5.6       L case, cm       552.5 3.65826       0.46         Li/D case       L/D case       62.8       2.3876       2.387       0.46         are difficult to wind w/o joints.       L/D case       62.8       2.387       0.36         Vote 2:       MG propellant burn rates       Worzle Exit O.D., cm       97.4       N/A       N/A         Vote 2:       MG propellant burn rates       W nozzle, kg       16.683       N/A       N/A         Vote 3:       Data is being extrapolated       W issulation, kg       16.683       N/A       N/A         Note 4:       Data is being extrapolated       W igniter, kg       11.0       1.31515       5.74         Note 4:       Data is being extrapolated       W igniter, kg       17.379       32.516       4.3         Note 4:       Data is being extrapolated       W igniter, kg       17.379       32.516       4.4         Note 4:       Data is being extrapolated       Stage, kg       17.379       32.516       4.4       10.1.31515       5.74         Note 4:       Data is being extrapolated       V ideal, m/sec       4.44       10.44       10.1.31515                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | ms       [Favgybac, N       1,112,000       N/A       N/A         note 1:       Cases with L/D greater than 5.6       L cases, cm       552.5 3.85626       0.46         L/D cases       L/D case       -       -       -       -       1112,000       N/A       N/A         lote 1:       Cases with L/D greater than 5.6       L nozzle, cm       -       62.8       2.3876       2.28         lote 2:       MG propellant to wind w/o joints.       Nozzle, cm       -       -       97.4       N/A       N/A         lote 2:       MG propellant burn rates       W propellant, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W nsulation, kg       -       245.2       9.5235       2.35         Vote 3:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.77         Note 4:       Data is being extrapolated       W singe, kg       -       17.379       32.5103       9.216         Note 4:       Data is being extrapolated       W singe, kg       -       17.379       32.5103       9.2103         Note 4:       Data is being extrapolated       W singe, kg       -       17.379       32.5103       9.2103                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ms     Favgybac, N     1,112,000     NA     NA       olde 1:     Cases, cm     552,53,58526     0.46       olde 1:     Cases with L/D greater than 5.6     Lozzle, cm     572,53,58526     0.46       olde 1:     Cases with L/D greater than 5.6     Lozzle, cm     62,8,2387     2.28       olde 2:     MG propellant to wind w/o joints.     Nozzle, kg     97,4     N/A     N/A       vote 2:     MG propellant burn rates     Nozzle, kg     16,683     N/A     N/A       vote 2:     MG propellant burn rates     Nozzle, kg     16,683     N/A     N/A       vote 2:     MG propellant burn rates     Nozzle, kg     133,030.30318     2.35       Note 3:     Data is being extrapolated     W igniter, kg     17,379     32.516       Note 4:     Data is being extrapolated     W sprove kg     17,379     32.516       Note 4:     Data is being extrapolated     W stage, kg     17,379     32.516       Note 4:     Data is being extrapolated     W stage, kg     17,379     32.516       Note 4:     Data is being extrapolated     W stage, kg     17,379     32.516       Note 4:     Data is being extrapolated     W stage, kg     17,379     32.516       Note 4:     Data is being extrapolated     W sta                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | ms       Favgyvac, N       1,112.000       N/A       N/A         note 1:       Cases with L/D greater than 5.6       L cases, cm       552.5       3.88266       0.46         lote 1:       Cases with L/D greater than 5.6       L nozzle, cm       62.8       2.882.0       N/A       N/A         lote 2:       MG propellant to wind w/o joints.       Nozzle, cm       882.0       N/A       N/A         lote 2:       MG propellant burn rates       W propellant, kg       245.2       9.5235       2.35         lote 3:       Data is being extrapolated       W igniter, kg       16.683       N/A       N/A         lote 3:       Data is being extrapolated       W igniter, kg       17.379       32.5103       3.713         lote 4:       Data is being extrapolated       W igniter, kg       17.379       32.5103       3.714         lote 4:       Data is being extrapolated       W igniter, kg       17.379       32.5103       3.716         lote 4:       Data is being extrapolated       W igniter, kg       17.379       32.5103       3.716         lote 4:       Data is being extrapolated       W igniter, kg       17.379       32.5103       3.716         lote 4:       Data is being extrapolated       W igniter, kg                                                                                                                                 | •                        | 200.000            |                  | (Favg)sl, N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |   | 1.036.540 N/A   | N/N     |
| Image     L case, cm     552.5 3.85026     0.46       iote 1:     Cases with L/D greater than 5.6     L nozzle, cm     97.4     N/A       vote 2:     MG propellant to wind w/o joints.     Nozzle, cm     97.4     N/A       vote 2:     MG propellant to wind w/o joints.     Nozzle, cm     97.4     N/A       vote 2:     MG propellant burn rates     Nozzle, kg     2.38     2.38       vote 2:     MG propellant burn rates     W propellant, kg     16.683     N/A       vote 3:     Data als being extrapolated     W prozele, kg     16.683     N/A       vote 3:     Data is being extrapolated     W sRM, kg     17.379     3.516       vote 4:     Data is being extrapolated     W sRM, kg     17.379     3.516       vote 4:     Data is being extrapolated     W sRM, kg     17.379     3.516       vote 4:     Data is being extrapolated     W SRM, kg     17.379     3.516       vote 4:     Data is being extrapolated     W SRM, kg     17.379     3.516       vote 4:     Data is being extrapolated     W SRM, kg     17.379     3.516       vote 4:     Data is being extrapolated     W stage, kg     17.379     3.516       vote 4:     Data is being extrapolated     W stage, kg     17.379     17.379 <td>ms     L case, cm     552.5 3.85826     0.46       tote 1:     Cases with L/D greater than 5.6     L nozzle, cm     552.5 3.85826     0.46       tote 1:     Cases with L/D greater than 5.6     L nozzle, cm     62.8     2.38     0.46       tote 2:     MG propellant to wind w/o joints.     Nozzle, stdt O.D., cm     97.4     N/A     N/A       vote 2:     MG propellant burn rates     W propellant, kg     16.683     N/A     N/A       vote 2:     MG propellant burn rates     W nozzle, kg     16.683     N/A     N/A       vote 2:     MG propellant burn rates     W nozzle, kg     16.683     N/A     N/A       vote 3:     Data is being extrapolated     W naulation, kg     16.683     N/A     N/A       vote 3:     Data is being extrapolated     W igniter, kg     17.379     32.516     4.3       vote 4:     Data is being extrapolated     W stage, kg     17.379     32.516     4.4       Note 4:     Data is being extrapolated     W stage, kg     17.379     32.516     4.4       Note 4:     Data is being extrapolated     W stage, kg     17.379     32.516     4.44       Note 4:     Data is being extrapolated     W stage, kg     17.379     17.379     32.516       Note 4:     Data</td> <td>ms     552.5 3.55826     0.46       iote 1: Cases with L/D greater than 5.6     L nozzle. cm     552.5 3.55826     0.46       iote 1: Cases with L/D greater than 5.6     L nozzle. cm     53.11 N/A     N/A       vote 2: MG propellant burn rates     Nozzle Exit O.D. cm     97.4 N/A     N/A       vote 2: MG propellant burn rates     W propellant, kg     16.683 N/A     N/A       vote 2: MG propellant burn rates     W propellant, kg     16.683 N/A     N/A       vote 3: Data is being extrapolated     W igniter, kg     11.0 1.31515     5.7       Note 4: Data is being extrapolated     W igniter, kg     11.0 1.31515     5.7       Note 4: Data is being extrapolated     W stage, kg     17.379     32.516       Note 4: Data is being extrapolated     W stage, kg     11.0 1.31515     5.7       Note 4: Data is being extrapolated     W igniter, kg     17.379     32.516       Note 4: Data is being extrapolated     W igniter, kg     10.012.3 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.012.3 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.012.2 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.012.2 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.092.2 N/A</td> <td>ms     L case, cm     552.5 3.85280     0.46       tote 1:     Cases with L/D greater than 5.6     L nozzle. cm     3.11 N/A     N/A       tote 2:     MG propellant to wind w/o joints.     Nozzle. cm     62.8 2.3876     2.285       tote 2:     MG propellant to wind w/o joints.     Nozzle. cm     882.0 N/A     N/A       tote 2:     MG propellant to wind w/o joints.     Nozzle. cm     882.0 N/A     N/A       tote 2:     MG propellant to wind 0.81 ps.     W propellant, kg     245.2 9.5235     2.35       0.34 and 0.81 ps.     W rasulation. kg     16.683 N/A     N/A     N/A       Note 3:     Data is being extrapolated     W siniter, kg     17,379     32.516       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated</td> <td></td> <th></th> <td></td> <td>(Favg)vac, N</td> <td></td> <td>1,112,000 N/A</td> <td>N/A</td> | ms     L case, cm     552.5 3.85826     0.46       tote 1:     Cases with L/D greater than 5.6     L nozzle, cm     552.5 3.85826     0.46       tote 1:     Cases with L/D greater than 5.6     L nozzle, cm     62.8     2.38     0.46       tote 2:     MG propellant to wind w/o joints.     Nozzle, stdt O.D., cm     97.4     N/A     N/A       vote 2:     MG propellant burn rates     W propellant, kg     16.683     N/A     N/A       vote 2:     MG propellant burn rates     W nozzle, kg     16.683     N/A     N/A       vote 2:     MG propellant burn rates     W nozzle, kg     16.683     N/A     N/A       vote 3:     Data is being extrapolated     W naulation, kg     16.683     N/A     N/A       vote 3:     Data is being extrapolated     W igniter, kg     17.379     32.516     4.3       vote 4:     Data is being extrapolated     W stage, kg     17.379     32.516     4.4       Note 4:     Data is being extrapolated     W stage, kg     17.379     32.516     4.4       Note 4:     Data is being extrapolated     W stage, kg     17.379     32.516     4.44       Note 4:     Data is being extrapolated     W stage, kg     17.379     17.379     32.516       Note 4:     Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ms     552.5 3.55826     0.46       iote 1: Cases with L/D greater than 5.6     L nozzle. cm     552.5 3.55826     0.46       iote 1: Cases with L/D greater than 5.6     L nozzle. cm     53.11 N/A     N/A       vote 2: MG propellant burn rates     Nozzle Exit O.D. cm     97.4 N/A     N/A       vote 2: MG propellant burn rates     W propellant, kg     16.683 N/A     N/A       vote 2: MG propellant burn rates     W propellant, kg     16.683 N/A     N/A       vote 3: Data is being extrapolated     W igniter, kg     11.0 1.31515     5.7       Note 4: Data is being extrapolated     W igniter, kg     11.0 1.31515     5.7       Note 4: Data is being extrapolated     W stage, kg     17.379     32.516       Note 4: Data is being extrapolated     W stage, kg     11.0 1.31515     5.7       Note 4: Data is being extrapolated     W igniter, kg     17.379     32.516       Note 4: Data is being extrapolated     W igniter, kg     10.012.3 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.012.3 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.012.2 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.012.2 N/A     N/A       Note 4: Data is being extrapolated     W igniter, kg     10.092.2 N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | ms     L case, cm     552.5 3.85280     0.46       tote 1:     Cases with L/D greater than 5.6     L nozzle. cm     3.11 N/A     N/A       tote 2:     MG propellant to wind w/o joints.     Nozzle. cm     62.8 2.3876     2.285       tote 2:     MG propellant to wind w/o joints.     Nozzle. cm     882.0 N/A     N/A       tote 2:     MG propellant to wind w/o joints.     Nozzle. cm     882.0 N/A     N/A       tote 2:     MG propellant to wind 0.81 ps.     W propellant, kg     245.2 9.5235     2.35       0.34 and 0.81 ps.     W rasulation. kg     16.683 N/A     N/A     N/A       Note 3:     Data is being extrapolated     W siniter, kg     17,379     32.516       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated     W singe, kg     17,379     32.5103       Note 4:     Data is being extrapolated                                                                                                                             |                          |                    |                  | (Favg)vac, N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |   | 1,112,000 N/A   | N/A     |
| L/D case       3.11       N/A       N/A         lote 1:       Cases with L/D greater than 5.6       L nozzle. km       97.4       N/A         are difficult to wind w/o joints.       Nozzle. km       97.4       N/A       N/A         dote 2:       MG propellant burn rates       Nozzle. kg       16.683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         0.34 and 0.81 tps.       W propellant, kg       13.011.01.31515       5.74       133.03.03618       2.65         Vote 3:       Data is being extrapolated       W igniter, kg       17.379       32.516       36.855.1003         Note 4:       Data is being extrapolated       W SRM, kg       17.379       32.5103       32.616         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       32.616         Note 4:       Data is being extrapolated       W SRB, kg       17.379       32.516       32.516         Note 4: <t< td=""><td>U/D case       3.11       N/A       N/A         Jote 1:       Cases with L/D greater than 5.6       L nozzle. cm       97.4       N/A       N/A         Jote 1:       Cases with L/D greater than 5.6       Nozzle. cm       97.4       N/A       N/A         Jote 2:       MG propellant to wind w/o joints.       Nozzle. kg       97.4       N/A       N/A         Jote 2:       MG propellant burn rates       W propellant, kg       -       882.0       N/A       N/A         Jote 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         Jote 3:       Data is being extrapolated       W insulation, kg       -       245.2       9.5355       2.35         Vote 3:       Data is being extrapolated       W igniter, kg       -       110.1.31515       5.77         Wote 4:       Data is being extrapolated       W sRM, kg       -       706       4.3918       4.3         Note 4:       Data is being extrapolated       W stage, kg       -       13.0.032.3618       4.3         Note 4:       Data is being extrapolated       W stage, kg       -       17.369       3.516       4.4       N/A       N/A         Note 4:       Data is being extrapolat</td><td>L/D cases with L/D greater than 5.6       L. nozzle, cm       5.311       N/A       N/A         lote 1: Cases with L/D greater than 5.6       L. nozzle, cm       62.8       2.3876       2.28         are difficult to wind w/o joints.       Nozzle Exit O.D., cm       882.0       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 3: Mc and 0.81 ips.       W nozzle, kg       16,683       N/A       N/A         Vote 3: Data is being extrapolated       W isnulation, kg       17.379       32.516       4.3         Vote 4: Data is being extrapolated       W SRM, kg       17.379       32.516       4.3         Vote 4: Data is being extrapolated       W SRM, kg       17.379       32.5103       4.3         Vote 4: Data is being extrapolated       W SRB, kg       17.379       32.5103       4.3         Vote 4: Data is being extrapolated       W SRB, kg       17.365       5.7       4.44       4.4         Vote 4: Data is being extrapolated       W SRB, kg       17.379       32.5103       4.4       4.4       4.4         Vote 4: Data is being extrapolated       W SRB, kg       17.050       0.922       4.4       7.0         Note 4: Data is being extrapolated</td><td>L/D cases with L/D greater than 5.6       L/D case       3.11       N/A       N/A         lote 1: Cases with L/D greater than 5.6       L nozzle, cm       97.4       N/A       N/A         dote 2: MG propellant to wind w/o joints.       Nozzle Exit O.D., cm       982.0       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         w propellant burn rates       W nozzle, kg       16,683       N/A       N/A         w propellant burn rates       W nozzle, kg       133.0       30.3618       2.357.2       5.5235       2.357.2       5.57.2       5.5235       2.35.1       3.74       N/A       N/A         wote 3: Data is being extrapolated       W igniter, kg       11.0       131.01       1315.5       5.74         wote 4: Data is being extrapolated       W stage, kg       17,379       32.516       4.44       N/A         wote 4: Data is being extrapolated       W stage, kg       17,379       32.516       4.44       N/A         wote 4: Data is being extrapolated       V ideal, m/sec       4.44       N/A       10.022       N/A         wote 4: Data is being extrapolated       V ideal, m/sec       4.44 BF+07       N/A       11.0.1231515       5.74</td><td>na</td><th></th><td></td><td>L case, cm</td><td></td><td>552.5 3.8582</td><td>8 0.46</td></t<>                                  | U/D case       3.11       N/A       N/A         Jote 1:       Cases with L/D greater than 5.6       L nozzle. cm       97.4       N/A       N/A         Jote 1:       Cases with L/D greater than 5.6       Nozzle. cm       97.4       N/A       N/A         Jote 2:       MG propellant to wind w/o joints.       Nozzle. kg       97.4       N/A       N/A         Jote 2:       MG propellant burn rates       W propellant, kg       -       882.0       N/A       N/A         Jote 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         Jote 3:       Data is being extrapolated       W insulation, kg       -       245.2       9.5355       2.35         Vote 3:       Data is being extrapolated       W igniter, kg       -       110.1.31515       5.77         Wote 4:       Data is being extrapolated       W sRM, kg       -       706       4.3918       4.3         Note 4:       Data is being extrapolated       W stage, kg       -       13.0.032.3618       4.3         Note 4:       Data is being extrapolated       W stage, kg       -       17.369       3.516       4.4       N/A       N/A         Note 4:       Data is being extrapolat                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | L/D cases with L/D greater than 5.6       L. nozzle, cm       5.311       N/A       N/A         lote 1: Cases with L/D greater than 5.6       L. nozzle, cm       62.8       2.3876       2.28         are difficult to wind w/o joints.       Nozzle Exit O.D., cm       882.0       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 3: Mc and 0.81 ips.       W nozzle, kg       16,683       N/A       N/A         Vote 3: Data is being extrapolated       W isnulation, kg       17.379       32.516       4.3         Vote 4: Data is being extrapolated       W SRM, kg       17.379       32.516       4.3         Vote 4: Data is being extrapolated       W SRM, kg       17.379       32.5103       4.3         Vote 4: Data is being extrapolated       W SRB, kg       17.379       32.5103       4.3         Vote 4: Data is being extrapolated       W SRB, kg       17.365       5.7       4.44       4.4         Vote 4: Data is being extrapolated       W SRB, kg       17.379       32.5103       4.4       4.4       4.4         Vote 4: Data is being extrapolated       W SRB, kg       17.050       0.922       4.4       7.0         Note 4: Data is being extrapolated                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | L/D cases with L/D greater than 5.6       L/D case       3.11       N/A       N/A         lote 1: Cases with L/D greater than 5.6       L nozzle, cm       97.4       N/A       N/A         dote 2: MG propellant to wind w/o joints.       Nozzle Exit O.D., cm       982.0       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         w propellant burn rates       W nozzle, kg       16,683       N/A       N/A         w propellant burn rates       W nozzle, kg       133.0       30.3618       2.357.2       5.5235       2.357.2       5.57.2       5.5235       2.35.1       3.74       N/A       N/A         wote 3: Data is being extrapolated       W igniter, kg       11.0       131.01       1315.5       5.74         wote 4: Data is being extrapolated       W stage, kg       17,379       32.516       4.44       N/A         wote 4: Data is being extrapolated       W stage, kg       17,379       32.516       4.44       N/A         wote 4: Data is being extrapolated       V ideal, m/sec       4.44       N/A       10.022       N/A         wote 4: Data is being extrapolated       V ideal, m/sec       4.44 BF+07       N/A       11.0.1231515       5.74                                                                                                                         | na                       |                    |                  | L case, cm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |   | 552.5 3.8582    | 8 0.46  |
| dote 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.       L nozzle, cm       62.8 2.3876       2.3876       2.3876         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2: MG propellant burn rates       W nozzle, kg       245.2 9,5235       2.35         0.34 and 0.81 ips.       W nozzle, kg       133.0 30.3018       2.64         0.34 and 0.81 ips.       W insulation, kg       133.0 30.3018       2.64         Note 3: Data is being extrapolated       W igniter, kg       11.0 1.31515       5.74         Note 4: Data is being extrapolated       W sRM, kg       17,379       32.516         Note 4: Data is being extrapolated       W sRM, kg       17,379       32.516         W stage, kg       18,085       55.1003       1.8         Note 4: Data is being extrapolated       W sRB, kg       4.146E+07       1.4         Note 4: Data is being extrapolated       W sRB, kg       13.665       1.3         Note 4: Data is being extrapolated       W sRB, kg       1.446E+07       1.446E+07                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | dote 1: Cases with L/D greater than 5.6       L nozzle. cm       62.8       2.3876       2.3876       2.28         dote 2: MG propellant to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         dote 2: Rbo) are tailorable between       W propellant, kg       245.2       9.5235       2.355         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.4         Note 3: Data is being extrapolated       W igniter, kg       111.0       1.31515       5.7         Note 4: Data is being extrapolated       W stage, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       17.379       32.516       4.4       4.4       1.4         Note 4: Data is being extrapolated       W SRB, kg       -       0.922       1.4       1.4       1.44       1.44       1.44                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | dote 1: Cases with L/D greater than 5.6       L nozzle. cm       62.8       2.3876       2.28         dote 2: MG propellant to wind w/o joints.       Nozzle Extt O.D cm       97.4       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         Note 3: Data is being extrapolated       W nsulation, kg       257.2       95.29       2.35         Note 4: Data is being extrapolated       W igniter, kg       17.01.31515       5.77         Note 4: Data is being extrapolated       W stage, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W stage, kg       18.085       55.1003       4.4       N/A         Note 4: Data is being extrapolated       W stage, kg       19.085       55.1003       4.4       N/A         Note 4: Data is being extrapolated       W stage, kg       17.379       32.516       4.3       4.4       N/A         Note 4: Data is being extrapolated       W stage, kg       17.379       32.5103       4.4       N/A         Note 4: Data is being extrapolated       W stage, kg       19.085       55.1003       N/A         Not                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | dote 1: Cases with L/D greater than 5.6       L nozzle, cm       62.8       2.3376       2.3876       2.283         dote 2: MG propellant to wind w/o joints.       Nozzle Exit O.D., cm       97.4       N/A       N/A         dote 2: MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2: Rbo) are tailorable between       W nozzle, kg       245.2       95235       2.35         vote 3: Data is being extrapolated       W igniter, kg       11.0       1.31515       5.77         wote 4: Data is being extrapolated       W igniter, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W igniter, kg       17.079       32.516       4.3         Note 4: Data is being extrapolated       W stage, kg       17.379       32.516       4.3         Note 4: Data is being extrapolated       W igniter, kg       17.379       32.516       4.4       N/A         Note 4: Data is being extrapolated       W stage, kg       17.01.31515       5.77       0.0922       N/A       N/A         Note 4: Data is being extrapolated       V ideal, m/sec       0.922       N/A       N/A       N/A         Note 4: Data is being extrapolated       V ideal, m/sec       4.44 BF+07       N/A       N/A                                                                                           |                          |                    |                  | L/D case                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |   | 3.11 N/A        | N/A     |
| are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         inte 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         inte 2:       Rbo) are tailorable between       W propellant, kg       -       245.2       9.5235       2.355         0.34 and 0.81 ips.       W nozzle, kg       -       183.0       30.3618       2.64         0.34 and 0.81 ips.       W case, kg       -       11.0       1.35       2.64         Vote 3:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.74         Note 4:       Data is being extrapolated       W sRM, kg       -       17,379       32.516       4.34       1.7         Note 4:       Data is being extrapolated       W SRB, kg       -       11.0       1.31515       5.74         Note 4:       Data is being extrapolated       W SRB, kg       -       17,379       32.516       4.44       N/A         Note 4:       Data is being extrapolated       W stage, kg       -       0.922       N/A       N/A <td>are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         dote 2:       Rbo) are tailorable between       W propellant, kg       16.683       N/A       N/A         0.34 and 0.81 ips.       W nozzle, kg       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       30.3618       2.6         0.34 and 0.81 ips.       W insulation, kg       133.0       30.3618       2.6         viote 3:       Data is being extrapolated       W igniter, kg       11.0       1.31515       5.7         Note 4:       Data is being extrapolated       W SRM, kg       17,379       32.516       4.3         Note 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.3         Note 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.4       4.4       1.0         Note 4:       Data is being extrapolated       V ideal, m/sec       4.44       10.0       1.446       1.446       1.7       1.446         Note 4:       Data is being extrapolated       V ideal, m/sec       <td< td=""><td>are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         (Rbo) are tailorable between       W nozzle, kg       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       257.2       6.08597       1.3         0.34 and 0.81 ips.       W stater, kg       11.0       131515       5.7         wote 3:       Data is being extrapolated       W igniter, kg       17,379       32.516         wote 4:       Data is being extrapolated       W SRM, kg       17,379       32.516         wote 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.3         wote 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.4       M/A         wote 706       G       0.922       M/A       M/A       A.44       M/A       M/A         wote 706       &lt;</td><td>are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         Rbo) are tailorable between       W propellant, kg       245.2       9.5235       2.35         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.64         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.65         0.34 and 0.81 ps.       W sinulation, kg       133.0       30.3618       2.66         vote 3:       Data is being extrapolated       W igniter, kg       11.0       1.31515       5.74         Note 4:       Data is being extrapolated       W SRB, kg       17,379       32.516       4.4         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       1.44         Note 4:       Data is being extrapolated       W stage, kg       1.7,379       32.516       4.44       N/A         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       N/A         Note 4:       <td< td=""><td>Jote 1: (</td><th>Cases with L/D</th><td>greater than 5.6</td><td>L nozzle, cm</td><td>•</td><td>62.8 2.387</td><td>6 2.28</td></td<></td></td<></td>                                      | are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16.683       N/A       N/A         dote 2:       Rbo) are tailorable between       W propellant, kg       16.683       N/A       N/A         0.34 and 0.81 ips.       W nozzle, kg       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       30.3618       2.6         0.34 and 0.81 ips.       W insulation, kg       133.0       30.3618       2.6         viote 3:       Data is being extrapolated       W igniter, kg       11.0       1.31515       5.7         Note 4:       Data is being extrapolated       W SRM, kg       17,379       32.516       4.3         Note 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.3         Note 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.4       4.4       1.0         Note 4:       Data is being extrapolated       V ideal, m/sec       4.44       10.0       1.446       1.446       1.7       1.446         Note 4:       Data is being extrapolated       V ideal, m/sec <td< td=""><td>are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         (Rbo) are tailorable between       W nozzle, kg       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       257.2       6.08597       1.3         0.34 and 0.81 ips.       W stater, kg       11.0       131515       5.7         wote 3:       Data is being extrapolated       W igniter, kg       17,379       32.516         wote 4:       Data is being extrapolated       W SRM, kg       17,379       32.516         wote 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.3         wote 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.4       M/A         wote 706       G       0.922       M/A       M/A       A.44       M/A       M/A         wote 706       &lt;</td><td>are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         Rbo) are tailorable between       W propellant, kg       245.2       9.5235       2.35         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.64         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.65         0.34 and 0.81 ps.       W sinulation, kg       133.0       30.3618       2.66         vote 3:       Data is being extrapolated       W igniter, kg       11.0       1.31515       5.74         Note 4:       Data is being extrapolated       W SRB, kg       17,379       32.516       4.4         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       1.44         Note 4:       Data is being extrapolated       W stage, kg       1.7,379       32.516       4.44       N/A         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       N/A         Note 4:       <td< td=""><td>Jote 1: (</td><th>Cases with L/D</th><td>greater than 5.6</td><td>L nozzle, cm</td><td>•</td><td>62.8 2.387</td><td>6 2.28</td></td<></td></td<> | are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         (Rbo) are tailorable between       W nozzle, kg       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       245.2       9.535       2.35         0.34 and 0.81 ips.       W naulation, kg       133.0       257.2       6.08597       1.3         0.34 and 0.81 ips.       W stater, kg       11.0       131515       5.7         wote 3:       Data is being extrapolated       W igniter, kg       17,379       32.516         wote 4:       Data is being extrapolated       W SRM, kg       17,379       32.516         wote 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.3         wote 4:       Data is being extrapolated       W stage, kg       17,379       32.516       4.4       M/A         wote 706       G       0.922       M/A       M/A       A.44       M/A       M/A         wote 706       <                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | are difficult to wind w/o joints.       Nozzle Extt O.D., cm       97.4       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         dote 2:       MG propellant burn rates       W propellant, kg       16,683       N/A       N/A         Rbo) are tailorable between       W propellant, kg       245.2       9.5235       2.35         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.64         0.34 and 0.81 ps.       W nozzle, kg       133.0       30.3618       2.65         0.34 and 0.81 ps.       W sinulation, kg       133.0       30.3618       2.66         vote 3:       Data is being extrapolated       W igniter, kg       11.0       1.31515       5.74         Note 4:       Data is being extrapolated       W SRB, kg       17,379       32.516       4.4         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       1.44         Note 4:       Data is being extrapolated       W stage, kg       1.7,379       32.516       4.44       N/A         Note 4:       Data is being extrapolated       W SRB, kg       18.085       55.1003       N/A         Note 4: <td< td=""><td>Jote 1: (</td><th>Cases with L/D</th><td>greater than 5.6</td><td>L nozzle, cm</td><td>•</td><td>62.8 2.387</td><td>6 2.28</td></td<> | Jote 1: (                | Cases with L/D     | greater than 5.6 | L nozzle, cm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | • | 62.8 2.387      | 6 2.28  |
| Inde 2:       MG propellant burn rates       Total Length, cm       682.0       N/A       N/A         Inte 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         Rbo) are tailorable between       W nozzle, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W insulation, kg       -       245.2       9.5235       2.35         viote 3:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.74         vote 4:       Data is being extrapolated       W igniter, kg       -       17,379       32.516       4.3         vote 4:       Data is being extrapolated       W stage, kg       -       11.0       1.31515       5.74         vote 4:       Data is being extrapolated       W stage, kg       -       17,379       32.516       4.3         vote 4:       Data is being extrapolated       W stage, kg       -       18,085       55.1003       17,379       32.516         vote 4:       Data is being extrapolated       W stage, kg       -       18,085       55.1003       17,379       32.516         vote 4:       Data is being extrapolated       V kdeal, m/sec       -       4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Indec 2:       MG propellant burn rates       Total Length. cm       -       882.0       N/A       N/A         Rbo) are tailorable between       W propellant, kg       -       16,683       N/A       N/A         0.34 and 0.81 ips.       W nozzle, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W insulation, kg       -       245.2       9.5235       2.35         vice 3:       Data is being extrapolated       W igniter, kg       -       183.0       30.3618       2.6         vice 4:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.7         vice 4:       Data is being extrapolated       W igniter, kg       -       17,379       32.516       4.3         viote 4:       Data is being extrapolated       W sRB, kg       -       11.0       1.31515       5.7         wote ange of regression.       W sRB, kg       -       13.065       55.1003       10.9         viote 4:       Data is being extrapolated       W kdcal, m/sec       -       0.922       N/A       N/A         wote range of regression.       Mass Fraction       -       0.922       N/A       N/A         impulse/sisi, N-secc       -<                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Total Length, cm       -       882.0       N/A       N/A         lote 2:       MG propellant burn rates       W propelant, kg       -       16.683       N/A       N/A         (Rbo) are tailorable between       W nozzle, kg       -       245.2       9.5335       2.35         0.34 and 0.81 ips.       W nsulation, kg       -       245.2       9.5335       2.35         0.34 and 0.81 ips.       W insulation, kg       -       245.2       9.5335       2.35         0.34 and 0.81 ips.       W simulation, kg       -       133.0       2.45.2       9.5335       2.35         0.34 and 0.81 ips.       W scase, kg       -       11.0       1.31515       5.7         below range of regression.       W SRM, kg       -       706       4.2.9918       4.3         Vote 4:       Data is being extrapolated       W stage, kg       -       17.379       32.516       4.3         Vote 4:       Data is being extrapolated       W stage, kg       -       17.379       32.516       4.4         Vote 4:       Data is being extrapolated       W stage, kg       -       17.379       32.516         dote 1:       Babove range of regression.       V stage, kg       -       0.922       N/                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Total Length, cm       -       682.0       N/A       N/A         lote 2:       MG propellant burn rates       W propellant, kg       -       16.683       N/A       N/A         (Rbo) are tailorable between       W nozzle, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W insulation, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W isulation, kg       -       183.0       30.3618       2.6         0.34 and 0.81 ips.       W simulation, kg       -       183.0       30.3618       2.6         0.35       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.7         wore taige of regression.       W SRM, kg       -       17,379       32.516       4.3         wore taige of regression.       W SRB, kg       -       16.085       55.1003       4.44         wore range of regression.       W SRB, kg       -       14.4       N/A       N/A         dote 4:       Data is being extrapolated       V ideal, m/sec       -       4.448E+07       N/A         dote 7:0818:       N-sec       -       0.922       N/A       N/A         (Impulse/vac, N-sec       <                                                                                                                                                                                         |                          | are difficult to w | vind w/o joints. | Nozzle Exit O.D., cm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |   | 97.4 N/A        | N/N     |
| iote 2:       MG propellant burn rates       W propellant, kg       -       16,683       N/A       N/A         iRbo) are tailorable between       W nozzle, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W insulation, kg       -       245.2       9.5235       2.35         vote 3:       Data is being extrapolated       W igniter, kg       -       183.0       30.3618       2.64         vote 4:       Data is being extrapolated       W igniter, kg       -       17,379       32.516       4.3         vote 4:       Data is being extrapolated       W stage, kg       -       17,379       32.516       4.3         vote 4:       Data is being extrapolated       W SRB, kg       -       17,379       32.516       4.3         vote 4:       Data is being extrapolated       W SRB, kg       -       706       42.9918       4.3         vote 4:       Data is being extrapolated       W SRB, kg       -       0.922       N/A       N/A         vote 4:       Data is being extrapolated       W stage, kg       -       0.922       N/A       N/A         above range of regression.       W SRB, kg       -       -       4.44       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | iote 2:       MG propellant burn rates       W propellant, kg       -       16,683       N/A       N/A         iote 2:       Rbo) are tailorable between       W nozzle, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W insulation, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ips.       W isulation, kg       -       257.2       6.08597       1.3         vote 3:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.7         wote 4:       Data is being extrapolated       W stage, kg       -       17,379       32.516       4.3         wote 4:       Data is being extrapolated       W SRB, kg       -       18,085       55.1003         wote 706       Fraction       -       0.922       N/A       N/A         how range of regression.       W stage, kg       -       17,379       32.516       4.44       N/A         wote range of regression.       W stage, kg       -       18,085       55.1003       10         wote range of regression.       V ideal, m/sec       -       0.922       N/A       N/A         More 1.       More 1.       -       -       0.922<                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | iote 2:       MG propellant burn rates       W propellant, kg       -       16,683       N/A       N/A         iote 2:       Rbo) are tailorable between       W nozzle, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ps.       W insulation, kg       -       245.2       9.5235       2.35         0.34 and 0.81 ps.       W insulation, kg       -       245.2       9.5235       2.35         vote 3:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.7         wote 4:       Data is being extrapolated       W sRM, kg       -       117,379       32.516       4.3         wote 4:       Data is being extrapolated       W stage, kg       -       117,379       32.516       4.3         wote 4:       Data is being extrapolated       W stage, kg       -       17,379       32.516         wote 4:       Data is being extrapolated       W stage, kg       -       106       4.44       N/A         wote ange of regression.       W stage, kg       -       0.922       N/A       N/A         wote range of regression.       W stage, kg       -       0.922       N/A       N/A         impove range of regression.       V i                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | dote 2:       MG propellant burn rates       W propellant, kg       -       16,683       N/A       N/A       N/A         Rbo) are tailorable between       W nozzle, kg       -       245,2       9.5235       2.355         0.34 and 0.81 ips.       W insulation, kg       -       245,2       9.5235       2.355         0.34 and 0.81 ips.       W insulation, kg       -       183,0       30.3618       2.64         Vote 3:       Data is being extrapolated       W igniter, kg       -       11.0       1.31515       5.74         Vote 4:       Data is being extrapolated       W sRM, kg       -       17,379       32.516       4.3         Note 4:       Data is being extrapolated       W sRB, kg       -       18,085       55.1003         Note 4:       Data is being extrapolated       W ideal, m/sec       -       4.146       N/A       N/A         Note 4:       Data is being extrapolated       W ideal, m/sec       -       18,085       55.1003       17,379       32.516         Note 4:       Data is being extrapolated       W ideal, m/sec       -       18,085       55.1003       17       17,379       32.516       17       17,379       32.516       17       17       17       17 </td <td></td> <th></th> <td></td> <td>Total Length, cm</td> <td></td> <td>882.0 N/A</td> <td>V/V</td>                                                       |                          |                    |                  | Total Length, cm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |   | 882.0 N/A       | V/V     |
| (Rbo) are tailorable betweenW nozzle, kg-245.29.52352.350.34 and 0.81 lps.W insulation, kg-257.26.065971.32vote 3:Data is being extrapolatedW igniter, kg-11.01.315155.74vote 4:Data is being extrapolatedW igniter, kg-11.01.315155.74vote 4:Data is being extrapolatedW stage, kg-17.37932.5164.3vote 4:Data is being extrapolatedW SRB, kg-13.0664.34.3vote 4:Data is being extrapolatedW SRB, kg-18.08555.10034.3vote 4:Data is being extrapolatedW SRB, kg-18.08555.10034.3vote 4:Data is being extrapolatedW SRB, kg-0.922N/AN/Aimpulse)sl. N-sec-4.146E+07N/AN/Aimpulse)sl. N-sec-4.146E+07N/AN/Aimpulse)vac. N-sec-4.448E+07N/AN/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | (Rbo) are tailorable betweenW nozzle, kg245.29.52352.350.34 and 0.81 ips.W insulation, kg-257.26.065971.350.34 and 0.81 ips.W tanulation, kg-257.26.065971.35vote 3: Data is being extrapolatedW igniter, kg-11.01.315155.7below range of regression.W stage, kg-17,37932.5164.3Note 4: Data is being extrapolatedW stage, kg-17,37932.5164.3Note 4: Data is being extrapolatedW SRB, kg-18,08555.10034.3Note 4: Data is being extrapolatedW Kall, m/sec-18,08555.10034.3Note 4: Data is being extrapolatedW Kall, m/sec-18,08555.10034.3Note 4: Data is being extrapolatedW ideal, m/sec-4.44N/AN/AImpulse)kg-0.922N/AN/A1/AN/AImpulse)kac, N-sec-4.448E+07N/AN/AImpulse)vac, N-sec-4.448E+07N/AN/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | W nozzle, kg245.29.52352.35(Rbo) are tailorable betweenW insulation, kg257.26.085971.30.34 and 0.81 ips.W isulation, kg-257.26.085971.3Vote 3:Data is being extrapolatedW igniter, kg-11.01.315155.7Wote 4:Data is being extrapolatedW stage, kg-17,37932.5164.3Note 4:Data is being extrapolatedW stage, kg-17,37932.5164.3Note 4:Data is being extrapolatedW stage, kg-18,08555.1003N/1Note 4:Data is being extrapolatedW field. m/sec-4.44N/AN/1Above range of regression.Mass Fraction0.922N/AN/1N/1(Impulse)/vac. N-sec-4.448E+07N/AN/1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | W nozzle, kg245.29.52352.350.34 and 0.81 ips.W insulation, kg257.26.065971.320.34 and 0.81 ips.W case, kg183.030.36182.64Vote 3:Data is being extrapolatedW igniter, kg111.01.315155.74Wote 4:Data is being extrapolatedW stage, kg17,37932.5164.3Note 4:Data is being extrapolatedW stage, kg17,37932.5164.3Note 4:Data is being extrapolatedW SRB, kg17,37932.5164.3Note 4:Data is being extrapolatedW stage, kg18,08555.10034.44N/ANote 4:Data is being extrapolatedV ideal, m/sec0.922N/AN/AImpulse)sl. N-sec4.146E+07N/AN/AN/AImpulse)sl. N-sec4.448E+07N/AN/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Jote 2:                  | MG propellant b    | ourn rates       | W propellant, kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |   | 16,683 N/A      | 1/N     |
| 0.34 and 0.81 ips.       W insulation, kg       257.2 6.06597       1.33         vote 3: Data is being extrapolated       W igniter, kg       11.0 1.31515       5.74         w igniter, kg       17.379       30.3618       2.66         below range of regression.       W stage, kg       17.379       32.516         wote 4: Data is being extrapolated       W stage, kg       17.379       32.516         wote 4: Data is being extrapolated       W SRB, kg       18.085       55.1003         wote 4: Data is being extrapolated       W stage, kg       18.085       10025       N/A         wote 4: Data is being extrapolated       W stage, kg       18.085       10025       N/A         wote 706       0.922       N/A       N/A       N/A         impulse)Is. N-sec       4.146E+07       N/A       N/A         impulse)Vac. N-sec       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.34 and 0.81 lps.       W insulation. kg       257.2 6.06597       1.3:         vote 3: Data is being extrapolated       W igniter. kg       11.0 1.31515       5.7         w igniter. kg       I 1.0 1.31515       5.7         below range of regression.       W stage, kg       17.379       32.516         Wote 4: Data is being extrapolated       W stage, kg       17.379       32.516         Wote 4: Data is being extrapolated       W SRB, kg       17.379       32.516         Wote 4: Data is being extrapolated       W SRB, kg       17.379       32.516         Wote 4: Data is being extrapolated       W SRB, kg       18.085       55.1003         Wote 4: Data is being extrapolated       W stage, kg       18.085       55.1003         Wote 4: Data is being extrapolated       W stage, kg       18.085       55.1003         Wote 4: Data is being extrapolated       W stage, kg       18.085       55.1003         Wote 4: Data is being extrapolated       W stage, kg       19.085       55.1003         Wote 4: Data is being extrapolated       W stage, kg       10.922       N/A         Wote 4: Discorn       0.922       N/A       10.922       N/A         Impulse)vac, N-sec       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0.34 and 0.81 lps.       W insulation, kg       257.2 6.06597       1.3:         vote 3: Data is being extrapolated       W igniter, kg       11.0 1.31515       5.7         w igniter, kg       17,379       32.516       4.3         w igniter, kg       18,085       55.1003       4.4         w igniter, kg       18,085       55.1003       4.4         w igniter, kg       18,085       55.1003       4.4         w igniter, kg       18,085       55.1003       4.4       4.4         w igniter, kg       18,085       55.1003       4.4       4.4         w igniter, kg       18,085       57.1003       4.4       4.4       4.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.34 and 0.81 ips.       W insulation. kg       257.2 6.06597       1.33         vote 3: Data is being extrapolated       W igniter. kg       11.0 1.31515       5.74         w igniter. kg       -       11.0 1.31515       5.74         below range of regression.       W sRM. kg       -       17,379       32.516         wote 4: Data is being extrapolated       W stage, kg       -       17,379       32.516         wote 4: Data is being extrapolated       W stage, kg       -       18,085       55.1003         wote 4: Data is being extrapolated       W stage, kg       -       18,085       55.1003         wote 4: Data is being extrapolated       W stage, kg       -       18,085       55.1003         wote 706       -       444       N/A       N/A         Mass Fraction       -       0.922       N/A       N/A         (impulse)kac, N-sec       -       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                          | (Rho) are tailors  | able between     | W nozzle, kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |   | 245.2 9.523     | 5 2.35  |
| W case, kg       -       183.0 30.3618       2.64         Vote 3: Data is being extrapolated       W igniter, kg       -       11.0 1.31515       5.74         below range of regression.       W SRM, kg       -       17.379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       706       4.3       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W stage, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W stage, kg       -       18.085       55.1003       10.444         Note 4: Data is being extrapolated       V ideal, m/sec       -       4.44       N/A       11.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | W case, kg       -       183.0 30.3618       2.6         Vote 3: Data is being extrapolated       W igniter, kg       -       11.0 1.31515       5.7         below range of regression.       W SRM, kg       -       17.379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       706       42.9918       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       11.0         Note 4: Data is being extrapolated       W Ideal, m/sec       -       444       N/A         Mass Fraction       -       0.922       N/A       N/A         Impulse)I. N-sec       -       4.448E+07       N/A       N/A         Impulse)Vac, N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Wote 3: Data is being extrapolated       W tanter, kg       -       183.0 30.3618       2.6         Wote 3: Data is being extrapolated       W tanter, kg       -       11.0 1.31515       5.7         below range of regression.       W SRM, kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       18,085       55.1003       4.1         above range of regression.       W Astage, kg       -       18,085       55.1003       1/1         Mass Fraction       V ideal, m/sec       -       4.146E+07       1/1       1/1         Impulse)vac, N-sec       -       4.448E+07       1/1       1/1       1/1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | W case, kg       -       183.0 30.3618       2.64         Vote 3: Data is being extrapolated       W igniter, kg       -       11.0 1.31515       5.74         below range of regression.       W SRM, kg       -       17.379       32.516       4.3         Note 4: Data is being extrapolated       W stage, kg       -       706       4.2.9918       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       N/A         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       N/A         Note 4: Data is being extrapolated       W SRB, kg       -       18.085       55.1003       N/A         Mass Fraction       V ideal, m/sec       -       4.146E+07       N/A       N/A         Impulse)kac, N-sec       -       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | -                        | 0.34 and 0.81 fr   | 38.              | W insulation, kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |   | 257.2 6.0859    | 97 1.3: |
| Note 3: Data is being extrapolated       W igniter. kg       -       11.0       1.31515       5.74         below range of regression.       W SRM. kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB. kg       -       706       42.9918       4.3         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.4         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.4         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.4         Note 4: Data is being extrapolated       W stage. kg       -       18,085       55.1003       11.4         Note 4: Data is being extrapolated       W stage. kg       -       18,085       55.1003       11.4         Note 4: Data is being extrapolated       W stage. kg       -       0.922       N/A       N/A         Mass Fraction       -       0.922       N/A       N/A       11.4       N/A       N/A         Impulse)vac. N-sec       -       4.448E+07       N/A       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Note 3: Data is being extrapolated       W igniter. kg       -       11.0 1.31515       5.7         below range of regression.       W SRM. kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB. kg       -       706       42.9918       4.3         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.0         Note 4: Data is being extrapolated       W SRB. kg       -       18,085       55.1003       11.0         above range of regression.       W SRB. kg       -       0.922       1/A       1/A         Mass Fraction       -       0.922       1/A       1/A       1/A         (Impulse)I. N-sec       -       4.448E+07       N/A       1/A         (Impulse)Vac. N-sec       -       4.448E+07       N/A       1/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Note 3: Data is being extrapolated       W igniter. kg       -       11.0 1.31515       5.7         below range of regression.       W SRM, kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       706       42.9918       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       18,085       55.1003       10         above range of regression.       W SRB, kg       -       18,085       55.1003       10         Mass Fraction       V ideal, m/sec       -       4.44       N/A       N/A         Impulse)isl. N-sec       -       4.146E+07       N/A       N/A         Impulse)vac. N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Note 3: Data is being extrapolated below range of regression.       W igniter. kg       -       11.0 1.31515       5.74         below range of regression.       W stage, kg       -       17,379       32.516       4.3         Note 4: Data is being extrapolated above range of regression.       W stage, kg       -       706       42.9918       4.3         Note 4: Data is being extrapolated above range of regression.       W SRB, kg       -       18,085       55.1003       N/A         Mote 4: Data is being extrapolated above range of regression.       W SRB, kg       -       18,085       55.1003       N/A         Mass Fraction       V ideal, m/sec       -       4.44       N/A       N/A         Impulse)lvac, N-sec       -       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                          | L too num too      |                  | W case, kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |   | 183.0 30.36     | 18 2.6  |
| w       SRM, kg       -       17,379       32.516         below range of regression.       w       stage, kg       -       706       42.9918       4.3         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003       N/A         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003         wore range of regression.       W       SRB, kg       -       444       N/A       N/A         above range of regression.       W ideal, m/sec       -       4.146E+07       N/A       N/A         (impulse)sl. N-sec       -       4.146E+07       N/A       N/A         (impulse)vac. N-sec       -       4.448E+07       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | w       SRM, kg       -       17,379       32.516         below range of regression.       w       stage, kg       -       706       42.9918       4.3         vote 4:       Data Is being extrapolated       w       SRB, kg       -       18,085       55.1003       11         vote 4:       Data Is being extrapolated       w       SRB, kg       -       444       N/A       N/A         vote 4:       Data Is being extrapolated       w       SRB, kg       -       444       N/A       N/A         above range of regression.       W       Mass Fraction       -       0.922       N/A       N/A         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/A       N/A         (Impulse)vac. N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | w       SRM, kg       -       17,379       32.516       4.3         w       stage, kg       -       706       42.9918       4.3         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003         above range of regression.       w       SRB, kg       -       18,085       55.1003         Mass Fraction       videal, m/sec       -       4.44       N/A       N/A         (Impulse)u.       N-sec       -       4.448E+07       N/A       N/A         (Impulse)vac, N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | w       SRM, kg       -       17,379       32.516         below range of regression.       w       stage, kg       -       706       42.9918       4.3         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003       1/4       1/A       N/A         vote 4:       Data is being extrapolated       w       SRB, kg       -       18,085       55.1003       1/A       N/A         above range of regression.       W       SRB, kg       -       18,085       55.1003       1/A       N/A         Mass Fraction       V       videal, m/sec       -       4.44       N/A       N/A         Impulse)lvac, N-sec       -       4.146E+07       N/A       N/A         (Impulse)vac, N-sec       -       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Inte 3.                  | Data is heind ex   | tranolated       | W igniter. kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | * | 11.0 1.315      | 15 5.7  |
| Wote 4: Data is being extrapolated       W stage, kg       -       706 42.9918       4.3         Wote 4: Data is being extrapolated       W SRB, kg       -       18,085 55.1003       4.44       N/A         N/A       above range of regression.       V ideal, m/sec       -       4.44       N/A       N/A         Mass Fraction       -       0.922       N/A       N/A       N/A         (impulse)lvac, N-sec       -       4.146E+07       N/A       N/A         (impulse)lvac, N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Wote 4: Data is being extrapolated       W stage, kg       -       706 42.9918       4.3         W SRB, kg       -       18,085 55.1003       W/A       N/A         above range of regression.       W tdeal, m/sec       -       444       N/A         Mass Fraction       -       0.922       N/A       N/A         (Impulse)sl, N-sec       -       4.146E+07       N/A       N/A         (Impulse)vac, N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Watage, kg       -       706 42.9918       4.3         Note 4: Data is being extrapolated       W SRB, kg       -       18,085 55.1003       N/1         W SrB, kg       -       18,085 55.1003       N/1       N/1       N/1         above range of regression.       V ideal, m/sec       -       444       N/A       N/1         Mass Fraction       -       0.922       N/A       N/1         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/1         (Impulse)vac. N-sec       -       4.448E+07       N/A       N/1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Wote 4: Data is being extrapolated above range of regression.       W SRB. kg       -       706 42.9918       4.3         W SRB. kg       -       18,085 55.1003       W/A       N/A         Note 4: Data is being extrapolated above range of regression.       V ideal. m/sec       -       444       N/A       N/A         Mass Fraction       -       0.922       N/A       N/A       N/A         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/A         (Impulse)vac. N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1010 0.                  | below range of     | regression.      | W SRM. Kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | ۰ | 17,379 32.51    | 9       |
| Note 4: Data is being extrapolated       W SRB, kg       -       18,085 55.1003         above range of regression.       V ideal, m/sec       -       444       N/A       N/I         Mass Fraction       -       0.922       N/A       N/I       N/I         (Impulse)sl, N-sec       -       4.146E+07       N/A       N/I         (Impulse)sl, N-sec       -       4.146E+07       N/A       N/I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Note 4: Data is being extrapolated       W SRB, kg       -       18,085 55.1003         above range of regression.       V ideal, m/sec       -       444       N/A       N/I         Mass Fraction       -       0.922       N/A       N/I       N/I         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/I         (Impulse)vac, N-sec       -       4.146E+07       N/A       N/I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Note 4: Data is being extrapolated       W SRB, kg       -       18,085 55.1003         above range of regression.       V ideal. m/sec       -       444       N/A         Mass Fraction       -       0.922       N/A       N/A         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/A         (Impulse)vac. N-sec       -       4.448E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Note 4: Data is being extrapolated       W SRB, kg       -       18.085 55.1003         above range of regression.       V idcal. m/sec       -       444       N/A       N/A         Mass Fraction       -       0.922       N/A       N/A         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/A         (Impulse)sl. N-sec       -       4.146E+07       N/A       N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                          | n Amar anna        | 0                | W stage, kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | ٠ | 706 42.99       | 18 4.3  |
| above range of regression. V ideal. m/sec - 444 N/A N/I<br>Mass Fraction - 0.922 N/A N/I<br>(Impulse)sl. N-sec - 4.146E+07 N/A N/I<br>(Impulse)vac. N-sec - 4.448E+07 N/A N/I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | above range of regression. 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V ideal. m/sec - 444 N/A N/J<br>Mass Fraction - 0.922 N/A N/J<br>(Impulse)sl. N-sec - 4.146E+07 N/A N/J<br>(Impulse)vac. N-sec - 4.448E+07 N/A N/J                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Vote 4.                  | Data is being ex   | rtrapolated      | W SRB, kg                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |   | 18,085 55.10    | 03      |
| Mass Fraction - 0.922 N/A N/I<br>(Impulse)sl, N-sec - 4.146E+07 N/A N/I<br>(Impulse)vac, N-sec - 4.448E+07 N/A N/I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Mass Fraction - 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Figure 49. Printed Output - "Briefing" - Metric Units

Figure 50. Script for Mg Clean Propellant Model (Medium Motors) Invalidate On Manual Recalc Select Range A57 Window Scale 65%

{Titles and dates}

Put "Medium Motors" Into A64 Put "Neutralizing Mg (DL-H435) Propellant" Into C64 Put "18 August 1992" Into A65

{Initial Independent Variable Setup}

Put 2000 Into C67{Meop, psia}Put 10 Into C68{Initial Area Ratio, Ei}Put 250000 Into C69{(Favg)vac, lbf}Put 40 Into C70{Burn Time, Tb, seconds}Put 70 Into C71{Dcase, in}Put 200000 Into C72{Push Weight, lbm}

{Load Range Information}

Put "900 To 2000" Into D67 Put "7 To 19" Into D68 Put "62K to 328K" Into D69 Put "30 To 105" Into D70 Put "30 To 105" Into D71

{Load Range Limit Checks}

Put "=If (C67<900, 1,0)" Into K67 Put "=If (C67>2000, 1,0)" Into K68 Put "=If (C68<7, 1,0)" Into K69 Put "=If (C68>19, 1,0)" Into K70 Put "=If (C69<62000, 1,0)" Into K71 Put "=If (C69>328000, 1,0)" Into K72 Put "=If (C70<30, 1,0)" Into K73 Put "=If (C70>105, 1,0)" Into K74 Put "=If (C71<30, 1,0)" Into K75 Put "=If (C71>105, 1,0)" Into K76

{Load Dependent Terms and Intermediate Results}

Put "=C71/C70" Into M76 Put "=C67\*M76" Into M78 Put "=(C67/1000)^0.39" Into M80 Put "=C69\*C70" Into M82 Put "=C69/C67" Into M84 Put "=M84/C68" Into M86 Put "=(G79/L3)/C70" Into M88 Put "=(G79/L3)/(C71\*C71)" Into M90 Put "=(G71/L2)\*C68" Into M92 Put "=((SqRt(G70)+SqRt(G70\*C68))/2\*G76)/(L2\*L2)" Into M94

Page: 2 27 March 1993 05:58:50 PM Parametric Database/Object 240 script Put "=(G79/L3)/C70\*(26.0314\*C70/(C71\*C71)+0.000046398)" Into M97 Put "=LN((C72+(G86/L3))/(C72+(G86-G79)/L3))" Into M100 {Load Results Formulas, RMSE and correlation limits, and percent error} Put "=(0.45361+0.31293\*M76+0.00001733331\*M78-0.37345\*M80)\*L2" Into G67 Put "=If(G67<0.306\*L2, ""Note 3"", If(G67>0.532\*L2, ""Note 4"", 0.0125\*L2))" Into H67 Put 2.995 Into 167 {(Isp)sl} Put "=G72\*C70/G79" Into G68 Put "N/A" Into H68 Put "N/A" Into I68 Put "=(243.468+3.47093\*C68-0.079374\*C68\*C68+0.000010827\*C69-0.026726\*C70)\*L5" Into G69 Put "=If(G69<261\*L5,""Note 3"",If(G69>286\*L5,""Note 4"",0.595\*L5))" Into H69 Put 0.217 Into I69 {(A throat)avg} Put "=(8.2551+0.0000009095\*M82+0.72572\*M84+0.58737\*M86)\*L2\*L2" Into G70 Put "=If(G70<46.5\*L2\*L2,""Note 3"",If(G70>368.2\*L2\*L2,""Note 4"",1.57\*L2\*L2))" Into H70 Put 0.872 Into I70 {(R throat)avg} Put "=SqRt(G70/3.141593)" Into G71 Put "N/A" Into H71 Put "N/A" Into 171 {(Favg)sl} Put "=(C69-14.7\*C68\*G70/(L2\*L2))\*L6" Into G72 Put "N/A" Into H72 Put "N/A" Into I72 {(Favg)vac} Put "=C69\*L6" Into G73 Put "N/A" Into H73 Put "N/A" Into I73 Put "=(6.918+26.0782\*M90+10.5873\*M80-0.049018\*C70+0.000008449\*C71\*C71\*C71\*L2" Into G74 Put "=If(G74<207\*L2,""Note 3"",If(G74>462\*L2,""Note 4"",1.519\*L2))" Into H74 Put 0.466 Into I74 {L/D case} Put "=G74/(C71\*L2)" Into G75 Put "=If(G75>5.6, ""Note 1"", ""N/A"")" Into H75 Put "N/A" Into I75 Put "=(-26.0584+6.33835\*(G71/L2)+0.16796\*M92-0.001205\*C67+0.46015\*C68)\*L2" Into G76 Put "=If(G76<5.3\*L2,""Note 3"",If(G76>89.2\*L2,""Note 4"",0.94\*L2))" Into H76

Put 2.282 Into 176

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{Nozzle Exit Dia} Put "=2\*G71\*SqRt(C68)" Into G77 Put "N/A" Into H77 Put "N/A" Into I77 {Total Length} Put "=G74+G76+(1.5\*C71)\*L2" Into G78 Put "N/A" Into H78 Put "N/A" Into I78 {W propellant} Put "=(C69\*L6)\*C70/G69" Into G79 Put "=If(G79>105000\*L3,""Note 4"",If(G79<15000\*L3,""Note 3"",""N/A""))" Into H79 Put "N/A" Into I79 Put "=(36.9679+0.000011857\*M82+0.1818\*M94+1.41166\*C70+9.22776\*G76/L2)\*L3" Into G80 {W nozzle} Put "=If(G80<221\*L3,""Note 3"",If(G80>1819\*L3,""Note 4"",21\*L3))" Into H80 Put 2.358 Into 180 {W insulation} Put "=(-170.912+0.09922\*C71\*C71+M97+1.41144\*C70)\*L3" Into G81 Put "=If(G81<260\*L3, ""Note 3"", If(G81>2085\*L3, ""Note 4"", 13.42\*L3))" Into H81 Put 1.33 Into 181 Put "=(-143.337+0.03013\*C71\*C71+3.5389\*C71+0.0006026\*C69+0.0000222242\*G79/L3)\*L3" Into G82 Put "=If(G82<394\*L3,""Note 3"",If(G82>5676\*L3,""Note 4"",66.95\*L3))" Into H82 Put 2.64 Into 182 {W igniter} Put "=(15.6963+0.00014004\*(G70/(L2\*L2))/(C71\*C71)+51.1973\*M88/C67-0.0074883\*C67)\*L3" Into G83 Put "=If(G83<16.13\*L3,""Note 3"",If(G83>106.5\*L3,""Note 4"",2.9\*L3))" Into H83 Put 5.74 Into 183 {W SRM} Put "=Sum(G79..G83)" Into G84 Put "=71.7\*L3" Into H84 Put " " Into 184 {W stage} Put "=(-502.96+0.16858\*C71\*C71+0.001425\*C71\*C71\*C71+3.07233\*(G74+G76)/L2)\*L3" Into G85 Put "=If(G85<674\*L3,""Note 3"",If(G85>4240\*L3,""Note 4"",94.8\*L3))" Into H85 Put 4.3 Into 185 {W SRB} Put "=G84+G85" Into G86 Put "=121.5\*L3" Into H86 Put " " Into 186 {V ideal} Put "=((G69/L5)\*32.18\*M100)\*L4" Into G87 Put "N/A" Into H87 Put "N/A" Into 187

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{Mass Fraction} Put "=G79/G86" Into G88 Put "N/A" Into H88 Put "N/A" Into I88

{(Impulse)sl} Put "=G72\*C70" Into G89 Put "N/A" Into H89 Put "N/A" Into I89

{(Impulse)vac} Put "=G73\*C70" Into G90 Put "N/A" Into H90 Put "N/A" Into I90

{Load Notes}

Put "Note 1:" Into A76 Put "Cases with L/D greater than 5.6" Into C76 Put "are difficult to wind w/o joints." Into C77

Put "Note 2:" Into A79 Put "MG propellant burn rates" Into C79 Put "(Rbo) are tailorable between" Into C80 Put "0.34 and 0.81 ips." Into C81

Put "Note 3:" Into A83 Put "Data is being extrapolated" Into C83 Put "below range of regression." Into C84

Put "Note 4:" Into A86 Put "Data is being extrapolated" Into C86 Put "above range of regression." Into C87

Automatic Recalc

Invalidate Off

| Ingredient | Weight Percent |
|------------|----------------|
| PGN        | 35.0           |
| AI         | 25.0           |
| AN**       | 40.0           |
|            | •              |

\* varied for mechanical property control \*\* varied for burn rate control

| Figure 51. | Nominal Compo | sition of Non | -Chlorine | Clean I | Propell | ant |
|------------|---------------|---------------|-----------|---------|---------|-----|
|------------|---------------|---------------|-----------|---------|---------|-----|

| Exhaust Product | Mass Fraction |
|-----------------|---------------|
| CO (g)          | 0.236         |
| CO2 (g)         | 0.0175        |
| AIOH            | 0.00001       |
| AlO2H           | 0.00001       |
| Al2O3 (I & s)   | 0.472         |
| ОН (g)          | 0.00017       |
| H (g)           | 0.00023       |
| H2 (g)          | 0.0274        |
| H2O (g)         | 0.0653        |
| NO (g)          | 0.00001       |
| N2 (g)          | 0.1811        |
|                 |               |

Figure 52. Theoretical Exhaust Products at 1,000 psi Chamber Pressure Expanded to 14.7 psi Non-Chlorine Clean Propellant

| Large Motors                  | Non-Chlorine (PGN          | /AN/AI   | L) Clean Propellan    | t                             |        |
|-------------------------------|----------------------------|----------|-----------------------|-------------------------------|--------|
| 14 January 1993               | Dá                         | nde      | Results               |                               | RMSE   |
| Independent Terms             | 1 000 200 T                | o 2000   | Rbo. in/sec           | . 0.540                       | 0.002  |
| Meop. psia                    | 7.0 5.7                    | 0 19     | (Isp)sl. sec-lbf/lbm  | - 244.10                      | N/A    |
| Initial Area Ratio, El        | 2 500 000 320 K            | TO 8.9 M | (Isp)vac, sec-lbf/lbm | . 267.69                      | N/A    |
| (Favg)vac, IDI                | 111 60                     | To 178   | (A throat)avg, in^2   | - 2,312.2                     | 11     |
| Burn Time, 10, seconds -      | 146 80                     | o 255    | (R throat)avg, in     | . 27.1                        | N/A    |
| Dease, In<br>Deash Weight Ibm | 1 000 000                  |          | (Favg)sl, lbf         | . 2,361,706                   | N/A    |
| Nosa Cone I /D                | 1.30                       |          | (Favg)vac, lbf        | - 2,590.000                   | N/A    |
| Nose Cone L/D                 | wine nierowali i i i i i i |          | L case, in            | <b>1,230.4</b>                | 5      |
| Dependencire renna            |                            |          | L/D case              | - 8.43                        | Note 1 |
| Note 1:                       | Cases with L/D greater t   | han 5.6  | L nozzle, in          | - 171.1                       | 3      |
|                               | are difficult to wind w/o  | joints.  | Nozzle Exit O.D., in  | <b>-</b> 140.6                | N/A    |
|                               |                            | •        | Total Length, in      | <b>.</b> 1,591.3              | N/A    |
| Note 2:                       | MG propellant burn rate    | es       | W propellant, lbm     | - 1,073,951                   | 3,048  |
| 1                             | (Rbo) are tailorable bety  | ween     | W nozzle, lbm         | - 13,442.8                    | 567    |
|                               | 0.33 and 0.818 ips.        |          | W insulation, lbm     | . 7,003.6                     | 241    |
|                               | •                          |          | W case, lbm           | <b>26,915.1</b>               | 909    |
| Note 3:                       | Data is being extrapolat   | ed       | W igniter, lbm        | <b>.</b> 639.2                | 22     |
|                               | below range of regression  | on.      | W nose cone, lbm      | . 3,742.3                     | N/A    |
|                               | 0 0                        |          | W ext insul, lbm      | - 763.5                       | N/A    |
| Note 4:                       | Data is being extrapolat   | ed       | W fwd skirt, lbm      | <b>-</b> 2,965.0              | N/A    |
|                               | above range of regression  | on.      | W aft skirt, lbm      | <b>14.659.7</b>               | N/A    |
|                               | 0 0                        |          | W separation, lbm     | - 1,257.5                     | N/A    |
|                               |                            |          | W misc, lbm           | <ul> <li>1.634.1</li> </ul>   | N/A    |
|                               |                            |          | W SRM, lbm            | <ul> <li>1.122E+06</li> </ul> | •      |
|                               |                            |          | W stage, lbm          | 2.502E+04                     |        |
|                               |                            |          | W SRB, lbm            | 1.147E+06                     | i      |
|                               |                            |          | V ideal, ft/sec       | 5.975E+03                     | N/A    |
|                               |                            |          | Mass Fraction         | <ul> <li>9.363E-01</li> </ul> | N/A    |
|                               |                            |          | (Impulse)sl, lbf-sec  | - 2.621E+08                   | 3      |
|                               |                            |          | (Impulse)vac, lbf-sec | - 2.875E+08                   | 3      |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |
|                               |                            |          |                       |                               |        |

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Figure 53. Printed Output - "Report" - English Units

| Large Motors<br>14 January 1993 | Non-Chlorine       | e (PGN/AN/AL     | ) Clean Propellan    | 4 |             |         |   |
|---------------------------------|--------------------|------------------|----------------------|---|-------------|---------|---|
| Indemendent Terms               |                    | Range            | Results              |   | R           | MSE     |   |
| Meon osta                       | 1,000              | 200 To 2000      | Rbo, cm/sec          |   | 1.370 0.    | 00508   |   |
| Initial Area Ratio. Ei          | 7.0                | 5 To 19          | (Isp)sl. sec-N/kg    |   | 2,393.78    | N/A     | _ |
| (Favøbac, Ibf                   | 2,590,000          | 320 K To 8.9 M   | (Isp)vac, sec-N/kg   |   | 2,625.18    | N/A     | _ |
| Rum Time. The seconds -         | 111                | 60 To 178        | (A throat)avg. cm^2  |   | 14,917.7 70 | 0.9676  |   |
| Deare in                        | 146                | 80 To 255        | (R throat)avg, cm    | • | 68.9        | N/A     |   |
| Push Weight Ihm                 | 1.000,000          |                  | (Favg)sl, N          |   | 10,504,867  | N/N     |   |
| Nose Cone L/D                   | 1.30               |                  | (Favg)vac, N         | • | 11.520.320  | N/A     |   |
| Denendent Terms                 |                    |                  | L case, cm           |   | 3,125.3     | 12.7    | _ |
|                                 |                    |                  | L/D case             | ĸ | 8.43 1      | Note 1  |   |
| Note 1:                         | Cases with L/D     | greater than 5.6 | L nozzle, cm         | ٠ | 434.6       | 7.62    | _ |
|                                 | are difficult to w | vind w/o loints. | Nozzle Exit O.D., cm |   | 357.2       | N/A     |   |
|                                 |                    |                  | Total Length, cm     |   | 4,042.0     | N/A     |   |
| Note 2:                         | MG propellant h    | ourn rates       | W propellant, kg     | ٠ | 487,0371    | .382.27 |   |
|                                 | (Rbo) are tailors  | able between     | W nozzle, kg         | ٠ | 6.096.3 2   | 57.135  | _ |
|                                 | 0.33 and 0.818     | tos.             | W insulation, kg     | • | 3,176.11    | 09.294  |   |
|                                 |                    | 4                | W case, kg           |   | 12,206.04   | 12.232  |   |
| Note 3:                         | Data is being ex   | trapolated       | W igniter, kg        |   | 289.9       | 9.977   |   |
|                                 | helow range of     | repression.      | W nose cone, kg      |   | 1,697.1     | V/N     |   |
|                                 |                    | D                | W ext insul, kg      | • | 346.2       | N/A     |   |
| Note 4:                         | Data is being ex   | ctrapolated      | W fwd skirt. kg      | • | 1.344.6     | N/A     | _ |
|                                 | above range of     | regression.      | W aft skirt, kg      |   | 6,648.2     | N/A     |   |
|                                 | 0                  | 0                | W separation, kg     |   | 570.3       | N/A     | - |
|                                 |                    |                  | W misc, kg           | ۰ | 741.1       | N/A     |   |
|                                 |                    |                  | W SRM. kg            |   | 5.088E+05   |         |   |
|                                 |                    |                  | W stage, kg          | • | 1.135E+04   |         | _ |
|                                 |                    |                  | W SRB, kg            | • | 5.202E+05   |         |   |
|                                 |                    |                  | V ideal, m/sec       | • | 1.821E+03   | N/A     |   |
|                                 |                    |                  | Mass Fraction        |   | 9.363E-01   | N/A     |   |
|                                 |                    |                  | (Impulse)sl, N-sec   |   | 1.166E+09   |         |   |
|                                 |                    |                  | (Impulse)vac, N-sec  |   | 1.279E+09   |         |   |
|                                 |                    |                  |                      |   |             |         |   |
|                                 |                    |                  |                      |   |             |         |   |
|                                 |                    |                  |                      |   |             |         | ~ |
|                                 |                    |                  |                      |   |             |         | _ |
|                                 |                    |                  |                      |   |             |         |   |
|                                 |                    |                  |                      |   |             |         |   |
|                                 |                    |                  |                      |   |             |         |   |

Figure 54. Printed Output - "Briefing" - Metric Units

- . .

# Figure 55. Equations for Non-Chlorine Clean Propellant Model

#### **Equations for Stage Components**

## Variable to beCalculatedEquation

Nose Cone Weight, lbm

 $W_{Nose \ Cone} = 3395 - 2098 N_{l/d} - 0.4705 (D_c/2)^2 + 2.533 x 10^{-5} \{ (D_c/2) \sqrt{(D_c/2)^2 + (N_{l/d}D_c)^2} \}^2$ 

External Insulation Weight, lbm

 $W_{ExtInsulation} = 87 + 0.7243D_c + 0.1071(D_c/2)^2$ 

Fwd Skirt and Attach Weight, lbm

 $W_{FwdSkin} = e^{(2.095+0.05276D_c - 0.0000846D_c^2)}$ 

Aft Skirt and Attach Weight, lbm

 $W_{AftSkirt} = e^{(2.89+0.06343D_c - 0.00012D_c^2)}$ 

Separation System Weight, lbm

 $W_{Separation} = 0.0011208 W_{srm}$ 

Misc Weight, lbm

 $W_{misc} = -1039 - 0.00204W_{srm} + 2.854L_{case & nozzle} + 0.07885(D_c/2)^2$ 

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# Large Motors Equations For Non-Chlorine Propellant

| Variable to be                              | Emotion                                                                                                                  | Method<br>& Range              |
|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| Burning Rate @ 1000 psia, ips               | $Rbo = 5.362 \left(\frac{D_e}{E}\right)^{0.9793} Meop^{-0.3713}$                                                         | RMSE = 0.002<br>(0.33-0.818)   |
| ropellant Weight, lbm                       | $W_p = 642.4 + 0.004462 \overline{F}_{\nu}^{+0.9955} T_b^{1.0027} E_i^{-0.07409} Meop^{0.002841}$                        | RMSE = 3,048<br>(200k-3M)      |
| acuum specific Impulse,                     | $Isp_{v} = \frac{\bar{F}_{v}T_{b}}{W_{v}}$                                                                               | Analytical<br>Equation         |
| of-sec/lbm<br>Average Nozzle Throat Area,   | $\overline{A}_{t} = -11.5 + 187.8W_{p}^{0.9949}Meop^{-0.9708}T_{b}^{-0.9838} + 1.923E - 5\overline{F}_{v} + 0.3461T_{b}$ | RMSE = 11<br>(334-9,760)       |
| n <sup>2</sup><br>Average Nozzle Throat     | $\overline{R}_{I} = \sqrt{\frac{\overline{A}_{I}}{3}}$                                                                   | Analytical<br>Equation         |
| Ladius, in<br>Diameter of Nozzle @ Exit, in | $D_n = 2\sqrt{(\bar{R}_i - 0.005T_b)^2 E_i}$                                                                             | Analytical<br>Equation         |
| Average Sea Level Thrust, lbf               | $\overline{F}_{si} = \overline{F}_v - 3.675 E_i \pi D_n^2$                                                               | Analytical<br>Equation         |
| Sea Level Specific Impulse,                 | $Isp_{vsl} = \frac{Isp_v \bar{F}_{il}}{\bar{F}_v}$                                                                       | Analytical<br>Equation         |
| Boss-Boss Case Length, in                   | $L_c = -3.0 + 26.79 \left[ \frac{W_p}{D_c^2} \right]^{0.9735} + 0.0008531 M + 0.008615 Meop$                             | RMSE = 5<br>(457-1,688)        |
| Nozzle Length (Aft Case Boss                | $L_n = -16.3 + 1.892E_i^{0.2937}\overline{A}_t^{+0.5206} - 0.002267Meop + 0.4660E_i - 0.02340T_b$                        | RMSE = 3<br>(50-380)           |
| Case length to Diameter Ratio,              | $L/D_c = \frac{L_c}{D_c}$                                                                                                | Analytical<br>Equation         |
| Booster Total Length, in                    | $L_{total} = L_c + L_n + N_{l'd}D_c$                                                                                     | Analytical<br>Equation         |
| Igniter Weight, Ibm                         | $W_{ign} = 16.6 + 0.2810 Meop^{0.1167} \overline{A}_t^{+1.287} D_c^{-0.6164}$                                            | RMSE = 22<br>(77-2,922)        |
| Nozzle Weight, lbm                          | $W_n = 327.3 + 0.02671 \sqrt{\overline{A}_t} (1 + E_i) L_n + 0.1664 \overline{A}_t^{0.6079} W_p^{0.4469} E_i^{0.1111}$   | RMSE = 567<br>(2.6k-49.8k)     |
| Internal Case Insulation, Ibm               | $W_{i} = -19.4 + 0.2425 W_{p}^{0.7148} T_{b}^{0.3103} L_{c}^{-0.1566} + \overline{A}_{i}^{0.06609}$                      | RMSE = 241<br>(1,700-16,800)   |
| Empty Case Weight, Ibm                      | $W_{c} = -122.9 + 5.155E - 4\bar{F}_{v} + 6.142E - 6L_{c}^{0.8250}Meop^{0.7722}\bar{F}_{v}^{+0.1108}D_{c}^{1.869}$       | RMSE = 909<br>(2,720-110k)     |
| Total Rocket Motor Weight,                  | $W_{srm} = W_p + W_n + W_i + W_c + W_{ign}$                                                                              | Analytical<br>Equation         |
| Total Stage Component                       | $W_{stg} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$                   | Analytical Eq.<br>(4,300-193K) |
| Total Booster weight, Ibm                   | $W_{srb} = W_{srm} + W_{sig}$                                                                                            | Analytical<br>Equation         |
| Booster Ideal Velocity, fl/sec              | $V_{ideal} = Isp_{v} \ln \left( \frac{W_{puts} + W_{irb}}{W_{puts} + W_{irb} - W_{prop}} \right) 32.18$                  | Analytical<br>Equation         |
| Booster Mass Fraction, dim                  | $Mf_{srb} = \frac{W_{p}}{W_{srb}}$                                                                                       | Analytical<br>Equation         |
| Total Impulse Sea Level,                    | $I_{st} = \overline{F}_{st} T_b$                                                                                         | Analytical Eq. (45M-720M)      |
| Total Impulse vacuum,                       | $I_v = \overline{F}_v T_b$                                                                                               | Analytical Eq.<br>(52M-861M)   |

# Figure 56. Script for Non-Chlorine Clean Propellant Model

Invalidate On Manual Recalc Select Range A116 Window Scale 65%

{Titles and dates} Put " Large Motors" Into A123 Put "Non-Chlorine (PGN/AN/AL) Clean Propellant" Into C123 Put "14 January 1993" Into A124

{Initial Independent Variable Setup}

Put 1000 Into C126{Meop, psia}Put 7 Into C127{Initial Area Ratio, Ei}Put 2590000 Into C128{(Favg)vac, lbf}Put 111 Into C129{Burn Time, Tb, seconds}Put 146 Into C130{Dcase, in}Put 1000000 Into C131{Push Weight, lbm}Put 1.3 Into C132{Nose Cone Length/Diameter}

{Load Range Information}

Put "200 To 2000" Into D126 Put "5 To 19" Into D127 Put "320 K To 8.9 M" Into D128 Put "60 To 178" Into D129 Put "80 To 255" Into D130

{Load Range Limit Checks}

```
Put "=If (C126<200, 1,0)" Into K126

Put "=If (C126>2000, 1,0)" Into K127

Put "=If (C127<5, 1,0)" Into K128

Put "=If (C127>19, 1,0)" Into K129

Put "=If (C128<320000, 1,0)" Into K130

Put "=If (C128>8900000, 1,0)" Into K131

Put "=If (C129<60, 1,0)" Into K132

Put "=If (C129>178, 1,0)" Into K133

Put "=If (C130<80, 1,0)" Into K134

Put "=If (C130>255, 1,0)" Into K135
```

{Load Results Formulas, RMSE and correlation limits, and percent error}

```
{Rbo}
Put "=(5.362*((C130/C129)^0.9793)*(C126^(-0.3713)))*L122" Into G126
Put "=If(G126<0.33*L122,""Note 3"",If(G126>0.818*L122,""Note 4"",0.002*L122))" Into H126
Put "" Into I126
```

{(Isp)sl} Put "=G128\*G131/(C128\*L126)" Into G127 Put "N/A" Into H127 Put "" Into I127

{(Isp)vac} Put "=(C128\*C129/(G138/L123))\*L125" Into G128 Put "N/A" Into H128 27 March 1993 06:05:18 PM Parametric Database/Object 45 script

Put "" Into I128

```
{(A throat)avg}
Put "=(-11.5+187.8*((G138/L123)^0.9949)*(C126^(-0.9708))*(C129^(-0.9838))
     +(1.932E-5)*C128+0.3461*C129)*L122*L122" Into G129
Put "=If(G129<334*L122*L122,""Note 3"",If(G129>9760*L122*L122,""Note 4"",11*L122*L122))" Into H12
Put "" Into I129
{(R throat)avg}
Put "=SqRt(G129/3.141593)" Into G130
Put "N/A" Into H130
Put "" Into I130
{(Favg)sl}
Put "=(C128-11.54535*G136*G136/(L122*L122))*L126" Into G131
Put "N/A" Into H131
Put "" Into I131
{(Favg)vac}
Put "=C128*L126" Into G132
Put "N/A" Into H132
Put "" Into I132
{L case}
Put "=(-3.0+26.79*((G138/L123)/(C130*C130))^0.9735+(8.531E-4)
     *(G138/L123)/C129+0.008615*C126)*L122" Into G133
Put "=If(G133<457*L122,""Note 3"",If(G133>1688*L122,""Note 4"",5*L122))" Into H133
Put "" Into I133
{L/D case}
Put "=G133/(C130*L122)" Into G134
Put "=If(G134>5.6,""Note 1"",""N/A"")" Into H134
Put "" Into I134
 {L nozzle}
Put "=(-16.3+1.892*(C127^0.2937)*((G129/(L122*L122))^0.5206)
      -0.002267*C126+0.4660*C127-0.02340*C129)*L122" Into G135
Put "=If(G135<50*L122,""Note 3"",If(G135>380*L122,""Note 4"",3*L122))" Into H135
 Put "" Into I135
 {Nozzle Exit Dia}
 Put "=(2*SqRt(((G130/L122-0.005*C129)^2)*C127))*L122" Into G136
 Put "N/A" Into H136
 Put "" Into I136
 {Total Length}
 Put "=G133+G135+(C132*C130)*L122" Into G137
 Put "N/A" Into H137
 Put "" Into I137
 {W propellant}
 Put "=(642.4+(0.004462*(C128^0.9955)*(C129^1.0027)*
      (C127^(-0.07409))*(C126^0.002841)))*L123" Into G138
 Put "=If(G138<200000*L123,""Note 3"",If(G138>3000000*L123,""Note 4"",3048*L123))" Into H138
 Put "" Into I138
```

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{W nozzle} Put "=(327.3+0.02671\*SqRt(G129/(L122\*L122))\*(1+C127)\*(G135/L122) +0.1664\*((G129/(L122\*L122))\*0.6079)\*((G138/L123)\*0.4469)\*(C127\*0.1111))\*L123" Into G139 Put "=If(G139<2600\*L123,""Note 3"",If(G139>49800\*L123,""Note 4"",567\*L123))" Into H139 Put "" Into I139 {W case insulation} Put "=(-19.4+0.2425\*((G138/L123)^0.7148)\*(C129^0.3103)\*((G133/L122)^(-0.1566)) +((G129/(L122\*L122))^0.06609))\*L123" Into G140 Put "=If(G140<1700\*L123,""Note 3"",If(G140>16800\*L123,""Note 4"",241\*L123))" Into H140 Put "" Into I140 {W case} Put "=(-122.9+(5.155E-4)\*C128+ (6.142E-6)\*((G133/L122)^0.8250)\*(C126^0.7722)\*(C128^0.1108)\*(C130^1.869))\*L123" Into G141 Put "=If(G141<2720\*L123,""Note 3"",If(G141>110000\*L123,""Note 4"",909\*L123))" Into H141 Put "" Into I141 {W igniter} Put "=(16.6+0.2810\*(C126^0.1167)\*((G129/(L122\*L122))^1.287)\*(C130^(-0.6164)))\*L123" Into G142 Put "=If(G142<77\*L123,""Note 3"",If(G142>2922\*L123,""Note 4"",22\*L123))" Into H142 Put "" Into I142 {W nose cone} Put "=(3395-2098\*C132-0.4705\*((C130/2)^2) +(2.533E-5)\*(((C130/2)\*SqRt(((C130/2)^2)+((C132\*C130)^2)))\*L123" Into G143 Put "N/A" Into H143 Put "" Into I143 {W external Insulation} Put "=(87+0.7243\*C130+0.1071\*((C130/2)^2))\*L123" Into G144 Put "N/A" Into H144 Put "" Into 1144 {W fwd skirt & attach} Put "=(Exp(2.095+0.05276\*C130-0.0000846\*C130\*C130))\*L123" Into G145 Put "N/A" Into H145 Put "" Into I145 {W aft skirt & attach} Put "=(Exp(2.89+0.06343\*C130-0.00012\*C130\*C130))\*L123" Into G146 Put "N/A" Into H146 Put "" Into I146 {W separation system} Put "=0.0011208\*G149" Into G147 Put "N/A" Into H147 Put "" Into I147 {W misc} Put "=(-1039-0.00204\*(G149/L123)+2.854\*((G133+G135)/L122)+0.07885\*((C130/2)^2))\*L123" Into G14 Put "N/A" Into H148 Put "" Into I148 {W SRM} Put "=Sum(G138..G142)" Into G149

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27 March 1993 06:05:19 PM Parametric Database/Object 45 script Put "" Into H149 Put "" Into I149 {W stage} Put "=Sum(G143..G148)" Into G150 Put "=If(G150<4300\*L123,""Note 3"",If(G150>193000\*L123,""Note 4"",""""))" Into H150 Put "" Into I150 {W SRB} Put "=G149+G150" Into G151 Put "" Into H151 Put "" Into 1151 Put "=(32.18\*(G128/L125)\*Ln((C131+(G151/L123))/(C131+(G151/L123)-(G138/L123))))\*L124" Into G152 Put "N/A" Into H152 Put "" Into I152 {Mass Fraction} Put "=G138/G151" Into G153 Put "N/A" Into H153 Put "" Into I153 {(Impulse)sl} Put "=If(G154<45000000\*L126,""Note 3"",If(G154>720000000\*L126,""Note 4"",""""))" Into H154 Put "" Into I154 {(Impulse)vac} Put "=C128\*C129\*L126" Into G155 Put "=If(G155<52000000\*L126,""Note 3"",If(G155>861000000\*L126,""Note 4"",""""))" Into H155 Put "" Into 1155 {Load Notes} Put "Note 1:" Into A135 Put "Cases with L/D greater than 5.6" Into C135 Put "are difficult to wind w/o joints." Into C136 Put "Note 2:" Into A138 Put "MG propellant burn rates" Into C138 Put "(Rbo) are tailorable between" Into C139 Put "0.33 and 0.818 ips." Into C140 Put "Note 3:" Into A142 Put "Data is being extrapolated" Into C142 Put "below range of regression." Into C143 Put "Note 4:" Into A145 Put "Data is being extrapolated" Into C145 Put "above range of regression." Into C146 **Automatic Recalc** Invalidate Off

| Ingredient     | Weight Percent |  |
|----------------|----------------|--|
| Fue            | Grain          |  |
| Escorez        | 60.0           |  |
| НТРВ           | 40.0           |  |
| Ox             | idizer         |  |
| 0 <sub>2</sub> | 100.0          |  |

Figure 57. Nominal Composition of Hybrid Propellant

| Exhaust Product      | Mass Fraction<br>@ O/F = 2.8 | Mass Fraction<br>@ O/F = 1.8 |
|----------------------|------------------------------|------------------------------|
| CO (g)               | 0.2032                       | 0.5632                       |
| CO <sub>2</sub> (g)  | 0.5236                       | 0.2591                       |
| ОН (g)               | 0.0155                       | 0.0000                       |
| H (g)                | 0.0003                       | 0.0000                       |
| H <sub>2</sub> (g)   | 0.0024                       | 0.0224                       |
| H <sub>2</sub> O (g) | 0.2286                       | 0.1536                       |
| NO (g)               | 0.0004                       | 0.0000                       |
| N <sub>2</sub> (g)   | 0.0011                       | 0.0017                       |
| O <sub>1</sub> (g)   | 0.0025                       | 0.0000                       |
| O <sub>2</sub> (g)   | 0.0224                       | 0.0000                       |

Figure 58. Theoretical Exhaust Products at 1,000 psi Chamber Pressure Expanded to 14.7 psi Hybrid Propellant

TA3-0421Fig

| Large Motors                                                | Hybrid Prope       | llants             |                       |                               |       |
|-------------------------------------------------------------|--------------------|--------------------|-----------------------|-------------------------------|-------|
| 23 March 1993                                               |                    | Range              | Results               |                               | RMSE  |
| Macpendent Lennis                                           | - 500              | 500 To 1500        | D nozzle exit, in     | <b>132.8</b>                  | N/A   |
| MCOP, USIA                                                  | _ 8                | 8 To 20            | (Isp)sl, sec-lbf/lbm  | - 238.76                      | N/A   |
| (Fourthmo lbf                                               | - 1.267.506        | 280 K To 21 M      | (Isp)vac, sec-lbf/lbm | - 284.48                      | 1.9   |
| Travgivac, ini<br>Burn Time The seconds                     | - 45               | 45 To 200          | (A throat)avg, in^2   | . 1,765.4                     | N/A   |
| Nose Cone L/D                                               | - 1.3              | 0.5 To 3.0         | (R throat)avg, in     | - 23.7                        | 0.9   |
| Mor Or Flux Ibm /a.in^9                                     | . 0.2              | 0.2 To 1.0         | (Favg)sl, lbf         | - 1,063,817                   | N/A   |
| MAR OR FILLS, IULI/ $\Rightarrow$ -LL 2<br>Aver MD $\cap/F$ | 1.8                | 1.8 To 2.8         | (Favg)vac, lbf        | <ul> <li>1,267,506</li> </ul> | N/A   |
| Duch Weight ihm                                             | 1.000.000          |                    | L tank & case, in     | <b>803.5</b>                  | 71    |
| ruan weight, iom                                            |                    |                    | L/D case              | - 4.91                        | N/A   |
| Dependent Terms                                             |                    | anticisten anticit | L nozzle, in          | - 125.7                       | 53    |
| L'OPCHICAND COMP                                            |                    |                    | D motor, in           | <b>163.5</b>                  | 3     |
|                                                             |                    |                    | Total Length, in      | . 1,141.9                     | N/A   |
| Note 1                                                      | : Data is being ex | trapolated         | W oxidizer, lbm       | - 128,454                     | N/A   |
|                                                             | below range of     | regression.        | W fuel, lbm           | <b>.</b> 71,363               | N/A   |
|                                                             |                    | -                  | W propellant, lbm     | - 199,818                     | N/A   |
| Note 2                                                      | : Data is being ex | trapolated         | W nose cone, lbm      | <b>6</b> ,307.4               | N/A   |
|                                                             | above range of     | regression.        | W ext insul, lbm      | <b>921.5</b>                  | N/A   |
|                                                             | <b>G</b>           | -                  | W fwd skirt, lbm      | - 4,724                       | N/A   |
|                                                             |                    |                    | W aft skirt, lbm      | - 23,240                      | N/A   |
|                                                             |                    |                    | W separation, lbm     | - 261                         | N/A   |
|                                                             |                    |                    | W misc, lbm           | <b>1,666</b>                  | N/A   |
|                                                             |                    |                    | W HRM, lbm            | - 232,514                     |       |
|                                                             |                    |                    | W stage, lbm          | = 3.712E+04                   |       |
|                                                             |                    |                    | W HRB, Ibm            | - 2.696E+05                   |       |
|                                                             |                    |                    | V ideal, ft/sec       | 1.568E+03                     | N/A   |
|                                                             |                    |                    | Mass Fraction         | 8.594E-01                     | 0.012 |
|                                                             |                    |                    | (Impulse)sl. lbf-sec  | - 4.787E+07                   | N/A   |
|                                                             |                    |                    | (Impulse)vac, lbf-sec | - 5.704E+07                   | N/A   |
|                                                             |                    |                    |                       |                               |       |
|                                                             |                    |                    |                       |                               |       |

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Figure 59. Printed Output - "Report" English Units

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Figure 60. Printed Output - "Briefing" - Metric Units

## Figure 61. Equations for Hybrid Rocket Booster Model

#### **Equations for Stage Components**

## Variable to beCalculatedEquation

Nose Cone Weight, lbm

 $W_{Nose \ Cone} = 3395 - 2098 N_{l/d} - 0.4705 (D_c/2)^2 + 2.533 x 10^{-5} \{ (D_c/2) \sqrt{(D_c/2)^2 + (N_{l/d}D_c)^2} \}^2$ 

External Insulation Weight, lbm

 $W_{ExtInsulation} = 87 + 0.7243D_c + 0.1071(D_c/2)^2$ 

Fwd Skirt and Attach Weight, lbm

 $W_{FwdSkin} = e^{(2.095+0.05276D_c - 0.0000846D_c^2)}$ 

Aft Skirt and Attach Weight, lbm

 $W_{AftSkirr} = e^{(2.89+0.06343D_c - 0.00012D_c^2)}$ 

Separation System Weight, lbm

 $W_{Separation} = 0.0011208 W_{srm}$ 

Misc Weight, lbm

 $W_{misc} = -1039 - 0.00204W_{srm} + 2.854L_{case & nozzle} + 0.07885(D_c/2)^2$ 

TA3-0321

### Large Hybrid Motor Design Equations

| Variable to be<br>Calculated              | Equation                                                                                                                                  | Method<br>& Range              |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| Vacuum specific Impulse,                  | $Isp_{v} = 314.4 - 8.242X + 0.4932X^{2}; where  X = Ln \left[ \overline{F}_{v}^{+0.1414} E_{i}^{3.938} O/F^{3.685} T_{b}^{-2526} \right]$ | RMSE = 1.9<br>(280.3-317.8)    |
| Average Nozzle Throat                     | $\overline{R}_{t} = 1.266 + 0.3718 Meop^{-0.5035} \overline{F}_{y}^{+0.5123} T_{b}^{0.007919}$                                            | RMSE = 0.9<br>(7.5-93.9)       |
| Radius, in<br>Impulse vacuum, Ibm-sec     | $I_{v} = \overline{F}_{v} T_{b}$                                                                                                          | Analytical<br>Equation         |
| Diameter of Nozzle @ Exit, in             | $D_n = 2\sqrt{(\overline{R}_i - 0.005T_b)^2 E_i}$                                                                                         | Analytical<br>Equation         |
| Average Sea Level Thrust, lbf             | $\overline{F}_{sl} = \overline{F}_{v} - 3.675\pi D_{n}^{2}$                                                                               | Analytical<br>Equation         |
| Sea Level Specific Impulse,               | $Isp_{vsl} = \frac{Isp_v\bar{F}_{tl}}{\bar{F}_v}$                                                                                         | Analytical<br>Equation         |
| Hybrid Roctet Motor diameter,             | $D_m = 59.8 + 0.005607X - 1.136e - 9X^2$ ; where $X = \overline{F}_v^{+0.5991} Fo_{max}^{-0.4856} T_b^{0.1652}$                           | RMSE = 3<br>(84-636)           |
| External Nozzle Length, in                | $L_{nos} = 190.1 - 294.4X - 205.3X^2 + 407.9X^3;  X = E_t^{0.1327} \overline{R}_t^{+1.568} \overline{F}_v^{-0.6560} Meop^{0.6478}$        | RMSE =53<br>(45-1005)          |
| Total Length of Tank Plus                 | $L_{T+C} = 16.7 + 2.860 Fo_{\max}^{0.1767} \overline{F}_{v}^{+0.4396} T_{b}^{0.4159} D_{m}^{-0.3175} Meop^{-0.002468} O/F^{-0.3836}$      | RMSE =71<br>(654-3255)         |
| Hybrid Rocket Motor length, in            | $L_{HRM} = L_{nos} + L_{T+C}$                                                                                                             | Analytical Eq.<br>(746-3845)   |
| Booster Total Length, in                  | $L_{HRB} = L_{HRM} + N_{lld}D_m$                                                                                                          | Analytical<br>Equation         |
| Fuel Used Weight, Ibm                     | $W_{fuel} = 0.9966\overline{F}_{v}T_{b}/[Isp_{v}(1+O/F)]$                                                                                 | Analytical<br>Equation         |
| O <sub>2</sub> Used Weight, lbm           | $Wo_2 = W_{fuel}O/F$                                                                                                                      | Analytical<br>Equation         |
| Total Weight Propellant Used,             | $W_p = W_{fuel} + Wo_2$                                                                                                                   | Analytical<br>Equation         |
| Hybrid Rocket Motor Mass<br>Fraction, dim | $Mf_{HRM} = -5.324 + 6.696 X - 0.7267 e - 6 X^2$ ; where                                                                                  | RMSE = 0.012<br>(0.73-0.91)    |
|                                           | $X = Meop^{-0.01183} E_i^{-0.001051} Fo_{\max}^{0.002209} O/F^{-0.003599} T_b^{-0.004171} I_v^{-0.0007922}$                               |                                |
| Total Hybrid Rocket Motor<br>Weight, Ibm  | $W_{HRM} = W_p / M f_{HRM}$                                                                                                               | Analytical<br>Equation         |
| Total Stage Component<br>Weight, Ibm      | $W_{stg} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$                                    | Analytical Eq.<br>(4,300-193K) |
| Total Hybrid Rocket Booster               | $W_{HRB} = W_{HRM} + W_{sig}$                                                                                                             | Analytical<br>Equation         |
| Booster Ideal Velocity, fl/sec            | $V_{ideal} = Isp_{v} \ln \left( \frac{W_{push} + W_{HRB}}{W_{push} + W_{HRB} - W_{p}} \right) 32.18$                                      | Analytical<br>Equation         |
| Total Impulse Sea Level,<br>lbf-sec       | $I_{sl} = \overline{F}_{sl} T_b$                                                                                                          | Analytical<br>Equation         |

## Figure 62. Script for Hybrid Rocket Booster Model

Invalidate On

Manual Recalc Select Range A422 Window Scale 65%

{Titles and dates} Put "Large Motors" Into A408 Put "Hybrid Propellants" Into C408 Put "23 March 1993" Into A409

{Initial Independent Variable Setup}

{Meop, psia} Put 500 Into C411 {Initial Area Ratio, Ei} Put 8 Into C412 {(Favg)vac, lbf} Put 1267506 Into C413 {Burn Time, Tb, seconds} Put 45 Into C414 {Nose Cone Length/Diameter} Put 1.3 Into C415 {Max Oxidizer Flux} Put 0.2 Into C416 {Average Oxidizer/Fuel Ratio, O/F} Put 1.8 Into C417 {Push Weight, lbm} Put 1000000 Into C418

{Load Range Information}

Put "500 To 1500" Into D411 Put "8 To 20" Into D412 Put "280 K To 21 M" Into D413 Put "45 To 200" Into D414 Put "0.2 To 1.0" Into D416 Put "1.8 To 2.8" Into D417

{Load Range Limit Checks}

Put "=If (C411<500, 1,0)" Into K411 Put "=If (C411>1500, 1,0)" Into K412 Put "=If (C412<8, 1,0)" Into K413 Put "=If (C412>20, 1,0)" Into K414 Put "=If (C413<280000, 1,0)" Into K415 Put "=If (C413>21000000, 1,0)" Into K416 Put "=If (C414<45, 1,0)" Into K417 Put "=If (C414<45, 1,0)" Into K418 Put "=If (C416<0.2, 1,0)" Into K419 Put "=If (C416<1.0, 1,0)" Into K420 Put "=If (C417<1.8, 1,0)" Into K421 Put "=If (C417>2.8, 1,0)" Into K422

{Load Results Formulas, RMSE and correlation limits, and percent error}

{D nozzle exit} Put "=(2\*SqRt((((G415/L402)-0.005\*C414)^2)\*C412))\*L402" Into G411 Put "N/A" Into H411 27 March 1993 06:14:53 PM Parametric Database/Object 16 script

Put "" Into I411

{(Isp)vac} Put "=LN((C413^0.1414)\*(C412^3.938)\*(C417^3.685)\*(C414^(-0.2526)))" Into M413 Put "=(314.4-8.242\*M412+0.4932\*M413\*M413)\*L405" Into G413 Put "=If(G413<280.3\*L405,""Note 1"",If(G413>317.8\*L405,""Note 2"",1.9\*L405))" Into H413 Put "" Into I413 {(Isp)sl} Put<sup>\*</sup>=((G413\*G416)/(C413\*L406))" Into G412 Put "N/A" Into H412 Put "" Into I412 {(R throat)avg} Put "=(1.266+(0.3718\*C411^(-0.5035))\*(C413^0.5123)\*C414^0.007919)\*L402" Into G415 Put "=If(G415<7.5\*L402,""Note 1"",If(G415>93.9\*L402,""Note 2"",0.9\*L402))" Into H415 Put "" Into I415 {(A throat)avg} Put "=3.141593\*G415\*G415" Into G414 Put "N/A" Into H414 Put "" Into 1414 {(Favg)sl} Put "=(C413-11.54535\*G411\*G411/(L402\*L402))\*L406" Into G416 Put "N/A" Into H416 Put "" Into I416 {(Favg)vac} Put "=C413\*L406" Into G417 Put "N/A" Into H417 Put "" Into I417 {L tank & case} Put "=(16.7+2.86\*(C416^0.1767)\*(C413^0.4396)\*(C414^0.4159)\*((G421/L402)^(-0.3175)) \*(C411^(-0.002468))\*(C417^(-0.3836)))\*L402" Into G418 Put "=If(G418<654\*L402,""Note 1"",If(G418>3255\*L402,""Note 2"",71\*L402))" Into H418 Put "" Into I418  $\{L/D \text{ case}\}$ Put "=G418/G421" Into G419 Put "N/A" Into H419 Put "" Into I419 {L nozzle} Put "=(C412^0.1327)\*((G415/L402)^1.568)\*(C413^(-0.6560))\*(C411^0.6478)" Into M420 Put "=(190.1-294.4\*M420-205.3\*M420\*M420+407.9\*M420^3)\*L402" Into G420 Put "=If(G420<45\*L402,""Note 1"",If(G420>1005\*L402,""Note 2"",53\*L402))" Into H420 Put "" Into I420 {D motor} Put "=(C413^0.5991)\*(C416^(-0.4856))\*(C414^0.1652)" Into M421 Put "=(59.8+0.005607\*M421-1.136E-9\*(M421\*M421))\*L402" Into G421 Put "=If(G421<84\*L402,""Note 1"",If(G421>636\*L402,""Note 2"",3\*L402))" Into H421 Put "" Into I421

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{Total Length} Put "=G420+G418+C415\*G421" Into G422 Put "N/A" Into H422 Put "" Into I422 {W oxidizer} Put "=G424\*C417" Into G423 Put "N/A" Into H423 Put "" Into 1423 {W fuel} Put "=(0.9966\*C413\*C414/((G413/L405)\*(1+C417)))\*L403" Into G424 Put "N/A" Into H424 Put "" Into I424 {W propellant} Put "=G423+G424" Into G425 Put "N/A" Into H425 Put "" Into I425 {W nose cone} Put "=(G421/L402)" Into M426 Put "=(3395-2098\*C415-0.4705\*((M426/2)^2) +(2.533E-5)\*(((M426/2)\*SqRt(((M426/2)^2)+((C415\*M426)^2)))^2))\*L403" Into G426 Put "N/A" Into H426 Put "" Into I426 {W external Insulation} Put "=(87+0.7243\*M426+0.1071\*((M426/2)^2))\*L403" Into G427 Put "N/A" Into H427 Put "" Into I427 {W fwd skirt & attach} Put "=(Exp(2.095+0.05276\*M426-0.0000846\*M426\*M426))\*L403" Into G428 Put "N/A" Into H428 Put "" Into I428 {W aft skirt & attach} Put "=(Exp(2.89+0.06343\*M426-0.00012\*M426\*M426))\*L403" Into G429 Put "N/A" Into H429 Put "" Into I429 {W separation system} Put "=0.0011208+G432" Into G430 Put "N/A" Into H430 Put "" Into I430 Put "=(-1039-0.00204\*(G432/L403)+2.854\*((G418+G420)/L402)+0.07885\*((M426/2)^2))\*L403" Into G43 Put "N/A" Into H431 Put "" Into I431 {W HRM} Put "=G425/G436" Into G432 Put "" Into H432 Put "" Into I432

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{W stage} Put "=Šum(G426..G431)" Into G433 Put "=If(G433<4300\*L403,""Note 1"",If(G433>193000\*L403,""Note 2"",""""))" Into H433 Put "" Into I433 {W HRB} Put "=G432+G433" Into G434 Put "" Into H434 Put "" Into I434 Put "=(32.18\*(G413/L405)\*Ln((C418+(G434/L403))/(C418+(G434/L403)-(G425/L403))))\*L404" Into G435 Put "N/A" Into H435 Put "" Into I435 Put "=(C411^(-0.01183))\*(C412^(-0.001051))\*(C416^0.002209)\*(C417^(-0.003599)) {Mass Fraction} \*(C414^0.004171)\*((G438/L406)^(-0.0007922))" Into M436 Put "=-5.324+6.696\*M436-(0.7267E-6)\*M436\*M436" Into G436 Put "=If(G436<0.73,""Note 1"",If(G436>0.91,""Note 2"",0.012))" Into H436 Put "" Into I436 {(Impulse)sl} Put "=G416\*C414" Into G437 Put "N/A" Into H437 Put "" Into I437 {(Impulse)vac} Put "=C413\*C414\*L406" Into G438 Put "N/A" Into H438 Put "" Into I438 {Load Notes} Put "Note 1:" Into A423 Put "Data is being extrapolated" Into C423 Put "below range of regression." Into C424 Put "Note 2:" Into A426 Put "Data is being extrapolated" Into C426 Put "above range of regression." Into C427 **Automatic Recalc** Invalidate Off

| Liquid Engines                  | LOX/H2   | 26 January 1993                   |         |
|---------------------------------|----------|-----------------------------------|---------|
| Independent Terms               | Value    | Valid Range                       |         |
| Major Variables                 |          |                                   |         |
| Vacuum Thrust, klbf             | 512.845  | 100 to 2,000                      |         |
| Chamber Pressure, psia          | 3,277.0  | 1,000 to 5,000                    |         |
| Mixture Ratio, O/F              | 6.011    | 4 to 8                            |         |
| Maximum Area Ratio              | 77.0     | 10 to 400                         |         |
| Parameters                      |          |                                   |         |
| Area Ratio of Nozzle Attachment | 5.0      |                                   |         |
| Nozzle Percent Length, %        | 80.0     | 70 to 140                         |         |
| Gimbal Angle, degrees           | 11.0     | 0 to 15                           |         |
| C <sup>+</sup> Efficiency       | 0.98450  | 0.85 to 0.999                     |         |
| Fuel Inlet Enthalpy, kcal/mole  | -1.270   | -2.154 to 1.856                   |         |
|                                 |          |                                   |         |
| Performance                     | Value    | Dimensions                        | Value   |
| Vacuum Thrust, klbf             | 512.845  | Throat Diameter, in               | 10.3    |
| Vacuum Isp, sec-lbf/lbm         | 452.98   | Throat Area, in <sup>2</sup>      | 03.4    |
| SL Thrust, klbf                 | 418.772  | Chamber Length, in                | 12.3    |
| SL Isp, sec-lbf/lbm             | 369.89   | Nozzle Exit Diameter, in          | 90.3    |
| ODE C-Star, ft/sec              | 7,753.62 | Engine Diameter, in               | 90.0    |
| L-Star, in                      | 30.40    | Nozzle Length, in                 | 119.0   |
| ODE Isp, sec-lbf/lbm            | 468.92   | Engine Length, in                 | 100.0   |
| Energy Release Efficiency       | 0.98450  |                                   | Volue   |
| Kinetic Efficiency              | 0.99993  | Weights, IDII                     | 1 725 0 |
| Divergence Efficiency           | 0.99283  | Turbomachinery                    | 229.0   |
| Boundary Layer Efficiency       | 0.98904  | Preburners<br>DB Ust Cas Manifold | 558.0   |
| Engine Efficiency               | 0.96666  | PB Hot Gas Manhou                 | 859.0   |
|                                 |          | Norgle                            | 1.250.0 |
|                                 |          | Cimbal Bearing                    | 105.0   |
|                                 |          | Values and Controls               | 722.0   |
|                                 |          | Controller and Mount              | 85.0    |
|                                 |          | POGO System                       | 94.0    |
|                                 |          | Propellant Ducts                  | 867.7   |
|                                 |          | Pressurization System             | 89.0    |
|                                 |          | Other Engine Systems              | 228.0   |
|                                 |          |                                   |         |
|                                 |          | Total Dry Weight                  | 6,811.7 |

Figure 63. Printed Output - "Report" - English Units - LOX/H2

| Liquid Engines                               | OX/H2     | 26 January 1993              |        |
|----------------------------------------------|-----------|------------------------------|--------|
| Independent Terms                            | Value     | Valid Range                  |        |
| Maior Variables                              |           |                              |        |
| Vacuum Thrust. klbf                          | 512.845   | 100 to 2,000                 |        |
| Chamber Pressure, Data                       | 3,277.0   | 1,000 to 5,000               |        |
| Michine Datio O/F                            | 6.011     | 4 to 8                       |        |
| Maximum Area Ratio                           | 77.0      | 10 to 400                    |        |
|                                              |           |                              |        |
| Parameters                                   | 2         |                              |        |
| Area Ratio of Nozzle Attachment              | 0.0       | 70 to 140                    |        |
| Nozzle Percent Length, 76                    | 0.00      | 0 to 15                      |        |
| Gimbal Angle, degrees                        | 0.08450   | 0.85 to 0.999                |        |
| C Enciency<br>Fuel Inlet Enthalpy, kcal/mole | -1.270    | -2.154 to 1.856              |        |
|                                              |           |                              |        |
| Performance                                  | Value     | Dimensions                   | Vahue  |
| Vacuum Thrust. kN                            | 2,281.248 | Throat Diameter, cm          | 26.1   |
| Vacuum Isp. Sec-N/kg                         | 4,442.25  | Throat Area, cm <sup>2</sup> | 536.9  |
| Si Thrust kN                                 | 1,862.791 | Chamber Length. cm           | 31.2   |
| Si len sec.N/kd                              | 3,627.39  | Nozzle Exit Diameter, cm     | 229.4  |
| ODE C-Star m/sec                             | 2,363.30  | Engine Diameter, cm          | 243.8  |
| L.Star cm                                    | 77.21     | Nozzle Length. cm            | 303.5  |
| ODE Isn sec.N/kg                             | 2,085.87  | Engine Length, cm            | 426.6  |
| Energy Release Efficiency                    | 0.98450   |                              |        |
| Kinetic Filiciency                           | 0.99993   | Weights, kg                  | Vahue  |
| Diversion Efficiency                         | 0.99283   | Turbomachinery               | 782.3  |
| DIVERSELLEE BUILDERS                         | 0.98904   | Preburners                   | 103.9  |
| Boundary Layer Emericy<br>Endine Efficiency  | 0.96666   | PB Hot Gas Manifold          | 253.1  |
|                                              |           | Thrust Chamber               | 389.6  |
|                                              |           | Nozzle                       | 566.9  |
|                                              |           | Gimbal Bearing               | 47.6   |
|                                              |           | Valves and Controls          | 327.4  |
|                                              |           | <b>Controller and Mount</b>  | 38.5   |
|                                              |           | POGO System                  | 42.6   |
|                                              |           | Propellant Ducts             | 393.5  |
|                                              |           | Pressurization System        | 40.4   |
|                                              |           | Other Engine Systems         | 103.4  |
|                                              |           | )                            |        |
|                                              |           |                              |        |
|                                              |           |                              |        |
|                                              |           |                              |        |
|                                              |           |                              |        |
|                                              |           | Total Dry Weight             | 3,089. |

Figure 64. Printed Output - "Briefing" - Metric Units - LOX/H2

| Liquid Engines                  | LOX/RP 26 January 1993 |                                                  |            |
|---------------------------------|------------------------|--------------------------------------------------|------------|
| And consultant Dennis           | Value                  | Valid Range                                      |            |
| Major Variables                 |                        |                                                  |            |
| Vacuum Thrust, klbf             | 2,020.700              | 500 to 3,000                                     |            |
| Chamber Pressure, psia          | 1,161.0                | 500 to 2,000                                     |            |
| Mixture Ratio, O/F              | 2.270                  | 1.5 to 5                                         |            |
| Maximum Area Ratio              | 16.0                   | 10 to 400                                        |            |
| Parameters                      |                        |                                                  |            |
| Area Ratio of Nozzle Attachment | 10.0                   | <b>TO</b> 140                                    |            |
| Nozzle Percent Length, %        | 80.3                   | 70 to 140                                        |            |
| Gimbal Angle, degrees           | 8.4                    | 0 to 15                                          |            |
| C* Efficiency                   | 0.93930                | 0.85 to 0.999                                    |            |
| Fuel Inlet Enthalpy, kcal/mole  | -5.570                 | -5.658 to -1.682                                 |            |
|                                 |                        |                                                  |            |
| Performance                     | Value                  | Dimensions                                       | Value      |
| Vacuum Thrust, klbf             | 2,020.700              | Throat Diameter, in                              | 34.0       |
| Vacuum Isp. sec-lbf/lbm         | 303.10                 | Throat Area, in <sup>2</sup>                     | 939.4      |
| SL Thrust, klbf                 | 1,799.811              | Chamber Length, in                               | 129.9      |
| SL Isp. sec-lbf/lbm             | 269.70                 | Nozzle Exit Diameter, in                         | 130.0      |
| ODE C-Star, ft/sec              | 5,949.15               | Engine Diameter, in                              | 143.0      |
| L-Star. in                      | 46.71                  | Nozzle Length, in                                | 155.0      |
| ODE Isp. sec-lbf/lbm            | 337.15                 | Engine Length, in                                | 220.4      |
| Energy Release Efficiency       | 0.93930                |                                                  |            |
| Kinetic Efficiency              | 0.99796                | Weights, Ibm                                     | Value      |
| Divergence Efficiency           | 0.99186                | Turbopump and Mount                              | 4,400.3    |
| Boundary Layer Efficiency       | 0.99210                | Thrust Chamber                                   | 8,507.0    |
| Engine Efficiency               | 0.92240                | Engine Mount                                     | 467.0      |
| g                               |                        | Oxidizer System                                  | 652.       |
|                                 |                        | Fuel System                                      | 042.       |
|                                 |                        | Purge System                                     | 30.        |
|                                 |                        | Controls (Hydraulic)                             | 193.       |
|                                 |                        | Controls (Electrical)                            | 170        |
|                                 |                        | Gimbal System Supply                             | 241        |
|                                 |                        | Gas Generator System                             | J41.       |
|                                 |                        | Exhaust System                                   | 1,201.     |
|                                 |                        | Flight Instrumentation                           | 145.       |
|                                 |                        | Ignition System                                  | +9.<br>540 |
|                                 |                        | Interface System                                 | 1 030      |
|                                 |                        | Pressurization System                            | 71         |
|                                 |                        | Insulation – Permanent<br>Thermal Insulation Set | 1,182.     |
|                                 |                        | Total Dry Weight                                 | 19,875     |

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Figure 65. Printed Output - "Report" - English Units - LOX/RP

| Liquid Engines                                  | LOX/RP          | 26 January 1993              |         |
|-------------------------------------------------|-----------------|------------------------------|---------|
|                                                 | Vahue           | Valid Range                  |         |
|                                                 |                 |                              |         |
| MAJOT VALIADICS                                 | 2.020.700       | 500 to 3,000                 |         |
|                                                 | 1 161 0         | 500 to 2.000                 |         |
| Chamber Pressure, psia                          | 0.101.1         | 1.5 to 5                     |         |
| Mixture Kano, O/r                               |                 | 10 to 400                    |         |
| Maximum Area Ratio                              | 0.01            |                              |         |
| Parameters                                      |                 |                              |         |
| Accordance of Norrale Attachment                | 10.0            |                              |         |
| Area Kaulo VI INZZIE Auachinisti                | 803             | 70 to 140                    |         |
| Nozzie Percent Leugui, 20                       | 0.000<br>A 0    | 0 to 15                      |         |
| Gimbal Angle, degrees                           | 1.0<br>0.0000 0 | 0 R5 to 0 999                |         |
| C* Efficiency<br>Eval Inlet Eathalmy kral/mole  | -5.570          | -5.658 to -1.682             |         |
|                                                 |                 |                              |         |
|                                                 | Vahio           | Dimensions                   | Value   |
| Vacuum Thrust, kN                               | 8,988.521       | Throat Area, cm <sup>2</sup> | 87.8    |
| Vacuum Isn sec.N/kg                             | 2,972.40        | Chamber Length, cm           | 6,060.7 |
| SI Thrust kN                                    | 8,005.958       | Nozzle Exit Diameter, cm     | 100.1   |
| SI Ten ser.N/kd                                 | 2.644.85        | Engine Diameter. cm          | 351.4   |
| ODE C Star m (sec                               | 1.813.30        | Nozzle Length, cm            | 364.5   |
| I star om                                       | 118.65          | Engine Length, cm            | 394.9   |
|                                                 | 1.499.70        | Engine Length, in            | 559.8   |
| UDE ISP, SCC-IV/Ag<br>Econor Delease Ffficiency | 0.93930         | 0                            |         |
| Ellergy Actease Entering                        | 0.99796         | Weights, kg                  | Vahue   |
| NITCHC EMICIENCY                                | 0.99186         | Turbopump and Mount          | 2,035.5 |
| Divergence Educiency                            | 010000          | Thrust Chamber               | 3,857.9 |
| Boundary Layer Emclency                         | 01266.0         | Fridae Mount                 | 211.8   |
| Engine Efficiency                               | 0.32240         |                              | 206 7   |
|                                                 | _               |                              | 100     |
|                                                 |                 | Fuel System                  | 0.107   |
|                                                 |                 | Purge System                 |         |
|                                                 |                 | Controls (Hydraulic)         | 8/./    |
|                                                 |                 | Controls (Electrical)        | 38.4    |
|                                                 |                 | Gimbal System Supply         | 81.4    |
|                                                 |                 | Gas Generator System         | 154.7   |
|                                                 |                 | Exhaust System               | 572.1   |
|                                                 |                 | Flight Instrumentation       | 65.8    |
|                                                 |                 | Ignition System              | 22.2    |
|                                                 |                 | Interface System             | 245.9   |
|                                                 |                 | Pressurization System        | 467.1   |
|                                                 |                 | Insulation – Permanent       | 32.4    |
|                                                 |                 | Thermal Insulation Set       | 536.3   |
|                                                 |                 | matel Dave Weisht            | . 510 0 |
|                                                 |                 | I OTAL DIY WEIGHT            | 2.010.  |

Figure 66. Printed Output - "Briefing" - Metric Units - LOX/RP

#### 3/27/93

| WINDO          | w      |
|----------------|--------|
| Input          | Input  |
| Parameter      | Value  |
| 1 Fvac, Klbf   | 50.000 |
| (25 to 100)    |        |
| Tc, °K         | 2,450  |
| (Fixed)        |        |
| Pc, psia       | 784    |
| (500 to 2,000) |        |
| Epsilon, -     | 200    |
| (100 to 700)   |        |

| Nuclear Engine Weight, Envelope and Performance Function |
|----------------------------------------------------------|
| OFFICE Derived Prismatic Core)                           |

| Fvac         Tc         Pc Epsilon % L         Del Isp         Total Wt         Envel Dia         Envel Dia           Klbf         °K         psia         -         sec         lbm         in         in           50 000         2,450         784         200 110         849.6         9,524.0         96.4         324.5 |        |          |     | OUU     | etu a    | WINDOW         |                 |                 |               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|----------|-----|---------|----------|----------------|-----------------|-----------------|---------------|
| 50 000 2,450 784 200 110 849.6 9,524.0 96.4 324.                                                                                                                                                                                                                                                                               | Fvac   | Tc<br>•K | Pc  | Epsilon | % L<br>- | Del Isp<br>sec | Total Wt<br>lbm | Envel Dia<br>in | Envel L<br>in |
|                                                                                                                                                                                                                                                                                                                                | 50.000 | 2,450    | 784 | 200     | 110      | 849.6          | 9,524.0         | 96.4            | 324.9         |

Thrust/Weight Ratio 5.25

Figure 67. Sample Output of Nuclear Thermal Rocket Model

.

### Propulsion System Database Figures

| Alternate Propulsion Subsystem Concepts<br>Database<br>Version 1.3 | 5 April 1993 | ht Center<br>at<br>135812 Continue<br>Canoga Park CA 91303                               |
|--------------------------------------------------------------------|--------------|------------------------------------------------------------------------------------------|
| Alternate Proj                                                     |              | NASA<br>Marshall Space Flight Center<br>Program Development<br>Huntsville, Alabama 35812 |

Figure 68. Propulsion System Database Opening Screen

March 27, 1993

# **Propulsion System Menu**

Please click icon for selected propulsion system



| Print | More<br>Data Summary of Propuls             | ion Systems                            | Reports Data Entry |
|-------|---------------------------------------------|----------------------------------------|--------------------|
|       | Engine Name                                 | Acronym                                | Engine Class       |
| 1     | Space Transportation Main Engine            | STME                                   | Cryogenic Liquid   |
| 2     | F-1                                         | F-1                                    | Hydrocarbon Liquid |
| 3     | F-1A                                        | F-1A                                   | Hydrocarbon Liquid |
| 4     | J-2                                         | J-2                                    | Cryogenic Liquid   |
| 5     | Simplified, High Performance J-2            | J-2S                                   | Cryogenic Liquid   |
| 6     | Space Shuttle Main Engine                   | SSME                                   | Cryogenic Liquid   |
| 7     | RD-170                                      | RD-170 (Russian<br>Designation 11D521) | Hydrocarbon Liquid |
| 8     | Integrated Modular Engine                   | IME                                    | Cryogenic Liquid   |
| 9     | Space Shuttle Redesigned Solid Rocket Motor | RSRM                                   | Solid Fuel         |
| 10    | Nuclear Thermal Rocket, NERVA Derivative    | NTRND                                  | Nuclear Thermal    |

#### Figure 70. Propulsion Systems Currently Available

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## Liquids

March 30, 1993

## Engine Reports

- Background Data
- Propulsion System Basic Information
- Engine Performance Report #1
- Engine Performance Report #2
- Start-Up/Shutdown Sequence Report
- Start-Up/Shutdown Profile #1
- Start-Up/Shutdown Profile #2
- Interface Report
- Engine Technology Development
- Advanced Development Plan
- Fingine Picture/Basic Data
- Engine Drawing
- Engine Balance

# Reports

0000 0-0000 0000

Summary

## **Engine Briefing Charts**

|                         | Chart #5 | Chart #6 |
|-------------------------|----------|----------|
|                         | Chart #3 | Chart #4 |
| Propulsion Element Data | Chart #1 | Chart #2 |

Background Data

- Startup Sequence
- Shutdown Sequence
- Interface Chart
- Engine Technology Development
- Advanced Development Plan
- Thrust Startup/Shutdown Profile
- Specific Impulse Startup/Shutdown Profile
- Mixture Ratio Startup/Shutdown Profile
- Mass Flow Startup/Shutdown Profile
- Engine Picture/Basic Data
- Engine Drawing
- Engine Balance

# Figure 71. Reports Available for Each Propulsion System

| March 30, 1993 Engine Performan                                                                                                                                     |                                                                                                                                                                                      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Engine Name: Space Transportation Main Engine<br>Class of Engine: Cryogenic Liquid                                                                                  | Chemical                                                                                                                                                                             |
| Propellants       Liquid Oxygen         Oxidizer       Liquid Hydrogen         Fuel       Liquid Hydrogen         Mixture Ratio – Engine/Thrust Chamber       6.000 | 6.993                                                                                                                                                                                |
| Nominal Chamber Pressure2,250Expansion Ratio45.02Engine Design Life (Flights)1                                                                                      | Engine Restarts                                                                                                                                                                      |
| Sea Level     Vacuum       Nominal     552,980     650,000       Maximum     357,980     455,000                                                                    | Engine Starts<br>Design 11<br>Demonstrated                                                                                                                                           |
| Thrust data in units of lbf                                                                                                                                         | Engine Reliability, secDesign5,500Demonstrated                                                                                                                                       |
| Sea Level     Vacuum       Maximum                                                                                                                                  | Nozzie Data Beil                                                                                                                                                                     |
| Specific Impulse Data<br><u>Sea Level</u> <u>Vacuum</u><br>@Nominal Thrust<br>@Maximum Thrust<br>@Minimum Thrust<br>Specific Impulse data in units of seconds       | Length (in)       133.63         Diameter (in)       91.67         Throat Area (sq. in)       146.61         Exit Area (sq. in)       6,600.3822         Expansion Ratio       45.02 |

Figure 72. Typical Report Page Layout

Figure 73.

#### Output for Space Transportation Main Engine (STME) Propulsion System

STME Propulsion System



- Specific Impulse (sec)364.5• Sea Level364.5• Vacuum428.5• Vacuum2,250(Nozzle Stagnation)2,250Engine Mixture Ratio6.000
- Expansion Ratio
   45.00
- Length (in) 161.00 Weight (lbm) 9,100

3/31/93

Advanced Propulsion Subsystem Concepts Database



3/18/93

Advanced Propulsion Subsystem Concepts Database



3/18/93

#### March 31, 1993

#### **Background Information**

| Engine Name:     | Space Transportation Main Engine |          |
|------------------|----------------------------------|----------|
| Class of Engine: | Cryogenic Liquid                 | Chemical |
| Background       |                                  |          |

The STME was designed to support propulsion requirements of the National Launch System (NLS). The NLS concept provides a lift capacity for a family of launch vehicles with a wide range of payload sizes (approximately 20,000 lbs and above) and missions. NLS family members may consist entirely of liquid propulsion units or combinations of liquid units and solid rocket motors.

The STME is capable of operating in either a NLS booster or core propulsion application. In either mode, the STME starts prior to vehicle liftoff. In the booster mode, the operation of some STME's will be terminated and detached from the vehicle with other elements while other STME's continue to operate.

In the core mode, the STME will continue to operate after booster (solid or liquid) separation until orbital (or near orbital) conditions are reached.

The STME is a pump fed liquid oxygen and liquid hydrogen engine that has been designed for high reliability and low cost. It employs a gas generator power cycle to drive separate LO2 and LH2 turbopump assemblies. Gas generator propellants are tapped-off the engine propellant system and burned to provide fuel rich gas to drive the turbines. Turbine exhaust gas is used to cool the engine nozzle extension. The engine is capable of operating at two discrete thrust levels, 100% and 70%. Engine start is accomplished by use of vehicle propellant tank head pressures. No helium spin start or solid start cartridge is required. The engine provides oxygen and hydrogen gases for propellant tank pressurization.

- Comments-

 References
 Source: STME Technical Information Document, 6 Jan 1993; ICD, Working Draft, Attachment J-3, 18 Sept 1992; Draft Contract End Item Specification, Phase C/D, Revision 10, Attachment J-2, 26 May 1992

| Date:       | Entered as of 31 | March | 1993 |
|-------------|------------------|-------|------|
| Entered by: | Dan Levack       |       |      |

March 31, 1993

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**Propulsion System General Data** 

| Creation Date Modification Da          | at <b>e</b> | Record Number                              |
|----------------------------------------|-------------|--------------------------------------------|
| 3/18/93 3/31/93                        |             | 1                                          |
| Engine Name                            | Space T     | ransportation Main Engine                  |
|                                        | Cryogeni    | ic Liquid Chemical                         |
|                                        | Thermod     | dynamic Expansion of Hot Gas               |
|                                        | STME        |                                            |
| Application                            | Booster     | Engine                                     |
| Manufacturer                           | Consortiu   | ium (Aerojet, Pratt & Whitney, Rocketdyne) |
| Drogram Status                         | Detailed    | Study                                      |
| Manrated                               |             |                                            |
| IOC/Date Studied (Month/Year)          | 12/1992     | 2                                          |
| Mixture Ratio – Engine/ Thrust Chamber |             | 6.000 6.993                                |
| - Propellants                          |             | 7                                          |
| Oxidizer Liquid Oxygen                 |             |                                            |
| Fuel Liquid Hydrogen                   |             |                                            |
| Engine Design Life (Flights)           | 1           |                                            |
| Restart Canability                     | No          |                                            |
|                                        | Gas Ge      | enerator                                   |
| Nominal Chamber Pressure               |             | 2,250                                      |
|                                        |             |                                            |
| Expansion Ratio                        |             | 45.00                                      |
| TVC Method                             | Gimbal      |                                            |
| - Dimensions                           |             |                                            |
| Maximum Length (Inches)                | L           | 161.00                                     |
| Maximum Width (inches)                 |             | 101.22                                     |
| Engine Mass (lbm)                      |             | 9,100.00                                   |
| Tables Thread Data Ibf                 |             |                                            |
| Engine inrust Data, ibi                | Sea Leve    | <u>Yacuum</u>                              |
| Nominal                                | 552,98      | 650,000                                    |
|                                        |             | -                                          |
| Maximum L                              |             |                                            |
| Minimum 🔤                              | 357,98      | 455,000                                    |
|                                        |             |                                            |

#### Engine Performance 1

| Engine Name: Space Transportation Main Engine<br>Class of Engine: Cryogenic Liquid                                                                                | Chemical                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Propellants       Liquid Oxygen         Oxidizer       Liquid Oxygen         Fuel       Liquid Hydrogen         Mixture Ratio – Engine/Thrust Chamber       6.000 | 6.993                                                                                                                                                           |
| Nominal Chamber Pressure2,250Expansion Ratio45.00Engine Design Life (Flights)1                                                                                    | Design O<br>Demonstrated                                                                                                                                        |
| Sea Level       Vacuum         Nominal       552,980       650,000         Maximum       1000000000000000000000000000000000000                                    | Engine Starts<br>Design 11<br>Demonstrated<br>Engine Reliability, sec<br>Design 5,500                                                                           |
| Throttle Ratio, Percent     Sea Level Vacuum Maximum     G4.70     70.00      Specific Impulse Data                                                               | Demonstrated       Nozzle Data       Type       Length (In)                                                                                                     |
| Sea Level       Yacuum         @Nominal Thrust       364.54       428.50         @Maximum Thrust                                                                  | Diameter (in)         91.67           Throat Area (sq. in)         146.61           Exit Area (sq. in)         6,597.45           Expansion Batio         45.00 |

#### March 31, 1993

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#### March 31, 1993

Engine Performance 2

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| ace Transportation Main Engine<br>Cryogenic Liquid                                                                                                                                     | Chemical                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9,100.0                                                                                                                                                                                | TVC         Method       Gimbal         Mass (lbm)                                                                                                                                    | <u>11.3</u><br>4.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 'urbopump<br>Inlet47<br>let554.0<br>Press                                                                                                                                              | Fuel Turbopump         Min Pump Inlet       32         Turbine Inlet       2,196.0         ures in psia                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 161                                                                                                                                                                                    | Diameter       Nozzle Exit       97.0       Maximum       101.2       Maximum Gimbal                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Envelope Dir                                                                                                                                                                           | nensions in incres                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 1t Masses<br>Component Allocations<br>Turbomachinery 1570<br>Fuel Turbopump 1718<br>Combuston Devices<br>Main Injector 1226<br>Combuston Chamber 1601<br>Nozzle 99<br>Gas Generator 92 | Controller 35<br>Sensors 35<br>Verwerk/Aduators 214<br>Interconnects 17<br>Propulant Feed 223<br>Miccollensous (System Hardware) 353<br>Support Devices 138                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                                                                                                                                                                        | ace Transportation Main Engine<br>Cryogenic Liquid<br>9,100.0<br>9,100.0<br>9,100.0<br>9,100.0<br>9,100.0<br>9,100.0<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1 | ace Transportation Main Engine Cryogenic Liquid Chemical  9,100.0  9,100.0  Method Gimbal Mass (lbm) Mass (lbm) Mass (lbm) Max Gimbal Angle (deg) Max Gimbal Rate (deg/e) Max Gimbal Rate (deg/e)  3enerator  Fuel Turbopump  Inlet 47 Inlet 554.0  Fuel Turbopump  Pressures in psia  Fuel Turbopump  Inlet 554.0  Diameter  Nozzie Exit 97.0  Maximum 101.2  Maximum Gimbal  In Gimbal  Convents Acoustors Convent Acoustors Convent |

#### Start-Up/Shutdown Sequences



#### Start-Up/Shutdown Profiles



Class of Engine: Cryogenic Liquid

Chemical





#### Start-Up/Shutdown Profiles

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid

Chemical

- Isp Profile





#### Interfaces





. . . . . .

#### **Technology Development**

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid

Chemical

- Technology Development

#### Advanced Development Plan

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid

Chemical

-Advanced Development Plan

|                                                                           | 1992 1993 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 1994 1 |
|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PROGRAM                                                                   | 4118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181314118131411813141181                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 20K VEHICLE<br>PROGRAM                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| ENGINE<br>PROGRAM MILESTONES                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| NGINE                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| DEVELOPMENT<br>lardware - 6 New<br>1 Refurb<br>'ests<br>B1A 100<br>B1B 90 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| lardware - 4 New CERT<br>2 Development<br>2 Development<br>Flight Engines |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Tests                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| B1A 94                                                                    | ╾┫╡┼┟╪┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

#### March 31, 1993

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Figure 74.

#### Output for F-1 Propulsion System

**F-1 Propulsion System** 



| 1,522,008<br>1,748,200                                             | 265.4<br>304.8                                                       | 982                                            | 2.270                       | 16.00           | 220.40      | 18,616       |
|--------------------------------------------------------------------|----------------------------------------------------------------------|------------------------------------------------|-----------------------------|-----------------|-------------|--------------|
| Nominal Thrust (Ibf) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Specific Impulse (sec) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Chamber Pressure (psia)<br>(Nozzle Stagnation) | <b>Engine Mixture Ratio</b> | Expansion Ratio | Length (in) | Weight (Ibm) |

**Nozzle Extension** Interface Panel\* 5 In. ] Gimbal Interface -43.9 64.8 Chemical 220.4 in. No. 1 Actuator Attach Point - Oxidizer Inlet 16.1 I.D. \*LOX pump inlet is 0.81 in. above gimbal interface (customer connect), fuel pump inlet is 5.16 in. below gimbal interface - No. 2 Gimbal Axis - Fuel Inlet 11.8 I.D. 50.0 Hydrocarbon Liquid ₽ Æ 35.4 35.4 25.9 25.9 143.5 in.-F Fuel Inlet 11.8 I.D. — No. 2 Actuator Attach Point ---35,4 No. 1 Gimbal Axis Class of Engine: **Engine Name:** 

Advanced Propulsion Subsystem Concepts Database

2/20/93





2/20/93

March 13, 1993

#### **Background Information**

| Engine | Name: | F-1 |
|--------|-------|-----|
|--------|-------|-----|

Class of Engine: Hydrocarbon Liquid

Chemical

#### Background

The F-1 rocket engine development was initiated at Rocketdyne in January 1959 under the direction of NASA, MSFC. The F-1 was developed to provide the power for the booster flight phase of the Saturn V vehicle. A cluster of five engines provided 7,610,000 lbs. of thrust in the first stage. Sixty-five engines were flown on 13 Saturn V missions between 1967 and 1973 with 100 percent success. A total of 98 production engines were delivered.

The F-1 is a single-start, fixed-thrust, liquid-bipropellant engine, calibrated to operate at a sea level thrust of 1,522,000 pounds and 2.27:1 mixture ratio, providing a specific impulse of 265.4 seconds. The engine is a relatively simple design using liquid oxygen and RP-1 (rocket grade of kerosene) for propellants. The engine design is suitable in a single or multi-engine installation. Although engine application was for only one flight, qualification requirements were established and demonstrated at 20 starts for a total of 2,250 seconds.

The engine features a two-piece thrust chamber that is tubular-walled and regeneratively cooled to the 10:1 expansion ratio plane, and double-walled and cooled with turbine exhaust gas to the 16:1 expansion ratio plane; a thrust chamber mounted turbopump that has two centrifugal pumps spline-connected on a single shaft driven by a two-stage, direct drive turbine; one-piece rigid propellant ducts that are used in pairs to direct the fuel and oxidizer to the thrust chamber; and a hypergolic fluid cartridge that is used for thrust chamber ignition. Power for the turbopump is supplied by a bipropellant gas generator system which burns high pressure fuel and oxidizer from the turbopump to drive the turbine. Turbine exhaust gas, prior to cooling the thrust chamber nozzle extension, is directed to a heat exchanger which conditions vehicle tank pressurants (oxygen for oxidizer tank and helium for the fuel tank). Thrust vector changes are achieved by gimbaling the entire engine. The gimbal block is located on the thrust chamber dome, and actuator attach points are provided by two outriggers on the thrust chamber body. The RP-1 fuel is used as the working fluid for the gimbal actuators, for the engine control system, and for the turbopump bearing lubricant.

The engine is started using a tank-head start with pressure-ladder sequence. Initially control pressure is supplied from the ground. Start is initiated by electrically firing the gas generator and nozzle extension pyrotechnic igniters and energizing the engine control valve start solenoid to open the main oxidizer valves and the gas generator valve. Propellants directed to the gas generator from the pump discharges (initially at tank head pressures) are combusted in the gas generator causing pump discharge pressures to increase. All subsequent start sequencing is accomplished by pressure actuated valves responding to build-up of fuel pump discharge pressure.

Engine cutoff is initiated electrically by energizing the engine control valve stop solenoid. This removes opening pressure and applies closing pressure to the propellant valves. When closing pressure is applied to the propellant valves, orifices in the control lines sequence the gas generator valve, oxidizer valves, and fuel valves closed, in that order.

Engine production was terminated in 1969.

#### Comments =

| References<br>Source: | F-1/F-1A Engine Data Package (BC91-74), Unpublished Rocketdyne Data; Technical Manual F-1 Rocket<br>Engine, R-3896-1, 31 March 1967 (Change 12 – 12 May 1972); The Saturn V F-1 Engine Revisited, AIAA<br>92-1547, 24 March 1992. |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Date:                 | 1991                                                                                                                                                                                                                              |
| Entered by:           | Dan Levack                                                                                                                                                                                                                        |

March 30, 1993

#### **Propulsion System General Data**

| Creation Date Modification Da          | ate       | Record Number                |
|----------------------------------------|-----------|------------------------------|
| 8/31/92 3/30/93                        |           | 2                            |
|                                        |           |                              |
| Engine Name                            | F-1       | when Liquid Chemical         |
| Class of Engine                        | Thermod   | dynamic Expansion of Hot Gas |
| Propulsion Type                        | F-1       |                              |
| Acronym                                | Saturn V  | / Booster Engine             |
| Application                            | Bechurel  | Il International Corporation |
| Manufacturer                           | TIOCKWOII | Anne Anolio / Saturn Flights |
| Program Status                         | TT Succe  |                              |
| Manrated                               | Yes       |                              |
| IOC/Date Studied (Month/Year)          | Sept 190  |                              |
| Mixture Ratio – Engine/ Thrust Chamber | L         | 2.270 2.410                  |
| Propellants                            |           | 1                            |
|                                        |           | 1                            |
| Fuel (MIL-P-205766)                    |           |                              |
| Engine Design Life (Flights)           | 1         |                              |
| Restart Capability                     | No        |                              |
| Engine Cycle                           | Gas Ger   | nerator                      |
| Nominal Chamber Pressure               |           | 982                          |
|                                        |           |                              |
| Expansion Ratio                        |           | 16.00                        |
|                                        | Gimbal    |                              |
| Dimensions                             |           |                              |
| Maximum Length (inches)                |           | 220.40                       |
| Maximum Width (inches)                 |           | 143.50                       |
| Engine Mass (lbm)                      | 1         | 8,616.00                     |
|                                        |           |                              |
| Engine Thrust Data, Ibf                | Sea Level | l Vacuum                     |
| · · · · · · · · · · · · · · · · · · ·  | 4.500.000 |                              |
| Nominal                                | 1,522,008 |                              |
| Maximum                                |           |                              |
| Minlmum                                |           |                              |
|                                        |           |                              |
|                                        |           |                              |

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March 13, 1993

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**Engine Performance 1** 

| Engine Name: F-1<br>Class of Engine: Hydrocarbon Liquid                             | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Propellants Liquid Oxygen (MIL-P-255086)                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Fuel     RP-1 (MIL-P-25576B)       Mixture Ratio - Engine/Thrust Chamber     2.270  | 2.410                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Nominal Chamber Pressure (psia)982Expansion Ratio16.00Engine Design Life (Flights)1 | Design Contracted Contractee Cont |
| Engine Thrust Data<br>Sea Level Vacuum<br>Nominal 1,522,008 1,748,200<br>Maximum    | Engine Starts<br>Design 20<br>Demonstrated 60                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Minimum Thrust data in units of ibf                                                 | Engine Reliability, secDesign2,250Demonstrated5,924                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Sea Level     Vacuuli       Maximum                                                 | Type Bell, Tubular Wa                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Specific Impulse Data<br><u>Sea Level</u> <u>Vacuum</u>                             | Length (in) 158.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| @Nominal Thrust     265.40     304.84       @Maximum Thrust                         | Throat Area (sq. in)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| @Minimum Thrust Specific Impulse data in units of seconds                           | Exit Area (sq. in)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

March 7, 1993

#### Engine Performance 2

| Engine Name: F-1                                                      | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Class of Engine: Hydrocarbon Liquid                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| - Engine Mass (Ibm)<br>Total Mass w/TVC 18,616.0<br>Total Mass wo/TVC | TVC       Method       Gimbal         Mass (Ibm)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Engine Cycle<br>Type Gas Generator<br>Pressures                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Oxidizer Turbopump<br>Min Pump Inlet 48.4<br>Turbine Inlet 945.0      | Min Pump Inlet 24.3<br>Turbine Inlet 945.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Envelope<br>Length<br>Nominal 220.4<br>Stowed Extended Maximum Gimbal | Diameter         Nozzle Exit       140.0         Maximum       143.5         Maximum Gimbal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Envelope Dime                                                         | nsions in inches                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Engine Component Masses                                               | nt 3.4932<br>8.506.8<br>467.0<br>652.0<br>642.4<br>3.63<br>193.3<br>94.6<br>193.3<br>993.7<br>993.7<br>993.7<br>105.0<br>44.0<br>993.7<br>105.0<br>44.0<br>993.7<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0<br>105.0 |

#### February 20, 1993 Start-Up/Shutdown Sequences



#### February 20, 1993












# Start-Up/Shutdown Profiles



### Interfaces

#### Engine Name: F-1

Class of Englne: Hydrocarbon Liquid

Chemical



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## **Technology Development**

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid

Chemical

Technology Development

#### March 24, 1993

### **Advanced Development Plan**

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid

Chemical



Figure 75.

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# Output for F-1A Propulsion System

F-1A Propulsion System



| 1,800,001<br>2,020,700                                             | 269.7<br>302.8                                  | 1,161                                          | 2.270                | 16.00           | 220.40      | 19,875       |
|--------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------|----------------------|-----------------|-------------|--------------|
| Nominal Thrust (Ibf) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Specific Impulse (sec)     Sea Level     Vacuum | Chamber Pressure (psia)<br>(Nozzle Stagnation) | Engine Mixture Ratio | Expansion Ratio | Length (in) | Weiaht (Ibm) |

Advanced Propulsion Subsystem Concepts Database



Advanced Propulsion Subsystem Concepts Database



### **Background Information**

F-1A Engine Name:

Hydrocarbon Liquid Class of Engine:

Chemical

#### Background

The F-1A engine is an uprated version of the F-1 engine originally used as the first-stage booster propulsion system for the Saturn V launch vehicle. The engine produces a sea level thrust of 1,800,000 pounds vs. 1,522,00 for the F-1. Functionally, the engine is identical to the F-1. Refer to the F-1 background information sheet for a general description of the engine configuration and operation.

During the late 1960's the F-1 engine development program was actively pursuing upgrades and improvements on the flight-certified production engine. The most significant improvement was to the Mark 10 turbopump. Pump design modifications included reducing the turbine diameter from 35 to 30 inches, material changes to improve producibility and structural improvements to permit operation at higher power levels. These changes gathered over 15,000 seconds of test maturity in both component and engine tests. A 1,800,000 pound sea level thrust capability was demonstrated on two F-1A configuration development engines using the improved turbopump (Mark 10A).

Step throttling of the engine from 1,800K to 1,350K and a condition monitoring system (CMS) are options which can be provided with the engine. CMS would enable holddown/shutdown capability on the launch pad and, dependent on vehicle configuration and mission requirements, engine out capability.

A NASA-MSFC funded study in 1992 concluded F-1A production could readily be restarted (at substantially less cost than a new center line engine) using "state-of-the-practice" manufacturing processes. Five spare F-1 flight engines in bonded storage at the Michaud Assembly Facility could be converted to the F 1A configuration to be used as "pathfinders" for assembly and test stand activation. Engine test facilities capable of testing the F-1A engine exist at USAF Phillips Lab in California; NASA's Marshall Space Flight Center in Huntsville, Alabama; and at Stennis Space Center in Mississippi.

Comments

References

F-1/F-1A Engine Data Package (BC91-74), Unpublished Rocketdyne Data Source:

1991 Date: Entered by: Dan Levack March 30, 1993

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**Propulsion System General Data** 

| Creation Date Modification Da                                                                                                                                      | ate                        | Record Number                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|-------------------------------------|
| 8/31/92 3/30/93                                                                                                                                                    | <b> </b>                   | <u>الا</u>                          |
| Engine Name<br>Class of Engine                                                                                                                                     | F-1A<br>Hydrocar           | rbon Liquid Chemical                |
| Propulsion Type<br>Acronym                                                                                                                                         | Thermod<br>F-1A            | dynamic Expansion of Hot Gas        |
| Application<br>Manufacturer                                                                                                                                        | Booster<br>Rockwel         | Engine Il International Corporation |
| Program Status<br>Manrated<br>IOC/Date Studied (Month/Year)                                                                                                        | 16 Tests<br>Yes<br>March 1 | s<br>1969 (Testing Completed)       |
| Mixture Ratio – Engine/ Thrust Chamber<br>Propellants<br>Oxidizer<br>Eucl<br>Engine/ Thrust Chamber<br>Liquid Oxygen (MIL-P-255086)<br>Eucl<br>BP-1 (MIL-P-25576B) |                            | 2.270                               |
| Engine Design Life (Filghts)<br>Restart Capability<br>Engine Cycle<br>Nominal Chamber Pressure                                                                     | 1<br>No<br>Gas Ge          | enerator<br>1,161                   |
| Expansion Ratio<br>TVC Method                                                                                                                                      | Gimbal                     | 16.00                               |
| Dimensions<br>Maximum Length (inches)<br>Maximum Width (inches)<br>Engine Mass (ibm)                                                                               |                            | 220.40<br>143.50<br>19,875.40       |
| Engine Thrust Data, Ibf                                                                                                                                            | Sea Leve                   | el <u>Vacuum</u>                    |
| Nominal                                                                                                                                                            | 1,800,00                   | 01 2,020,700                        |
| Maximum L                                                                                                                                                          | 1 250 00                   |                                     |

March 13, 1993

**Engine Performance 1** 

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| Ingine Name: F-1A                           |                            |
|---------------------------------------------|----------------------------|
| Class of Engine: Hydrocarbon Liquid         | Chemical                   |
| Propellants                                 |                            |
| OxIdizer Liquid Oxygen (MIL-P-255086)       |                            |
| Fuel RP-1 (MIL-P-25576B)                    |                            |
| Mixture Ratio – Engine/Thrust Chamber 2.270 |                            |
| Nominal Chamber Pressure (psia)             | Engine Restarts            |
| Expansion Ratio                             | Design0                    |
| Engine Design Life (Filghts)                | Demonstrated               |
| Engine Thrust Data                          |                            |
|                                             | Engine Starts              |
| Nominal 1,800,001 2,020,700                 | Design1                    |
| Maximum                                     | Demonstrated16             |
| Minimum 1,350,001 1,570,700                 |                            |
| Thrust data in units of lbf                 | Engine Reliability, sec    |
| Infust data in units of ist                 | Design                     |
| Throttle Ratio, Percent                     | Demonstrated 1,753         |
| <u>Sea Level</u> <u>Vacuum</u>              |                            |
| Maximum 100.00 100.00                       | - Nozzie Data              |
| Minimum 75.00 77.73                         | Type Bell, Tubular Wa      |
| - Specific Impulse Data                     | Length (in) 158.00         |
| Sea Level Vacuum                            | Diameter (in) 138.20       |
|                                             | Throat Area (sq. in) 961.0 |
| @Minimum Thrust                             | Exit Area (sq. in)         |
| Specific Impulse data in units of seconds   | Expansion Ratio 16.0       |

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Engine Performance 2

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| Engine Name: F-1A<br>Class of Engine: Hydrocarbon Liquid                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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| Engine Mass (Ibm)         Total Mass w/TVC         19,875.4         Total Mass wo/TVC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | TVC         Method       Gimbal         Mass (ibm)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Type Gas Generator                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Pressures<br>Oxidizer Turbopump<br>Min Pump Inlet<br>Turbine Inlet<br>Pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Fuel Turbopump     Min Pump Inlet     Turbine Inlet     es in psla                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Envelope<br>Length<br>Nominal 220.4<br>Stowed<br>Extended<br>Maximum Gimbal<br>Envelope Dime                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Diameter<br>Nozzle Exit 140.0<br>Maximum 143.5<br>Maximum Gimbal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Engine Component Masses<br>Turospump and mon<br>Codiare System<br>Purge System<br>Controls (Hydraulid)<br>Controls (Editorial<br>Controls (Hydraulid)<br>Controls (Editorial<br>Controls (Editorial<br>Controls (Hydraulid)<br>Controls (Hydraulid)<br>Control (Hydraulid | IRY 4.185.5<br>8.505.8<br>487.0<br>653.0<br>643.4<br>38.2<br>1 193.2<br>247.5<br>643.4<br>38.2<br>1 193.2<br>247.5<br>347.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5<br>247.5 |

# February 20, 1993 Start-Up/Shutdown Sequences



Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid

Chemical





# Start-Up/Shutdown Profiles

| Class of Engine: Hydrocarbon Liquid |  |
|-------------------------------------|--|
|                                     |  |
| Mixture Ratio Profile               |  |
|                                     |  |
|                                     |  |
|                                     |  |

### Interfaces

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid

Chemical



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# **Technology Development**

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid

Chemical

Technology Development

## February 20, 1993 Advanced Development Plan

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid

Chemical

- Advanced Development Plan

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Figure 76.

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# Output for J-2 Propulsion System

**J-2 Propulsion System** 



| 161,548<br>230,000                                                 | 298.4<br>424.9                                  | 780                                            | 5.500                       | 27.16           | 133.00      | 4,050        |
|--------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------|-----------------------------|-----------------|-------------|--------------|
| Nominal Thrust (Ibf) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Specific Impulse (sec)     Sea Level     Vacuum | Chamber Pressure (psia)<br>(Nozzle Stagnation) | <b>Engine Mixture Ratio</b> | Expansion Ratio | Length (in) | Weight (Ibm) |

Advanced Propulsion Subsystem Concepts Database







# **Background Information**

| Engine Name: J<br>Class of Engine:                                                                                                                                                                                                                                                                                                                                                          | -2<br>Cryogenic Liquid                                                                                                                                                                                                                                                                                                                                                                                                | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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|                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul> <li>Background –</li> <li>The J-2 engine was develop of the Saturn V vehicle</li> <li>The J-2 rocket engine is fuel. Each propellant is turbopumps are powere chamber is tubular-wall combustion area. The eturbines for starting the engine.</li> <li>The J-2 engine envelop dry. Thrust vector contrinjector dome, and gim propellant feed system, instrumentation system</li> </ul> | eloped to provide the power for t<br>a high-performance, multiple-re<br>pumped into the thrust chamber<br>d in series by a single gas genera<br>ed and is regeneratively cooled b<br>ngine has a refillable start tank fr<br>engine. This feature, combined<br>the is 80.75 inches in diameter and<br>to is achieved by gimbaling the<br>bal actuator attach points are local<br>gas generating system, start system. | he SIVB stage of the Saturn IB vehicle and for the SII and SIVB stages<br>start engine that uses liquid oxygen for oxidizer and liquid hydrogen for<br>by separate gas-turbine-driven, direct-drive turbopumps. The two<br>ator that uses the same propellants as the thrust chamber. The thrust<br>by circulating fuel through the tubes before the fuel is injected into the<br>rom which pressurized gaseous hydrogen is routed to the turbopump<br>with the augmented spark ignition system, makes the J 2 a multi-start<br>d 133 inches long and the engine weighs approximately 3,492 pounds<br>entire engine. The gimbal is installed at the center of the thrust chamber<br>ated on the thrust chamber body. The rocket engine comprises the<br>stem, ignition n system, control system, purge system, and the flight |
|                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Comments                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| No Comments.                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| References<br>Source: Tech<br>(R-3                                                                                                                                                                                                                                                                                                                                                          | nnical Data J-2 Rocket Engine,<br>825-1A)                                                                                                                                                                                                                                                                                                                                                                             | Change No. 12 (R-3825-1), Technical Data J-2 Rocket Engine                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

Date:18 October 1972, 4 December 1973Entered by:Dan Levack

March 30, 1993

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**Propulsion System General Data** 

| B/31/92       B/30/93       4         Engine Name       U2         Class of Engine       Chryogenic Liquid         Propulsion Type       Thermodynamic Expansion of Hot Gas         Acronym       U2         Application       Stages II and IVB of Saturn V Launch Vehicle         Manufacturer       Rockwell International Corporation         Program Status       Used on SIVB stage of the Saturn IB and the SII and S         Manrated       Yes         IOC/Date Studied (Month/Year)       5.500         Mixture Ratio - Engine/ Thrust Chamber       5.500         Propellants       Soldizer         Oxidizer       Liquid Oxygen         Fuel       Liquid Aydrogen         Engine Design Life (Flights)       30         Restart Capability       Yes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Dimensions       133.00         Maximum Length (Inches)       133.00         Maximum Width (Inches)       81.00         Engine Thrust Data, Ibf       Sea Level       Yacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Maximum       161,548                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Creation Date Modification D           | Date     | Record Number                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|----------|-----------------------------------------------|
| Engine Name       J-2         Class of Engine       Cryogenic Liquid       Chemical         Propulsion Type       Thermodynamic Expansion of Hot Gas         Acronym       J-2         Application       Stages II and IVB of Saturn V Launch Vehicle         Manufacturer       Rockwell International Corporation         Program Status       Used on SIVB stage of the Saturn IB and the SII and S         Manrated       Yes         IOC/Date Studied (Month/Year)       Stages         Mixture Ratio – Engine/ Thrust Chamber       5.500         Propellants       Stages         Oxidizer       Liquid Oxygen         Fuel       Sa Generator         Nominal Chamber Pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 8/31/92 3/30/93                        |          | 4                                             |
| Class of Engine       Cryogenic Liquid       Untermidia         Propulsion Type       Thermodynamic Expansion of Hot Gas         Acronym       U-2         Application       Stages II and IVB of Satum V Launch Vehicle         Manufacturer       Rockwell International Corporation         Program Status       Yes         Marrated       Yes         IOC/Date Studied (Month/Year)       Stoges         Mixture Ratio – Engine/ Thrust Chamber       5.500         Propellants       Stoges         Oxidizer       Liquid Oxygen         Fuel       Capability         Yes       Stages         Engine Design Life (Flights)       30         Restart Capability       Yes         Expansion Ratio       27.18         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (Inches)       133.00         Maximum Width (Inches)       31.00         Engine Thrust Data, Ibf       Sea Lavel       Yacuum         Nominal<                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Engine Name                            | J-2      |                                               |
| Propulsion Type       Intermedynamic Expansion of Not Cass         Acronym       U-2         Application       Stages II and IVB of Satum V Launch Vehicle         Manufacturer       Rockweil International Corporation         Program Status       Used on SIVB stage of the Saturn IB and the SII and SI         Manrated       Yes         IOC/Date Studied (Month/Year)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Class of Engine                        | Cryogeni | ic Liquid Chemical                            |
| Acronym       U-2         Application       Stages II and IVB of Saturn V Launch Vehicle         Manufacturer       Rockwell International Corporation         Program Status       Used on SIVB stage of the Saturn IB and the SII and S         Manrated       Yes         IOC/Date Studied (Month/Year)       Status         Mixture Ratio - Engine/ Thrust Chamber       5.500         Propellants       Oxidizer         Oxidizer       Liquid Oxygen         Fuel       Liquid Oxygen         Fuel       Cliquid Oxygen         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Width (Inches)       81.00         Engine Mass (Ibm)       4,050.00         Maximum       161.548       230,000         Maximum       161.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Propulsion Type                        |          |                                               |
| Application       Stages in and Ve Or Saturn V claurer Connect         Manufacturer       Rockwell International Corporation         Program Status       Used on SiVB stage of the Saturn IB and the Sil and S         Manrated       Yes         IOC/Date Studied (Month/Year)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Acronym                                | J-2      | Hand IVR of Seturn V Launch Vehicle           |
| Manufacturer       HeckWeil International Corporation         Program Status       Used on SiVB stage of the Saturn IB and the Sil and S         Manrated       Yes         IOC/Date Studied (Month/Year)       5.500         Mixture Ratio - Engine/ Thrust Chamber       5.500         Propellants       Oxidizer         Oxidizer       Liquid Oxygen         Fuel       Liquid Hydrogen         Engine Design Life (Flights)       30         Restart Capability       Yes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Width (inches)       81.00         Engine Thrust Data, lbf       Sea Level       Yacuum         Nominal       161,548       230,000         Maximum       161,548       230,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Application                            | Stages   | land IVB of Saturn V Lauren Vernere           |
| Program Status       Used of SiVE stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of the Oatum to an end of sive stage of the Oatum to an end of sive stage of the Oatum to an end of the Oatum tend of the Oatum tend tend of the Oatum tend tend of the Oatum tend of the Oat | Manufacturer                           | Rockwei  | SN/R store of the Saturn IB and the SII and S |
| Manrated       Ives         IOC/Date Studied (Month/Year)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Program Status                         |          | SIVE stage of the Gatern is and the           |
| IOC/Date Studied (Month/Year)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Manrated                               | Yes      |                                               |
| Mixture Ratio - Engine/ Thrust Chamber 5.300<br>Propeliants Oxidizer Liquid Oxygen Fuel Liquid Hydrogen Engine Design Life (Flights) Restart Capability Yes Engine Cycle Gas Generator Nominal Chamber Pressure 780 Expansion Ratio 27.16 TVC Method Gimbal Dimensions Maximum Length (inches) 133.00 Maximum Width (inches) 81.00 Engine Mass (lbm) 4,050.00 Engine Thrust Data, lbf Engine Thrust Data, lbf Nominal 161.548 230,000 Maximum 161.548 182,000 Minimum 113,548 182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | IOC/Date Studied (Month/Year)          |          | 5 500                                         |
| Propenants         Oxidizer       Liquid Oxygen         Fuel       Liquid Hydrogen         Engine Design Life (Flights)       30         Restart Capability       Yes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (Inches)       81.00         Engine Mass (Ibm)       4,050.00         Engine Thrust Data, Ibf       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Maximum       161,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Mixture Ratio – Engine/ Thrust Chamber |          |                                               |
| Fuel       Liquid Hydrogen         Engine Design Life (Flights)       30         Restart Capability       Yes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (Inches)       133.00         Maximum Width (inches)       81.00         Engine Mass (Ibm)       4,050.00         Engine Thrust Data, Ibf       Sea Level       Yacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Maximum       161,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                        |          | 1                                             |
| Fuer       Engine Design Life (Flights)       30         Restart Capability       Yes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (Inches)       133.00         Engine Mass (Ibm)       4,050.00         Engine Thrust Data, lbf       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Maximum       161,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Suel Liquid Hydrogen                   |          | 1                                             |
| Engine Design Life (Flights)       130         Restart Capability       Yes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (inches)       133.00         Engine Mass (lbm)       4,050.00         Engine Thrust Data, lbf       Sea Level       Yacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Minimum       113,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                        |          | <u></u>                                       |
| Restart Capability       IYes         Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (Inches)       133.00         Maximum Width (inches)       81.00         Engine Mass (Ibm)       4,050.00         Engine Thrust Data, lbf       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Engine Design Life (Flights)           | 30       |                                               |
| Engine Cycle       Gas Generator         Nominal Chamber Pressure       780         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (inches)       133.00         Maximum Width (inches)       81.00         Engine Mass (lbm)       4,050.00         Engine Thrust Data, lbf       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Restart Capability                     | Yes      |                                               |
| Nominal Chamber Pressure       700         Expansion Ratio       27.16         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (inches)       133.00         Maximum Width (inches)       81.00         Engine Mass (Ibm)       4,050.00         Engine Thrust Data, Ibf       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       182,000         Minimum       113,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Engine Cycle                           |          |                                               |
| Expansion Ratio27.16TVC MethodGimbalDimensions133.00Maximum Length (Inches)133.00Maximum Width (Inches)81.00Engine Mass (Ibm)4,050.00Engine Thrust Data, IbfSea LevelNominal161,548161,548230,000Maximum161,548230,000Minimum113,548182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Nominal Chamber Pressure               | L        |                                               |
| Expansion natio       Gimbal         TVC Method       Gimbal         Dimensions       133.00         Maximum Length (Inches)       81.00         Maximum Width (Inches)       81.00         Engine Mass (Ibm)       4,050.00         Engine Thrust Data, Ibf       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Minimum       113,548       182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Expansion Batio                        |          | 27.16                                         |
| Dimensions133.00Maximum Length (Inches)133.00Maximum Width (inches)81.00Engine Mass (Ibm)4,050.00Engine Thrust Data, IbfSea LevelVacuumNominal161,548Maximum161,548Maximum161,548Maximum113,548Minimum113,548                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                        | Gimbal   |                                               |
| Maximum Length (Inches)133.00Maximum Width (inches)81.00Engine Mass (Ibm)4,050.00Engine Thrust Data, IbfSea LevelVacuumNominal161,548Maximum161,548Maximum161,548Maximum113,548Minimum113,548                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | - Dimensions                           |          |                                               |
| Maximum Width (inches)81.00Engine Mass (lbm)4,050.00Engine Thrust Data, lbfSea LevelVacuumNominal161,548230,000Maximum161,548230,000Minimum113,548182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maximum Length (Inches)                |          | 133.00                                        |
| Engine Mass (lbm)4,050.00Engine Thrust Data, lbfSea LevelVacuumNominal161,548230,000Maximum161,548230,000Minimum113,548182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Maximum Width (inches)                 |          | 81.00                                         |
| Engine Thrust Data, lbf         Sea Level         Vacuum           Nominal         161,548         230,000           Maximum         161,548         230,000           Minimum         113,548         182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Engine Mass (Ibm)                      |          | 4,050.00                                      |
| Engine Thrust Data, lbfSea LevelVacuumNominal161,548230,000Maximum161,548230,000Minimum113,548182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                        |          |                                               |
| Nominal         161,548         230,000           Maximum         161,548         230,000           Minimum         113,548         182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Engine Thrust Data, Ibf                | Sea Leve | el <u>Vacuum</u>                              |
| Maximum <u>161,548</u> <u>230,000</u><br>Minimum <u>113,548</u> <u>182,000</u>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Nominal                                | 161,54   | 48 230,000                                    |
| Maximum101,548182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                        | 161 54   | 48 230,000                                    |
| Minimum 113,548 182,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Maximum L.                             | 101,04   |                                               |
| · · · · · · · · · · · · · · · · · · ·                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Minimum 🗖                              | 113,54   | 48 182,000                                    |

March 13, 1993

**Engine Performance 1** 

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| Engine Name: J-2                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Class of Engine: Cryogenic Liquid                                                                                                                                                                                                                                  | Chemical                                                                                                                                                                                                              |
| Propellants       Liquid Oxygen         Oxldizer       Liquid Oxygen         Fuel       Liquid Hydrogen         Mixture Ratio – Engine/Thrust Chamber       5.500                                                                                                  |                                                                                                                                                                                                                       |
| Nominal Chamber Pressure (psia)780Expansion Ratio27.16Engine Design Life (Flights)30                                                                                                                                                                               | Engine Restarts                                                                                                                                                                                                       |
| Engine Thrust Data       Sea Level       Vacuum         Nominal       161,548       230,000         Maximum       161,548       230,000         Minimum       113,548       182,000         Thrust data in units of lbf       Throttle Ratio, Percent       Yacuum | Engine Starts       30         Design       30         Demonstrated       30         Engine Reliability, sec       3,750         Design       3,750         Demonstrated       3,750         Demonstrated       3,750 |
| Maximum         100.00         100.00           Minimum         79.00         79.00                                                                                                                                                                                | Type Beil, Tubular Wal                                                                                                                                                                                                |
| Specific Impulse DataSea LevelVacuum@Nominal Thrust298.44424.90@Maximum Thrust298.44424.90@Minimum Thrust268.27430.00                                                                                                                                              | Length (in)       77.00         Diameter (in)       77.00         Throat Area (sq. in)       169.70         Exit Area (sq. in)       4,609.052                                                                        |
| Specific Impulse data in units of seconds                                                                                                                                                                                                                          | Expansion Ratio 27.10                                                                                                                                                                                                 |

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**Engine Performance 2** 

| Engine Name: J-2<br>Class of Engine: Cryogenic Liquid                                                                                                                                       | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Engine Mass (Ibm)<br>Total Mass w/TVC 3,492.0<br>Total Mass wo/TVC                                                                                                                          | Method Gimbal Mass (Ibm) Max Gimbal Angle (deg) Max Gimbal Rate (deg/s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Engine Cycle         Type       Gas Generator         Pressures       Oxidizer Turbopump         Min Pump Inlet       33         Turbine Inlet       89.3         Pressures       Pressures | Fuel Turbopump<br>Min Pump Inlet 27<br>Turbine Inlet 652.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Envelope<br>Length<br>Nominal<br>Stowed<br>Extended<br>Maximum Gimbal<br>Envelope Dimense                                                                                                   | Diameter                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Engine Component Masses                                                                                                                                                                     | 77     Shari Tush Dindungi Vales     39       Onder Turken Styren Vales     19       313     Manner And Discussion     19       314     Manner And Discussion     19       315     Manner And Discussion     19       316     High-Turken Statistic     64       317     Manner Mark Califord     10       318     Andiers Understatistic Fichard     33       319     Andiers Indenstatistic Fichard     30       311     Andiers Indenstatistic Fichard     30       312     Turken English Ansenstatistic     20       313     Indenstatistic Fichard     30       314     Andiers' Landrageti Ansenstatistic Fichard     30       315     Holm Anglishin Ansenstatistic     20       32     Holm Anglishin Ansenstatistic     20       313     Chard English Ansenstatistic     20       314     Chard English Ansenstatistic     20       315     Turket Dry Weight     3,482 |

## Start-Up/Shutdown Sequences



Start-Up/Shutdown Profiles



Start-Up/Shutdown Profiles



### Interfaces



Class of Englne: Cryogenic Liquid

Chemical



#### March 13, 1993

## **Technology Development**

Engine Name: J-2

Class of Engine: Cryogenic Liquid

Chemical



### **Advanced Development Plan**



March 24, 1993

Class of Engine: Cryogenic Liquid





### Figure 77.

# Output for Simplified, High Performance J-2 (J-2S) Propulsion System

J-2S Propulsion System



| 196,903<br>265,000                                                 | 321.8<br>433.1                                  | 1,200                                          | 5.500                | 40.00           | 133.00      | 4,050        |
|--------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------|----------------------|-----------------|-------------|--------------|
| Nominal Thrust (Ibf) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Specific Impulse (sec)     Sea Level     Vacuum | Chamber Pressure (psia)<br>(Nozzle Stagnation) | Engine Mixture Ratio | Expansion Ratio | Length (in) | Weight (Ibm) |



Advanced Propulsion Subsystem Concepts Database





3/7/93
### **Background Information**

| March 7, | 1993 |
|----------|------|
|----------|------|

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid

Chemical

#### Background

The J-2S rocket engine development program was initiated at Rocketdyne in 1965 under the direction of the National Aeronautics and Space Administration, Marshall Space Flight Center. The J-2S is a simplified, higher thrust and performance version of the highly reliable J-2 engine. It uses liquid oxygen and liquid hydrogen for propellants.

The J-2S is designed for use in a single or multi-engine installation. The engine is nominally calibrated to operate at a vacuum thrust of 265,000 pounds and 5.5:1 mixture ratio, providing a specific impulse of 436 seconds.

Engine mixture ratio can be controlled (inflight) from 4.5:1 to 6.0:1. Control is accomplished by by-passing liquid oxygen from the discharge side of the oxidizer turbopump to the inlet side through an electroservo actuated variable position valve.(i.e., the propellant utilization valve).

The thrust chamber is a tubular wall, regeneratively cooled design having a bell shaped nozzle with an expansion area ratio of 40:1. A gimbal bearing, attached to the thrust chamber assembly, provides a thrust vector control capability of 7.5 degrees.

The starting power for the turbopumps is provided by a solid propellant turbine starter (SPTS). Up to three SPTS units may be mounted on the engine to provide a multiple space re-start capability.

The engine has a pneumatic control system for valve actuation. The pneumatic supply (gaseous helium) is provided from an engine mounted tank. An electrical control system, which employs solid state logic elements, sequences the engine start and shutdown operations. The electrical power is stage supplied.

A heat exchanger mounted in the turbine exhaust duct can provide either heated helium or heated oxygen for oxidizer tank pressurization. Heated hydrogen, tapped-off from the thrust chamber fuel injection manifold, is available for fuel tank pressurization.

A 6:1 throttling capability has been demonstrated by regulating the tap-off turbine drive gases. Additional engine versatility can be achieved by operating in a low thrust, tank pressure-fed mode. This mode of operation may be used for on-orbit propulsive maneuvers, or pre-mainstage propellant settling.

The J-2S design life is 30 starts and 3,750 seconds duration. Engine testing has demonstrated operation of the engine for a greater total duration and a greater number of engine starts.

#### - Comments =

No Comments.

- References Source: J-2S Brochure (322-497T), The J-2 Rocket Engine (BC71-56), Unpublished Rocketdyne data

Date:?,1971Entered by:J. A. McClanahan, Dan Levack

March 30, 1993

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**Propulsion System General Data** 

| <b>Creation Date</b>      | Modification Da  | at <b>e</b>     | -           | Record Numbe       | r<br>Fl |
|---------------------------|------------------|-----------------|-------------|--------------------|---------|
| 5/18/92                   | 3/30/93          |                 |             |                    | 5       |
| Engine Name               |                  | Simplifie       | d, High Pe  | rformance J-2      |         |
| Class of Engine           |                  | Cryogeni        | c Liquid    | Chemical           |         |
| Propulsion Type           |                  | Thermod         | namic Exp   | pansion of Hot Ga  | s       |
| Acronym                   |                  | J-2S            |             |                    |         |
| Application               |                  | ETO / Sp        | ace Transf  | 0r                 |         |
| Manufacturer              |                  | Rockwell        | Internation | al Corporation     |         |
| Program Status            |                  | 6 Flight-I      | Design Eng  | ines Built and Tes | sted    |
| Manrated                  |                  | Yes             |             |                    |         |
| IOC/Date Studied (Mor     | nth/Year)        | 6-1-72          |             |                    |         |
| Mixture Ratio – Engine    | / Thrust Chamber |                 | 5.500       | 5.8                | 30      |
| - Propellants             | (202             |                 |             |                    |         |
|                           | trogen           |                 |             |                    |         |
|                           | aroden           |                 |             |                    |         |
| Engine Design Life (Fl    | ights)           | 30              |             |                    |         |
| <b>Restart Capability</b> |                  | 2               |             |                    |         |
| Engine Cycle              |                  | Tap-Off         | Turbine Dri | V8                 |         |
| Nominal Chamber Pro       | essure           |                 | 1,200       |                    |         |
| Expansion Patio           |                  |                 | 40.00       |                    |         |
|                           |                  | Gimbal          |             |                    |         |
| Dimensions                |                  |                 |             |                    |         |
| Maximum Length (in        | ches)            |                 | 133.00      |                    |         |
| Maximum Width (inc        | hes)             |                 | 80.00       |                    |         |
| Engine Mass (Ibm)         |                  |                 | 4,050.00    |                    |         |
| - Engine Thrust Data.     | ibf              |                 |             |                    |         |
| Lighte three setup        |                  | <u>Sea Leve</u> | L           | Vacuum             |         |
| Nominal                   |                  | 196,90          | <u>3</u> [  | 265,000            |         |
| Maximum                   |                  |                 | ] [         |                    |         |
| Minimum                   |                  |                 | ] [         |                    |         |
|                           |                  |                 |             |                    | 1       |

#### March 13, 1993

### **Engine Performance 1**

| Engine Name: Simplified, High Performance J-2                                                                                | Chemical                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Class of Engine: Cryogenic Liquid                                                                                            |                                                                                                         |
| Propellants     Oxidizer     Liquid Oxygen     Euel     Liquid Hydrogen     Mixture Ratio – Engine/Thrust Chamber     5.500  | 5.830                                                                                                   |
| Nominal Chamber Pressure (psia)1,200Expansion Ratio40.00Engine Design Life (Flights)30                                       | Design 2<br>Demonstrated                                                                                |
| Sea Level       Vacuum         Nominal       196,903       265,000         Maximum                                           | Engine Starts<br>Design 120<br>Demonstrated 99<br>Engine Reliability, sec<br>Design 3,750               |
| Throttle Ratio, Percent<br><u>Sea Level</u> <u>Vacuum</u><br>Maximum                                                         | Demonstrated 11,509 Nozzle Data                                                                         |
| Minimum                                                                                                                      | Type Beil, Tubular Wail                                                                                 |
| Specific Impulse Data       Sea Level       Vacuum         @Nominal Thrust       321.79       433.08         @Maximum Thrust | Length (in)87.70Diameter (in)76.80Throat Area (sq. in)116.90Exit Area (sq. in)4,676Expansion Ratio40.00 |

**Engine Performance 2** 

| Engine Name: Simplified, High Performance J-2<br>Class of Engine: Cryogenic Liquid          | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Total Mass w/TVC 4,050.0<br>Total Mass w/TVC 50.0                                           | TVC       Gimbal         Method       Gimbal         Mass (lbm)       Image: Comparison of the second |
| Engine Cycle<br>Type Tap-Off Turbine Drive                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Oxidizer Turbopump<br>Min Pump Inlet 19.5<br>Turbine Inlet 115.0<br>Pressure                | Fuel Turbopump<br>Min Pump Inlet 4.4<br>Turbine Inlet 1,021.0<br>es in psia                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Envelope<br>Length<br>Nominal 133<br>Stowed Extended Extended Maximum Gimbai Envelope Dimer | Diameter         Nozzie Exit       80.0         Maximum       80.0         Maximum Gimbal       116.0         nsions in inches       80.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Engine Component Masses                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

# Start-Up/Shutdown Sequences

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid

Chemical

StartUp Sequence

Shutdown Sequence

### Start-Up/Shutdown Profiles

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid

Chemical

----- Thrust Profile=-

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# Start-Up/Shutdown Profiles

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid

Chemical

Isp Profile

| Mixture Ratio Profile |   |  |
|-----------------------|---|--|
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|                       | - |  |

#### March 7, 1993

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### Interfaces

 Engine Name:
 Simplified, High Performance J-2

 Class of Engine:
 Cryogenic Liquid



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### **Technology Development**

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid

Chemical

Technology Development

# Advanced Development Plan

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid

Chemical

Advanced Development Plan=

March 7, 1993

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Figure 78.

# Output for Space Shuttle Main Engine (SSME) Propulsion System

SSME Propulsion System



| Nominal Thrust (lbf) | 375,004<br>469,000                                                 | 362.5<br>453.3                                  | 3,028                                          | 6.011                | 77.50           | 168.00      | 6,979        |
|----------------------|--------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------|----------------------|-----------------|-------------|--------------|
|                      | Nominal Thrust (Ibf) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Specific Impulse (sec)     Sea Level     Vacuum | Chamber Pressure (psia)<br>(Nozzle Stagnation) | Engine Mixture Ratio | Expansion Ratio | Length (in) | Weight (Ibm) |



**Advanced Propulsion Subsystem Concepts Database** 



2/22/93

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#### Eebruary 22, 1993

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### **Background Information**

| Engine Name:                                                                                                                                                                         | S                                                                | Spa                                              | ce Shu                                                                          | ttle Ma                                                                           | ain Eng                                                                                         | ine                                                                                             |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------|
| Class of Engin                                                                                                                                                                       | <b>e:</b>                                                        | (                                                | Cryoge                                                                          | nic Liq                                                                           | uid                                                                                             |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 | Chei                                                                      | nical                                                                               |                                                                               |                                                                           |                                                                 | <u> </u>                                                             |                                                                          |                      |
| - Background                                                                                                                                                                         |                                                                  |                                                  |                                                                                 |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       | -<br>                                                                        |                                                                                 |                                                                           | _                                                                                   |                                                                               | _                                                                         | _                                                               |                                                                      |                                                                          | <u>ننی</u>           |
| The Space Shuttle I<br>thrust. They are ign<br>phase of the Space<br>engines has an expa<br>thrust range of 65 t<br>provides a higher th<br>to be kept within d<br>phases. Gaseous h | Main<br>nited<br>Trar<br>ansic<br>o 10<br>arust<br>esign<br>ydro | Er<br>lon<br>nspon<br>9 p<br>lev<br>n lin<br>gen | ngines (<br>the grootation<br>atio of<br>ercent<br>rel duri<br>mits. T<br>and o | SSME<br>ound at<br>System<br>77.5:1<br>of the ong<br>lift-4<br>The eng<br>xygen a | 's) are re<br>a launch<br>m, and c<br>and ope<br>design t<br>off and t<br>ines are<br>are tappe | eusable,<br>and ope<br>continue<br>erates at<br>hrust lev<br>the initia<br>gimbal<br>ed off the | high p<br>erate in<br>a to ope<br>a mix<br>vel (rat<br>al asce<br>ed to p<br>e engin | perform<br>n paral<br>erate for<br>ture ra<br>ted por<br>nt phas<br>provide<br>ne for | nance<br>lel wi<br>or a n<br>tio of<br>wer le<br>se and<br>e pitcl<br>pressu | , liqu<br>th the<br>omin<br>6:1.<br>:<br>evel, l<br>i allow<br>h, yaw<br>urizin | id-pro<br>e solid<br>al 500<br>The e<br>RPL -<br>ws ort<br>w and<br>g the | pellan<br>I rocke<br>) secor<br>ngines<br>- 469,0<br>piter ac<br>roll co<br>externa | t rock<br>t boos<br>ads tot<br>are c<br>000 lb<br>celera<br>ontrol<br>al tank | et eng<br>sters c<br>al firi-<br>ontinu<br>f vacu<br>tions<br>durin<br>x. | gines<br>luring<br>ing tin<br>uously<br>uum t<br>and c<br>g the | with v<br>g the ir<br>me. E<br>y throt<br>hrust).<br>dynam<br>orbite | ariable<br>nitial as<br>ach of<br>tleable<br>This<br>ic press<br>r boost | cen<br>the<br>ove    |
| A staged combustion<br>combustion cycle,<br>completely burned<br>Hydrogen fuel is u<br>products. An elect                                                                            | on p<br>prop<br>at hi<br>sed t<br>roni                           | ow<br>ella<br>igh<br>io c<br>c ei                | er cyclo<br>ants are<br>temper<br>ool all<br>ngine c                            | e coupl<br>partial<br>ature a<br>combus<br>ontrolle                               | ed with<br>lly burne<br>nd press<br>stion de<br>er auton                                        | high con<br>ed at hig<br>sure in the<br>vices co<br>natically                                   | mbusti<br>gh pres<br>he mai<br>ompone<br>perfor                                      | ion cha<br>sure a<br>in char<br>ents w<br>rms ch                                      | amber<br>nd rel<br>nber t<br>hich a<br>heckou                                | r press<br>ativel<br>before<br>tre dir<br>ut, sta                               | sures<br>ly low<br>e expa<br>rectly<br>art, ma                            | is emp<br>tempo<br>inding<br>expose<br>instag                                       | loyed<br>erature<br>throug<br>ed to l<br>e, and                               | . In t<br>in the<br>gh the<br>nigh to<br>engin                            | he SS<br>he pre<br>high<br>empe<br>ne shu                       | ME st<br>burner<br>area r<br>rature<br>utdown                        | taged<br>rs, then<br>ratio no<br>combu<br>n funct                        | zzle<br>stio<br>ions |
| Input Notes:<br>The performance c                                                                                                                                                    | hara                                                             | cte                                              | ristics                                                                         | given h                                                                           | ere are f                                                                                       | for the F                                                                                       | light-F                                                                              | Phase I                                                                               | lI Con                                                                       | figur                                                                           | ation.                                                                    |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| Demonstrated life<br>(HPFTP) and the l<br>components. For t<br>seconds. For the H                                                                                                    | – Tł<br>nigh<br>he H<br>POJ                                      | ne n<br>pre<br>IPF<br>IP,                        | umber<br>ssure o<br>TP, 95<br>83% o                                             | of seco<br>xidizer<br>% of th<br>f the co                                         | onds sho<br>turbop<br>e comp<br>omponer                                                         | own repr<br>ump (Hl<br>onents h<br>nts have                                                     | resent a<br>POTP)<br>have be<br>been o                                               | all the<br>). The<br>een de<br>demon                                                  | comp<br>numi<br>monsi<br>strate                                              | oonen<br>ber is<br>trated<br>d for                                              | ts exc<br>for th<br>for 1<br>15,00                                        | ept the<br>lease<br>5,000<br>0 seco                                                 | high<br>demo<br>secon<br>nds au                                               | press<br>onstra<br>ds and<br>nd the                                       | ure fu<br>ted ti<br>d the<br>rest                               | nel turl<br>me am<br>rest fo<br>for 10,                              | bopum<br>10ng th<br>10,00<br>,000 se                                     | p<br>ose<br>Ю<br>con |
| LPFTP - low pr                                                                                                                                                                       | essu                                                             | re f                                             | uel tur                                                                         | oopum                                                                             | р                                                                                               |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| HPFTP – high p                                                                                                                                                                       | ressi                                                            | ure<br>re (                                      | fuel tu<br>widize                                                               | rbopun<br>r turboi                                                                | np<br>numo                                                                                      |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| HPOTP - high n                                                                                                                                                                       | ress                                                             | ure                                              | oxidiz                                                                          | er turbo                                                                          | opump                                                                                           |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| MFV – main fue                                                                                                                                                                       | l va                                                             | lve                                              |                                                                                 |                                                                                   | •                                                                                               |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| MOV – main ox                                                                                                                                                                        | idize                                                            | er v                                             | alve                                                                            |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| FPOV – fuel pre                                                                                                                                                                      | burn                                                             | ler (                                            | oxidize                                                                         | r suppl                                                                           | y vaive                                                                                         | alve                                                                                            |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| OPOV = oxidize                                                                                                                                                                       | r pre<br>miti                                                    | rol                                              | valve                                                                           |                                                                                   | աթթոյ                                                                                           | uive                                                                                            |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| FBV – fuel bypa                                                                                                                                                                      | ISS V                                                            | alv                                              | e                                                                               |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| OBV – oxidizer                                                                                                                                                                       | ьура                                                             | ass                                              | valve                                                                           |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| MCC – main co                                                                                                                                                                        | mbu                                                              | isti                                             | on chai                                                                         | nber                                                                              |                                                                                                 |                                                                                                 | _                                                                                    |                                                                                       | _                                                                            |                                                                                 |                                                                           | _                                                                                   |                                                                               | _                                                                         |                                                                 |                                                                      |                                                                          |                      |
| Comments-                                                                                                                                                                            | _                                                                |                                                  |                                                                                 |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       | _                                                                            |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           | _                                                               |                                                                      |                                                                          | <u>الم</u>           |
| No Comments.                                                                                                                                                                         |                                                                  |                                                  |                                                                                 |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
|                                                                                                                                                                                      |                                                                  |                                                  |                                                                                 |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |
| 1                                                                                                                                                                                    |                                                                  |                                                  |                                                                                 |                                                                                   |                                                                                                 |                                                                                                 |                                                                                      |                                                                                       |                                                                              |                                                                                 |                                                                           |                                                                                     |                                                                               |                                                                           |                                                                 |                                                                      |                                                                          |                      |

RI / RD87-142, CPIA/M5 (Oct 1985), Space Shuttle Obios Volisio, Julia Ingine Main Engine Pocket Data (RSS-8559-10. Document (ICD-13M15000, Rev. "V"), Space Shuttle Main Engine Pocket Data (RSS-8559-10.

6-1-1991,10/85,13 July 1989, 22 August 1984 Date: Entered by: J. A. McClanahan, Dan Levack

March 30, 1993

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**Propulsion System General Data** 

| Creation Date Modification Da                                                                                             | te Record Number                                                                                                                                                                                                                                  |  |
|---------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| 4/20/92 3/29/93                                                                                                           | ] [ <sup>1</sup> ]                                                                                                                                                                                                                                |  |
| Engine Name<br>Class of Engine<br>Propulsion Type<br>Acronym<br>Application<br>Manufacturer<br>Program Status<br>Manrated | Space Shuttle Main Engine         Cryogenic Liquid       Chemical         Thermodynamic Expansion of Hot Gas         SSME         ETO         Rockwell International Corporation         Space Transportation System, 4 Orbiter Fleet         Yes |  |
| IOC/Date Studied (Month/Year)                                                                                             | 6.011 6.034                                                                                                                                                                                                                                       |  |
| Propellants<br>Oxidizer Liquid Oxygen<br>Fuel Liquid Hydrogen                                                             |                                                                                                                                                                                                                                                   |  |
| Engine Design Life (Flights)<br>Restart Capability<br>Engine Cycle<br>Nominal Chamber Pressure                            | 550 Staged Combustion 3,028                                                                                                                                                                                                                       |  |
| Expansion Ratio<br>TVC Method                                                                                             | 77.50<br>Gimbal                                                                                                                                                                                                                                   |  |
| Dimensions<br>Maximum Length (inches)<br>Maximum Width (inches)<br>Engine Mass (ibm)                                      | 168.00<br>90.00<br>6,979.00                                                                                                                                                                                                                       |  |
| Engine Thrust Data, Ibf                                                                                                   | Sea Level <u>Vacuum</u>                                                                                                                                                                                                                           |  |
| Nominal C                                                                                                                 | 375,004     469,000       418,304     512,300                                                                                                                                                                                                     |  |

| Enaine | Performance | 1 |
|--------|-------------|---|
|--------|-------------|---|

| Engine Name: Space Shuttle Main Engine<br>Class of Engine: Cryogenic Liquid                                                                   | Chemical                                                                        |
|-----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Propellants Liquid Oxygen Oxidizer Fuel Mixture Ratio – Engine/Thrust Chamber 6.011                                                           | 6.034                                                                           |
| Nominal Chamber Pressure (psia)3,028Expansion Ratio77.50Engine Design Life (Flights)55                                                        | Engine Restarts<br>Design 0<br>Demonstrated 0                                   |
| Engine Thrust Data<br>Sea Level Vacuum<br>Nominal 375,004 469,000<br>Maximum 418,304 512,300                                                  | Engine Starts<br>Design 55<br>Demonstrated 27,000                               |
| Minimum 209,204 303,200<br>Thrust data in units of lbf                                                                                        | Engine Reliability, sec<br>Design 27,000<br>Demonstrated 37,000                 |
| Sea Level         Vacuum           Maximum         111.30         109.00           Minimum         56.10         65.00                        | Nozzie Data<br>Type Bell, Tubular Wall                                          |
| Specific Impulse Data<br>Sea Level Vacuum                                                                                                     | Length (in) 121.00                                                              |
| @Nominal Thrust       362.45       453.30         @Maximum Thrust       370.37       453.60         @Minimum Thrust       311.94       452.10 | Throat Area (sq. in)         83.40           Exit Area (sq. in)         6,463.5 |
| Specific Impulse data in units of seconds                                                                                                     | Expansion Ratio 77.50                                                           |

March 13, 1993

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### Engine Performance 2

February 22, 1993

| Class of Engine: Cryogenic Liquid                                                                                                                                   | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Engine Mass (Ibm)<br>Total Mass w/TVC 6,979.0<br>Total Mass wo/TVC                                                                                                  | Method Gimbal<br>Mass (Ibm)<br>Max Gimbal Angle (deg) 1<br>Max Gimbal Rate (deg/s) 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Engine Cycle         Type       Staged Combustion         Pressures       Oxidizer Turbopump         Min Pump Inlet       4,924.         Turbine Inlet       4,924. | Fuel Turbopump<br>Min Pump inlet<br>Turbine inlet 4,932.0<br>ressures in psia                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Envelope<br>Length<br>Nominal<br>Stowed<br>Extended<br>Maximum Gimbal<br>Envelope                                                                                   | 168       Diameter         168       Nozzle Exit       90.7         Maximum       94.0         Maximum Gimbai       153.0         e Dimensions in inches       1000000000000000000000000000000000000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Extended<br>Maximum Gimbai<br>Envelope<br>Engine Component Masses                                                                                                   | Analysis and Controls and Contr |

### February 20, 1993 Start-Up/Shutdown Sequences



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### Start-Up/Shutdown Profiles



### February 22, 1993 Start-Up/Shutdown Profiles



#### February 22, 1993

Interfaces



#### February 22, 1993

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### **Technology Development**

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid

Chemical

Technology Development

### Advanced Development Plan

| Engine Name:     | Space Shuttle Main Engine |
|------------------|---------------------------|
| Class of Engine: | Cryogenic Liquid          |

Chemical



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March 27, 1993

Figure 79.

# Output for RD-170 Propulsion System

RD-170 Propulsion System



| 1,630,545<br>1,776,926                                             | 309.2<br>337.0                                  | 3,556                                          | 2.630                | 36.80           | 158.00      | 23,507       |
|--------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------|----------------------|-----------------|-------------|--------------|
| Nominal Thrust (Ibf) <ul> <li>Sea Level</li> <li>Vacuum</li> </ul> | Specific Impulse (sec)     Sea Level     Vacuum | Chamber Pressure (psia)<br>(Nozzle Stagnation) | Engine Mixture Ratio | Expansion Ratio | Length (in) | Weight (Ibm) |
|                                                                    |                                                 |                                                |                      |                 |             | •            |

Advanced Propulsion Subsystem Concepts Database



2/20/93



2/22/93

# Background Information

| Engine Name:                                                        | RD-170                                                                                                              |                                                                                                                                                 |
|---------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Class of Engine:                                                    | Hydrocarbon Liquid                                                                                                  | Chemical                                                                                                                                        |
| Background —                                                        |                                                                                                                     |                                                                                                                                                 |
| The RD-170 is the most booster on the Energyia 4-combustion chamber | t powerful rocket engine currently in<br>heavy-lift launcher and (in the RD-<br>engine driven by a single turbopump | production anywhere in the world, and it is used as the strap-on<br>171 variant) on the first stage of the Zenit launcher. It is a<br>assembly. |
| Engine development wa<br>1985. The first flight o                   | as started in 1976 and the first flight<br>f the RD-170 occurred in May 1985                                        | of the RD-171 occurred during the first launch of a Zenit booster in as the booster engine on Energiya.                                         |
| The West is aware of tw<br>occurred in the fall of 1                | vo successful unmanned Energiya lau<br>990, which is believed to be related t                                       | inches, and one flight failure of a Zenit launcher is known to have o a failure of the RD-171 engine.                                           |
| Reference Sources:                                                  |                                                                                                                     |                                                                                                                                                 |
| 1. "RD-170Super Pov                                                 | vered Liquid Propellant Rocket Engi                                                                                 | ne of New Generation", by F. Chelkis, obtained September 1990.                                                                                  |
| 2. "The RD-170 Liquid                                               | Rocket Engine", NPO Energomash                                                                                      | publication, undated.                                                                                                                           |
| 3. Letter, F. Chelkis to                                            | W. Ezell, August 28, 1991.                                                                                          |                                                                                                                                                 |
| 4. Technology Detail S<br>Kingsway North, Clifto                    | Special Report 2, "USSR Rocket Eng<br>on, York YO3 6JH, United Kingdom                                              | ines, second edition", January 1992, by Technology Detail, 99                                                                                   |
|                                                                     |                                                                                                                     |                                                                                                                                                 |
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|                                                                     |                                                                                                                     |                                                                                                                                                 |
|                                                                     |                                                                                                                     |                                                                                                                                                 |
|                                                                     |                                                                                                                     |                                                                                                                                                 |
| Comments                                                            |                                                                                                                     |                                                                                                                                                 |
|                                                                     |                                                                                                                     |                                                                                                                                                 |
|                                                                     |                                                                                                                     |                                                                                                                                                 |
|                                                                     |                                                                                                                     |                                                                                                                                                 |
| Source:                                                             | See "Engine Background"                                                                                             |                                                                                                                                                 |
| 1                                                                   |                                                                                                                     |                                                                                                                                                 |
| Date:                                                               | Jim Glass                                                                                                           |                                                                                                                                                 |

March 30, 1993

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**Propulsion System General Data** 

| Creation Date Modification D           | Date Record Number                         |  |  |  |
|----------------------------------------|--------------------------------------------|--|--|--|
| 3/29/93                                | 7                                          |  |  |  |
| Engine Name                            | RD-170                                     |  |  |  |
| Class of Engine                        | Hydrocarbon Liquid Chemical                |  |  |  |
| Propuision Type                        | Thermodynamic Expansion of Hot Gas         |  |  |  |
| Acronym                                | RD-170 (Russian Designation 11D521)        |  |  |  |
| Application                            | Booster Engine for Energiya                |  |  |  |
| Manufacturer                           | NPR Energomash                             |  |  |  |
| Program Status                         | Two successful flights, one flight failure |  |  |  |
| Manrated                               | Yes (but not yet flown manned)             |  |  |  |
| IOC/Date Studied (Month/Year)          | May 1987                                   |  |  |  |
| Mixture Ratio – Engine/ Thrust Chamber | 2.630                                      |  |  |  |
| Propellants                            |                                            |  |  |  |
|                                        |                                            |  |  |  |
|                                        |                                            |  |  |  |
| Engine Design Life (Filghts)           | 10                                         |  |  |  |
| Restart Capability                     |                                            |  |  |  |
| Engine Cycle                           | Staged Combustion                          |  |  |  |
| Nominal Chamber Pressure               | 3,556                                      |  |  |  |
|                                        |                                            |  |  |  |
| Expansion Ratio                        | 36.80                                      |  |  |  |
| TVC Method                             | Gimbal                                     |  |  |  |
| Dimensions                             | 158.00                                     |  |  |  |
| Maximum Length (inches)                | 130.00<br>56.20                            |  |  |  |
| Maximum Width (inches)                 | 56.30                                      |  |  |  |
| Engine Mass (lbm)                      | 23,507.00                                  |  |  |  |
| - Engine Thrust Data Ibf               |                                            |  |  |  |
| S                                      | Sea Level Vacuum                           |  |  |  |
| Nominal                                | 1,630,545 1,776,926                        |  |  |  |
| Maximum                                | 1,719,391 1,865,772                        |  |  |  |
| Minimum                                | 742,082 888,463                            |  |  |  |
|                                        |                                            |  |  |  |

March 13, 1993

**Engine Performance 1** 

| Engine Name: RD-170                         |                                      |
|---------------------------------------------|--------------------------------------|
| Class of Engine: Hydrocarbon Liquid         | Chemical                             |
| - Propellants                               |                                      |
| Oxidizer Liquid Oxygen                      |                                      |
| Fuel Kerosene                               |                                      |
| Mixture Ratio – Engine/Thrust Chamber 2.630 |                                      |
| Nominal Chamber Pressure (psia) 3,556       | Engine Restarts                      |
| Expansion Ratio 36.80                       | Design                               |
| Engine Design Life (Flights) 10             | Demonstrated 0                       |
| Engine Thrust Data                          |                                      |
|                                             | Engine Starts                        |
| Nominal 1,830,943                           | Design 10                            |
| Maximum 1,719,391 1,865,772                 | Demonstrated 19                      |
| Minimum 742,082 888,463                     |                                      |
| Thrust data in units of lbf                 | Engine Reliability, sec              |
|                                             | Design                               |
| Throttle Ratio, Percent                     | Demonstrated 2,567                   |
| Maximum 105.00                              |                                      |
| Minimum 49.00                               | Type Boll with beliest slotted liner |
| - Specific Impulse Data                     | Type Ben with hencer slotted inter   |
| Sea Level Vacuum                            | Length (in) 70.00                    |
| @Nominal Thrust 309.24 337.00               | Diameter (In) 112.60                 |
| @Maximum Thrust                             | Throat Area (sq. in) 270.60          |
| @Minimum Thrust                             | Exit Area (sq. in) 9,958.08          |
| Specific Impulse data in units of seconds   | Expansion Ratio 36.80                |

#### February 20, 1993

Engine Performance 2

| - Engine Mass (Ibm)                                                                          | TVC                                                                     |
|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Total Mass w/TVC23,507.0Total Mass wo/TVC140.4                                               | Method Gimbal Mass (Ibm) Max Gimbal Angle (deg) Max Gimbal Rate (deg/s) |
| Engine Cycle         Type       Staged Combustion         Pressures       Oxidizer Turbopump | <br>- Fuel Turbopump                                                    |
| Min Pump Inlet 92.45<br>Turbine Inlet Pressures in                                           | Ain Pump Inlet 34.1                                                     |
| Envelope<br>Length<br>Nominal 158<br>Stowed Extended Maximum Gimbal                          | - Diameter<br>Nozzle Exit 56.3<br>Maximum Maximum Gimbal                |
| Envelope Dimensions                                                                          | in inches                                                               |

# February 20, 1993 Start-Up/Shutdown Sequences

Engine Name: RD-170 Class of Engine: Hydrocarbon Liquid Chemical StartUp Sequence

Shutdown Sequence

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#### February 20, 1993

### Start-Up/Shutdown Profiles

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid

Chemical

- Thrust Profile

| = Flowrate Profile |  |
|--------------------|--|
|                    |  |
|                    |  |

#### February 20, 1993

# Start-Up/Shutdown Profiles

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid

Chemical



| Mixture R | latio Profile |  |      |
|-----------|---------------|--|------|
|           |               |  |      |
|           |               |  |      |
|           |               |  |      |
|           |               |  |      |
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|           |               |  |      |
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|           |               |  |      |
|           |               |  | <br> |
|           |               |  |      |

#### February 22, 1993

Interfaces

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### Interfaces

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid

Chemical

| Personalar                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Value                                          | Value                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Note                                           | English                                       |
| Vecuum Privat                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 301.4 tennes form                              | 444,447.4 BH *                                |
| Chamber pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 200 lights am                                  | 3,000.04 pain                                 |
| Cooland Intel pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 400 kg/kg am                                   | 6,973.00 pers                                 |
| California (CC) consumption<br>Fund discovery contestigation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 164.76 light per chamber                       | 363.21 BA                                     |
| Consumption ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                | T M Bank as h                                 |
| Abeshile                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                | COLUMN AND AND AND AND AND AND AND AND AND AN |
| The second secon | 3.304.84 N-a/g                                 | 337.0 eesende *                               |
| Nogzie arte ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 38.8448 (dash rate 6.07)                       |                                               |
| Chamber height                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 2,400 mm                                       | 97.09 Inch                                    |
| Nagzie auf diemeter                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                | 1000.21 m                                     |
| Chamber mass                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                |                                               |
| Cubitar pump discharge pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | and lighting, and                              | 8,246.17 pain                                 |
| Fuel pump decharge pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | CCD lugitus, con                               | 7,111.67 pela<br>11.378 7 min                 |
| Rat putte discharge protoure<br>Challen curte ficeraie                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 1,734 hg/s (4 chambars)                        | 3,622.75 MA                                   |
| Fuel purch flowrete                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | elle tigts (4 stambers)                        | 1.482.83 846 *                                |
| IGoli pump flowrate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 30 hg/s (4 sharebore)                          | 66.14 B/6                                     |
| Turbino iniat temporature<br>Turbino pressure ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 880 C<br>1.89                                  | 1427.7 M                                      |
| Turbine efficiency                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9.82                                           |                                               |
| Custom pump eliciency                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 0.74                                           |                                               |
| Fuel pump efficiency                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 100,000,000                                    | 254 784 14                                    |
| ND-119- Hand - Provide Links - Constant And<br>Industrial by - Revision Salary dam provides 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | n manar al 20 August 1991 Yan Path Chube Is W. | Parturi                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                |                                               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                |                                               |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Value                                                            | Value                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Metric                                                           | English                            |
| tembrai son-loval Bruzi                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 740 tannas laras (4 chambarn)                                    | 1,831,404 10                       |
| tenting vanues thrutt                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 808.4 tonnes force (4 chatters)<br>Mit income force (6 chatters) | 1,777,798,4 bit *<br>873,081,4 bit |
| tembrai qui-off Privat<br>tembrai ann-ievel penetite impulse                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 3,000.2 M-eAu                                                    | 309.3 seconds*                     |
| interiori adalario callo                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 2.83 (provincelly qualed @ 2.63)                                 | 2.63*                              |
| tening as of charter pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 6.73 halfes, cm                                                  | 10.365 pein                        |
| analise alle en presiden<br>Secular Alle tre                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 181 extends                                                      |                                    |
| iry angine mass (verticus versions)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 10,700 10 12,175 MgF                                             | 23,000 to 24,041 %<br>105,07 Inch  |
| falsi angina langin<br>Ingina asit disessi (4 shumbard)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 3,005 mm                                                         | 140.36 Inch                        |
| and the state of the second seco | 8.7 to 7.1 hydrog, and prominal 0.0)                             | 01.07 to 100.50 pois current 12.48 |
| Apericant fuel intet static pressure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 3.3 to 4.5 toples, an (nominal 3.4)                              | 48.84 to 86.43 pain pureau 34.14*  |
| iteningi addaar isist temperatura<br>iteningi kuli isist temperatura                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | -160 C (256.16 K)<br>-16 C (256.16 K)                            | 464.67 8                           |
| iladmum gimbal angle                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | plus or minus & degrees                                          |                                    |
| istum battle volume (prournatic controls)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 100 Blanc                                                        | 5 66 outic heat                    |
| taken balla pressure (prouvalle controle)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 235 halfes, om                                                   | 3,128.1 peik                       |
| insine service ille                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 10 Rights                                                        |                                    |
| Ergina ralability                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.000                                                            |                                    |
| ا التقادي بلغة ستابة ومتقامة. وطعت بالمسلب و                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | inder af 28 August 1991 han Falk Chalds ta                       |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | -                                                                | Partesi 08-88-1881 JPC             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                  |                                    |
### February 20, 1993

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## **Technology Development**

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid

Chemical

- Technology Development=

#### February 20, 1993

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### **Advanced Development Plan**

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid

Chemical

Advanced Development Plan

Figure 80.

# Output for Advanced LOX/H2 Engine (IME) Propulsion System

IME Propulsion System



87.70

6.000

246.3 480.0

15,393 30,000 1,746

700.00

1,048

3/27/93

**Advanced Propulsion Subsystem Concepts Database** 



3/18/93

Advanced Propulsion Subsystem Concepts Database 15 ÷---Chemical X Lox :: Integrated Modular Engine R. MCOOLANT X Į. **Cryogenic Liquid** LHZ Erghe h M 肉 Class of Engine: Engine Name:

3/13/93

**.**\_\_\_\_

### **Background Information**

| Engine Name:     | Integrated Modular Engine |          |
|------------------|---------------------------|----------|
| Class of Engine: | Cryogenic Liquid          | Chemical |

#### Background

An Integrated Modular Engine system design was developed which meets Air Force National Launch System Upper Stage design requirements. The resulting Integrated Modular Engine (IME) is a 30,000 lb thrust LO2/LH2 propulsion system powered by a hybrid expander cycle using three bell thrust chambers and two turbopump sets. The modular design is adaptable to a wide range of applications via adding additional thrust chamber and turbopump modules. The propulsion system attributes include enhanced performance, operability, and reliability. Specific impulse performance is 480 seconds vacuum. Propulsion system launch operability is enhanced as the system requires loading only two fluids on the pad: LO2 and LH2. Reliability improvements include a simple design with no pneumatics, hydraulics or helium purges and a backup turbopump module. In addition, gaseous hydrogen and oxygen for tank pressurization could also be used to supply small GH2 and GO2 RCS thrusters, eliminating the need for a storable propellant (hydrazine) RCS system on the stage.

Quality Function Deployment methodology was used to refine propulsion requirements, evolve design strategies and develop an exceptionally capable propulsion system. The IME study identified technology programs, described risks and minimization via backup positions and presented a cost effective development program. Engine average unit cost is estimated to be about \$2.6M and a development program cost is estimated to be about \$45M.

#### - Comments

No Comments.

References Source:

e: RI/RD92-134 (Operational Integrated Modular Engine Study)

Date: 3-4-93

Entered by: T. J. Harmon

March 30, 1993

-

**Propulsion System General Data** 

| Creation Date Modification Da                                                                         | ate                               | Record Number                                                             |
|-------------------------------------------------------------------------------------------------------|-----------------------------------|---------------------------------------------------------------------------|
| 12/11/92 3/29/93                                                                                      | ]                                 | 8                                                                         |
| Engine Name<br>Class of Engine<br>Propulsion Type                                                     | Integrate<br>Cryogenic<br>Thermod | ted Modular Engine<br>hic Liquid Chemical<br>dynamic Expansion of Hot Gas |
| Acronym<br>Application<br>Manufacturer                                                                | IME<br>Air Force<br>Conceptu      | e Upper Stage<br>tual Engine (Rocketdyne Study)                           |
| Program Status<br>Manrated<br>IOC/Date Studied (Month/Year)<br>Mixture Ratio – Engine/ Thrust Chamber | Study: R                          | RI/RD90-134       1992       6.000                                        |
| Propellants<br>Oxidizer Liquid Oxygen<br>Fuel Liquid Hydrogen                                         |                                   |                                                                           |
| Engine Design Life (Flights)<br>Restart Capability<br>Engine Cycle<br>Nominal Chamber Pressure        | 1<br>3<br>Hybrid: I               | Fuel Side Expander, Oxid Side Preburner                                   |
| Expansion Ratio                                                                                       | Different                         | 700.00<br>ntial Throttling                                                |
| Maximum Length (Inches)<br>Maximum Width (Inches)<br>Engine Mass (Ibm)                                |                                   | 87.70<br>136.00<br>1,048.00                                               |
| Engine Thrust Data, ibf                                                                               | Sea Leve                          | ei <u>Vacuum</u>                                                          |
| Nominal                                                                                               | 15,393                            | 93 30,000                                                                 |
|                                                                                                       |                                   | [                                                                         |

March 13, 1993

**Engine Performance 1** 

| Propellants         Oxidizer       Liquid Oxygen         Fuel       Liquid Hydrogen         Mixture Ratio – Engine/Thrust Chamber       6.000         Nominal Chamber Pressure (psia)       1,746         Expansion Ratio       700.00         Engine Design Life (Flights)       1         Engine Thrust Data       1         Nominal       15,393         Maximum       1         Minimum       1         Thrust data in units of lbf       0         D       Sea Level       Vacuum  | agine Restarts                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| Nominal Chamber Pressure (psia)       1,746         Expansion Ratio       700.00         Engine Design Life (Flights)       1         Engine Thrust Data       1         Nominal       15,393         Maximum       1         Minimum       1         Thrust data in units of lbf       0         Throttle Ratio, Percent       Yacuum         Vacuum       1         Vacuum       0         Maximum       0         Thrust data in units of lbf       0         Desceries       Vacuum | ngine Restarts<br>nsign 3<br>monstrated        |
| Sea Level       Vacuum         Nominal       15,393       30,000         Maximum                                                                                                                                                                                                                                                                                                                                                                                                        |                                                |
| Thrust data in units of ibi<br>D<br>Throttle Ratio, Percent<br><u>Sea Level</u> <u>Vacuum</u>                                                                                                                                                                                                                                                                                                                                                                                           | igine Starts<br>sign 3<br>monstrated 9         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | emonstrated 2,200 cozzle Data                  |
| Specific Impulse Data       Image: Specific Impulse Data         Specific Impulse Data       Image: Specific Impulse Data         @Nominai Thrust       Image: Specific Impulse Data         @Maximum Thrust       Image: Specific Impulse Data         Specific Impulse Data       Image: Specific Impulse Data                                                                                                                                                                        | Solution     State       ameter (in)     35.57 |

# Engine Performance 2

March 7, 1993

| Engine Name: Integrated Modular Engine<br>Class of Engine: Cryogenic Liquid                                                                                                                                                         | Chemical                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Engine Mass (Ibm)<br>Total Mass w/TVC 1,048.0<br>Total Mass wo/TVC<br>Engine Cycle<br>Type Hybrid: Fuel Side Expander, Oxid Side Pr<br>Pressures<br>Oxidizer Turbopump<br>Min Pump Inlet 19.8<br>Turbine Inlet 4,843.0<br>Pressures | TVC         Method       Differential Throttling         Mass (lbm)                                                       |
| Envelope<br>Length<br>Nominal 87.7<br>Stowed 87.7<br>Extended 87.7<br>Maximum Gimbal 87.7<br>Envelope Dimen                                                                                                                         | Diameter<br>Nozzle Exit 136.0<br>Maximum 136.0<br>Maximum Gimbal 136.0                                                    |
| Engine Component MassesComponent Mass. lbmThrust Chambers (3)502Turbomachinery – High Pressure (4)102Turbomachinery – Low Pressure (4)28Propellant Valves, Ducts, Flanges211External LH2 Feed Line20Thrust Mount Cap3               | Preburner (2)29GOX Heat Exchanger (2)5Controller24Harness and Sensors13Ignition System14Misc Components and Contingency97 |

# 3 Start-Up/Shutdown Sequences

| Engine Name:     | Integrated Modular I | Engine                                                                                                                       |
|------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------|
| Class of Engine: | Cryogenic Liquid     | Chemical                                                                                                                     |
| StartUp Sequence |                      | Chamber Pressure<br>75 ms ec<br>Oxygen Injection Pressure<br>Ox Valve Open<br>Hydrogen Injection Pressure<br>Fuel Valve Open |
| Shutdown Sequen  | Ce                   |                                                                                                                              |

# Start-Up/Shutdown Profiles

Integrated Modular Engine Engine Name:

Class of Engine: Cryogenic Liquid Chemical

Thrust Profile

Flowrate Profile

#### March 7, 1993

# Start-Up/Shutdown Profiles

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid

Chemical

Isp Profile

| Mixture Ratio Profile |  |  |   |  |
|-----------------------|--|--|---|--|
|                       |  |  |   |  |
|                       |  |  |   |  |
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|                       |  |  |   |  |

### March 7, 1993

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### March 7, 1993

### Interfaces

| Engine Name:     | Integrated Modular Engine |          |
|------------------|---------------------------|----------|
| Class of Engine: | Cryogenic Liquid          | Chemical |
|                  |                           |          |



#### March 13, 1993

## **Technology Development**

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid

Chemical

| F                                    | Y | 1993 | 1994     | 1995            | 1996                                   | 1997               | 1998                    | 1999 | 2000 | 200 |
|--------------------------------------|---|------|----------|-----------------|----------------------------------------|--------------------|-------------------------|------|------|-----|
|                                      |   |      | /8<br>/8 | Test Bed<br>CDR | Fechnologies,<br>Test Bed<br>Completed | Comp<br>Tee<br>Com | onent<br>ling<br>lieted |      |      |     |
| · MILESTONES                         |   | 7    |          |                 | <b>∀</b>                               | 7                  | 7                       |      |      |     |
| • TECHNOLOGY                         |   |      |          | <u></u>         |                                        |                    |                         |      |      |     |
| (MATERIALS, PROCESSES, PARTS, COMP.) |   |      |          |                 |                                        |                    |                         |      |      |     |
| · TEST BED CONSTRUCTION              |   |      |          |                 |                                        |                    |                         |      |      |     |
| · COMPONENT TESTING IN TEST BED      |   |      |          |                 |                                        |                    | 1                       |      |      |     |
|                                      |   |      | /        | TECHNOLO        | GY PROGRAM                             | <u>├ヽ</u>          |                         |      |      |     |
|                                      |   |      | <u> </u> |                 | T                                      | <b>├</b> ──∕       |                         |      |      |     |
|                                      |   |      |          |                 | <u> </u>                               | C/D                | 1                       | 1    |      |     |



# Advanced Development Plan

Engine Name: integrated Modular Engine

Class of Engine: Cryogenic Liquid

March 7, 1993

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Chemical

Advanced Development Plan

Figure 81.

## Output for Space Shuttle Redesigned Solid Rocket Motor (RSRM) Propulsion System

**RSRM** Propulsion System



| 2,146,371<br>2,405,000                     | 238.7<br>267.5                                  | <b>a)</b> 612.1       | 123.4       | 7.72            | 1,513.4     | 1,255,979    |
|--------------------------------------------|-------------------------------------------------|-----------------------|-------------|-----------------|-------------|--------------|
| <ul><li>Sea Level</li><li>Vacuum</li></ul> | Specific Impulse (sec)     Sea Level     Vacuum | Chamber Pressure (psi | Action Time | Expansion Ratio | Length (in) | Weight (Ibm) |
|                                            | ٠                                               | •                     | ٠           | ٠               | •           | ٠            |



2/14/93

February 14, 1993

1

## **Background Information**

|                                                                                                                                                                                            | Calid Fuel                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Chemical                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Class of Engine:                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Background                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| The original design and develor<br>increase the performance in the<br>launched on the shuttle in Aug                                                                                       | opment of the SRM occurred during the early 1980s with the design referred gust of 1983 (STS-8). The design presented of the second sec | he mid-1970s and the first shuttle flight was in April 1981. Modifications were made to<br>it to as the high performance motor (HPM). The final configuration of the HPM was first<br>sented here commenced in mid-1986 and is referred to as the RSRM. It first flew in 1988.                                                                                                                                                                                                        |
| Marshall Space Flight Center<br>Space Operations is the contra<br>(USBI), Sunnyvale, California<br>plates, tunnel covers, and exte<br>Grumman) has the contract fo                         | (MSFC) has the overall management<br>actor responsible for the development<br>a, has responsibility for the SRB aft a<br>rmal tank (ET) attach ring, while the j<br>or the SRM and SRB assembly, check                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | responsibility for the design and procurement of the solid rocket boosters (SRB). Thiokol<br>and production of the SRMs, the major component of the SRB. United Space Boosters, Inc.<br>and forward skirt refurbishment and assembly, USBI also supplies systems tunnel floor<br>ioint venture of Lockheed Space Operations Company (composed of Lockheed, Thiokol, and<br>out, launch, recovery, and disassembly.                                                                    |
| The two SRMs on the Space<br>pad, the two SRBs support the<br>RSRM booster has a thrust (s<br>provide 71.4 percent of the th<br>vehicle. SRB apogee occurs 7<br>approximately 122 nmi (141 | Shuttle provide the main thrust to lif<br>e entire weight of the ET and orbiter<br>ea level) of 2.9 Mlb at launch. They<br>rust at liftoff and accelerate the shuttl<br>75 sec after SRB separation, at an alti<br>mi) down range.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | t the vehicle off the pad and up to an altitude of about 150,000 ft, 24 nmi (28 mi). On the<br>and transmit the weight load through their structure to the mobile launch platform. Each<br>are ignited after the three shuttle main engines total thrust level is verified. The two SRMs<br>e to approximately 3,100 mph before separating from the remainder of the shuttle launch<br>tude of 220,000 ft, 35 nmi (41 mi) down range. SRB impact occurs in the ocean                  |
| The SRMs are the largest soli<br>diameter. At launch, each we                                                                                                                              | id propellant motors ever flown and tighs 1,255,978 lb of which 88 percer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | the first designed for reuse. Each is 126.11 ft (1,513.38 in.) long and 12.16 ft (146.08 in.) in<br>it, 1,107.168 lb, is propellant. The boosters are designed to be used 20 times.                                                                                                                                                                                                                                                                                                   |
| Primary elements of each boo<br>instrumentation, recovery avi                                                                                                                              | oster are the motor (including case, pr<br>onics, pyrotechnics, deceleration syst                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | opellant, igniter, and nozzle), structure, separation systems, operational flight<br>em, thrust vector control system, and range safety destruct system.                                                                                                                                                                                                                                                                                                                              |
| Each booster is attached to th<br>forward end of the SRB forw<br>severed by small explosives a                                                                                             | e ET at the SRB's aft frame by two la<br>ard skirt. On the launch pad, each boo<br>at liftoff.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | ateral struts and a diagonal strut. The forward end of each SRB is attached to the ET at the oster also is attached to the mobile launch platform at the aft skirt by four bolts which are                                                                                                                                                                                                                                                                                            |
| The propellant mixture in eac<br>iron oxide (a burn rate cataly<br>(1.96 percent). The propellan<br>perforation (CP) grain in the<br>thrust at ignition, then reduce<br>pressure (Max Q).  | ch SRB motor consists of ammonium<br>st, approximately 0.3 percent), a poly<br>it is molded into an 11-point star-shap<br>aft portion of the forward segment. E<br>es the thrust by approximately one-th                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | perchlorate (oxidizer, approximately 69.7 percent by weight), aluminum (fuel, 16 percent),<br>mer (a binder that holds the mixture together, 12.04 percent), and an epoxy curing agent<br>wed perforation in the forward portion of the forward segment that transitions into a cylindrica<br>sach of the three aft segments have aft tapered CP grains. This configuration provides high<br>ird, 20 sec after liftoff to prevent overstressing of the vehicle during maximum dynamic |
| Each RSRM is made up of fu<br>transportation, and handling.                                                                                                                                | our solid rocket motor casting segme<br>Each segment is shipped to the laund                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | nts. The segmented design provides maximum flexibility in RSRM fabrication,<br>ch site on a heavy duty railcar with a specially built cover.                                                                                                                                                                                                                                                                                                                                          |
| The nozzle expansion ratio or<br>redundant auxiliary power un<br>erodes and chars during firin                                                                                             | of each booster is 7.72:1. The moveab<br>nits and hydraulic pumps. The omnidi<br>g. The nozzle is a convergent-diverge                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | the nozzle is gimbaled for thrust vector control (TVC) direction. Each SRB has its own irectional gimbaling capability is 8 deg. Each nozzle has a carbon cloth phenolic liner which ent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism.                                                                                                                                                                                                        |
| The cone-shaped aft skirt rea<br>mounted on the forward skirt<br>contained avionics and TVC                                                                                                | tets the aft loads between the SRB and<br>t provide the thrust and directional co-<br>system which consists of two auxilia                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | d the mobile launch platform. Eight separation motors, four mounted on the aft skirt and four<br>ntrol to clear the SRBs from the orbiter and external tank after booster separation. The aft ski-<br>try power units, hydraulic pumps, and hydraulic system.                                                                                                                                                                                                                         |
| Comments                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Source:                                                                                                                                                                                    | Design Data Book (DDB)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | for Space Shuttle Redesigned Solid Rocket Motor (RSRM) – (TWR-1688                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Date                                                                                                                                                                                       | 11/01/89                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                                                                                                                                                            | · · ·                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

1. 2. •

March 30, 1993

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**Propulsion System General Data** 

| Creation Date Modification D<br>8/31/92 3/29/93                                                                                                        | )ate                                                         | Record Number                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------------------------|
| [8/31/92]       [3/29/93]         Engine Name         Class of Engine         Propulsion Type         Acronym         Application         Manufacturer | Solid Fue<br>Solid Fue<br>Thermody<br>RSRM<br>ETO<br>Thiokol | huttle Redesigned Solid Rocket Motor<br>el Chemical<br>lynamic Expansion of Hot Gas |
| Program Status<br>Manrated<br>IOC/Date Studied (Month/Year)<br>Mixture Ratio – Engine/ Thrust Chamber<br>– Propellants                                 | Operation<br>Yes<br>1988                                     |                                                                                     |
| Oxidizer AP<br>Fuel Aluminum Powder<br>Engine Design Life (Flights)                                                                                    | 20                                                           |                                                                                     |
| Restart Capability<br>Engine Cycle<br>Nominal Chamber Pressure                                                                                         |                                                              | 612                                                                                 |
| Expansion Ratio<br>TVC Method                                                                                                                          | Gimbal                                                       | 7.72                                                                                |
| Maximum Length (inches)<br>Maximum Width (inches)<br>Engine Mass (ibm)                                                                                 | <br>1,25                                                     | 1,513.38<br>152.60<br>55,979.00                                                     |
| – Engine Thrust Data, Ibf                                                                                                                              | Sea Level                                                    | <u>Vacuum</u>                                                                       |
| Nominal                                                                                                                                                | 2,146,371                                                    | 1 2,405,000                                                                         |
| Minimum                                                                                                                                                |                                                              |                                                                                     |

### February 14, 1993

### **Motor Performance 1**

Engine Name:

(

Space Shuttle Redesigned Solid Rocket Motor

Chemical

178.75

149.67

2,278

7.72

19

Class of Engine: Solid Fuel

| ~ | 101 | 105 |
|---|-----|-----|
|   |     |     |
|   |     |     |
|   |     |     |

| <u>Material</u>          | Weight, Percent | Function           |                           |
|--------------------------|-----------------|--------------------|---------------------------|
| AP                       |                 |                    |                           |
| Aluminum Power           | 16              | Fuel               |                           |
| HB Polymer (PBAN)        | 12.04           | Binder             |                           |
| Epoxy Resin              | 1.96            | Curing Agent       |                           |
| Ferric Oxide (Fe2O3)     | 0.3             | Burn Rate Catalyst |                           |
|                          |                 |                    |                           |
|                          |                 |                    |                           |
|                          |                 |                    |                           |
| Motor Thrust, Ibf        | Sea Lo          | evel Vacuum        |                           |
| Maximum Expected O       | perating 3,34   | 8,371 3,607,000    |                           |
| Maximum Operating        | 3,05            | 5,3713,314,000     |                           |
| Burn Time Average        | 2,33            | 7,371 2,596,000    |                           |
| Action Time Average      | 2,14            | 6,371 2,405,00     | 0                         |
|                          |                 |                    |                           |
| Impulse, lot-sec         | <u>Sea L</u>    | evel <u>Vacuum</u> | _                         |
| Burn Time                | 260,85          | 289,713,60         | 9                         |
| Action Time              | 264,86          | 2,217 296,777,00   | 0                         |
| Throttle Ratio           | Magai           | Nozzle             | Data                      |
| <u>s</u>                 | ea Level Vacuu  | Type               | Bell – carbon phenolic ab |
|                          |                 |                    | Г                         |
|                          |                 |                    |                           |
| - Specific Impulse, sec- | bf/lbm          | Diameter (         | in)                       |
|                          | Sea Level Va    | cuum Throat Are    | a (sq. in)                |
| Burn Time Ava            |                 | Expansion          | Ratio                     |
|                          | 238.73          | 267.50             |                           |
| Action Lime Avg          | 200.70          |                    | nce nauo, percent         |

### February 22, 1993

## Motor Performance 2

| Class of Engine: Cold Full                                                                                                                                                                          |                                                                        |                                                                                                                                                                                                                                                                              |                                                                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| - Engine Mass (lbm)                                                                                                                                                                                 |                                                                        | Method Gimba                                                                                                                                                                                                                                                                 | 1                                                                                                        |
| Total Mass w/TVC                                                                                                                                                                                    | 1,255,979                                                              | Mass (ibm)<br>Max Gimbal Angle                                                                                                                                                                                                                                               | (deg)                                                                                                    |
| Envelope<br>Length<br>Nominal                                                                                                                                                                       | 1513.38                                                                | Diameter                                                                                                                                                                                                                                                                     |                                                                                                          |
| Stowed<br>Extended<br>Maximum Gimbal                                                                                                                                                                |                                                                        | Maximum<br>Maximum Gimbal                                                                                                                                                                                                                                                    |                                                                                                          |
|                                                                                                                                                                                                     |                                                                        |                                                                                                                                                                                                                                                                              |                                                                                                          |
|                                                                                                                                                                                                     | Envelope Dime                                                          | ensions in inches                                                                                                                                                                                                                                                            |                                                                                                          |
| Engine Component Masses                                                                                                                                                                             | Envelope Dime                                                          | ensions in inches                                                                                                                                                                                                                                                            |                                                                                                          |
| Engine Component Masses                                                                                                                                                                             | Envelope Dime                                                          | Propellant<br>Motor                                                                                                                                                                                                                                                          | 1,107,035                                                                                                |
| Engine Component Masses<br>Weights.lbm<br>Case<br>Insulation                                                                                                                                        | Envelope Dime<br>98,010<br>20,191                                      | Propellant<br>Motor<br>Igniter<br>External Insulation                                                                                                                                                                                                                        | 1,107,035<br>134<br>637                                                                                  |
| Engine Component Masses<br>Weights.lbm<br>Case<br>Insulation<br>Liner                                                                                                                               | 98,010<br>20,191<br>1,347                                              | Propellant<br>Motor<br>Igniter<br>External Insulation<br>Shipping Segment                                                                                                                                                                                                    | 1,107,035<br>134<br>637<br>1,247,802                                                                     |
| Engine Component Masses<br><u>Weights.lbm</u><br>Case<br>Insulation<br>Liner<br>Inhibitor<br>Igniter Inerts<br>Systems Tunnel<br>Instrumentation<br>Joint Heater Cable                              | 98,010<br>20,191<br>1,347<br>1,800<br>485<br>533<br>80<br>24           | Propellant<br>Motor<br>Igniter<br>External Insulation<br>Shipping Segment<br>Items Shipped Separate<br>Exit Cone*<br>Separation System<br>Stiffener Rings*<br>Joint Heater System<br>Exit Cone Installation<br>S&A Installation                                              | 1,107,035<br>134<br>637<br>1,247,802<br>6,193<br>231<br>908<br>348<br>22<br>15                           |
| Engine Component Masses<br><u>Weights.lbm</u><br>Case<br>Insulation<br>Liner<br>Inhibitor<br>Igniter Inerts<br>Systems Tunnel<br>Instrumentation<br>Joint Heater Cable<br>Nozzle-to-Forward Section | 98,010<br>20,191<br>1,347<br>1,800<br>485<br>533<br>80<br>24<br>17,524 | Propellant<br>Motor<br>Igniter<br>External Insulation<br>Shipping Segment<br>Items Shipped Separate<br>Exit Cone*<br>Separation System<br>Stiffener Rings*<br>Joint Heater System<br>Exit Cone Installation<br>S&A Installation<br>RSRM Installation<br>System Tunnel Joints | 1,107,035<br>134<br>637<br>1,247,802<br>6,193<br>231<br>908<br>348<br>22<br>15<br>439<br>21<br>1,255,979 |

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### February 22, 1993 Start-Up/Shutdown Sequences

Space Shuttle Redesigned Solid Rocket Motor **Engine Name:** Chemical Class of Engine: Solid Fuel StartUp Sequence Expected Nominal Operational RSRM Sequence Activity Time (sec) SSME Ignition -6.0 Fire signal to ignition system initiators 0.0 RSRM liftoff at 563.5 psia chamber pressure 0.23 Burnout of star section web in forward segment 21.5 Burnout of aft tapered section in aft segment commences 78.5 Burnout of aft tapered section in aft segment complete and tailoff commences 111.6 Separation sequence initiated; chamber pressure is 50 psia 122.2 RSRM physically separated (approximately) 125.9 127.1 Propellant burnout Nozzle extension is severed and jettisoned 396.2 Splashdown 405.5

Shutdown Sequence

### February 20, 1993

## Start-Up/Shutdown Profiles

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel

Chemical

- Isp Profile -

1

|         |                  | Manula           |           |            |             |         |               | Nozzie            |           |            |             |
|---------|------------------|------------------|-----------|------------|-------------|---------|---------------|-------------------|-----------|------------|-------------|
|         | Meedend          | Stemation        | Vacuum    | Total Mass | Specific    |         | Headend       | Stagnation        | Vacuum    | Total Mass | Specific    |
| Time    | Pressure         | Preseure         | Thrust    | Flow Rate  | Impluee     | Time    | Pressure      | Pressure          | Thrust    | FIOW PLANE | iligitate   |
| i Hire  | neia             | neie             | bf        | ibm/sec    | sec-lbf/lbm | seconde | peia          | peia              | Bor .     | IDITYBEC   | 38C-10/10/1 |
| Hecongs | (Nominal 60 *F   | and 0.368 los Bu | im Ratel  |            |             |         | (Nominal 60 " | Fand 0.368 ips Bu | im Flate) |            |             |
|         | (100100000000000 |                  |           |            |             |         |               |                   |           |            |             |
|         | 010.03           | 817 85           | 3 177 675 | 11.648.3   | 268.20      | 84.0    | 597.97        | 593.55            | 2,430,344 | 9,138.5    | 200.90      |
| 1.0     | 810.83           | 812.63           | 3 162 360 | 11.783.2   | 268.38      | 68.0    | 565.47        | 561.54            | 2,304,312 | 8,669.4    | 205.00      |
| 2.0     | 890.99           | 012.00           | 3 108 184 | 11 891 1   | 268.79      | 92.0    | 539.01        | 536.47            | 2,202,168 | 8,289.2    | 265.67      |
| 4.0     | 890.58           | 010./4           | 3,190,104 | 12 243 4   | 269.37      | 96.0    | 515.03        | 511.87            | 2,109,693 | 7,944.9    | 265.54      |
| 8.0     | 890.00           | 040.37           | 0,200,001 | 12 201 9   | 269.64      | 100.0   | 489.72        | 486.88            | 2,011,079 | 7,577.5    | 265.40      |
| 12.0    | 887.96           | 840.91           | 3,314,302 | 10,205,2   | 200.01      | 104.0   | 459.83        | 457.32            | 1,891,307 | 7,133.3    | 265.14      |
| 16.0    | 879.63           | 839.04           | 3,321,175 | 12,300.2   | 270.16      | 108.0   | 426.35        | 424.15            | 1,756,305 | 6,631.5    | 264.84      |
| 20.0    | 873.85           | 837.86           | 3,330,801 | 12,320.0   | 270.10      | 112.0   | 367.07        | 365.03            | 1,506,404 | 5,727.9    | 262.9       |
| 24.0    | 632.69           | 802.25           | 3,195,860 | 11,044.9   | 270.00      | 114.0   | 264.85        | 263.61            | 1,081,918 | 4,147.6    | 260.65      |
| 28.0    | 778.24           | 753.37           | 3,009,303 | 11,100.2   | 200.00      | 118.0   | 170 55        | 169 74            | 670.474   | 2,680.9    | 250.09      |
| 32.0    | 735.86           | 715.26           | 2,862,180 | 10,630.1   | 209.20      | 110.0   | 100 72        | 109.20            | 421 968   | 1.731.3    | 243.73      |
| 36.0    | 699.16           | 681.95           | 2,733,822 | 10,167.9   | 268.87      | 118.0   | 00.72         | 99.28             | 363,268   | 1,575.3    | 243.3       |
| 40.0    | 664.90           | 650.61           | 2,612,666 | 9,731.1    | 268.49      | 110.4   | 00.03         | 90.04             | 146 920   | 1 428.3    | 242.8       |
| 44.0    | 638.28           | 626.28           | 2,519,380 | 9,396.4    | 268.12      | 118.8   | ¥0.37         | 08.84             | 314 800   | 1 297 5    | 242 47      |
| 48.0    | 615.63           | 605.40           | 2,439,656 | 9,111.0    | 267.77      | 119.2   | 82.02         | 01.04             | 314,000   | 1 185 4    | 242 0       |
| 52.0    | 594.16           | 585.27           | 2,362,641 | 8,835.1    | 267.42      | 119.6   | 73.60         | /3.20             | 202,001   | 1.025.5    | 241 5       |
| 56.0    | 600.75           | 592.61           | 2,396,414 | 8,967.5    | 267.23      | 120.0   | 65.33         | 65.02             | 250,130   | 1,035.5    | 241.5       |
| 60.0    | 610.67           | 603.19           | 2,443,418 | 9,149.3    | 267.06      | 120.4   | 57.39         | 57.12             | 222,121   | 310.0      | 247.6       |
| 64.0    | 622.55           | 615.64           | 2,498,140 | 9,360.1    | 266.89      | 120.8   | 50.15         | 49.91             | 197,245   | /96.5      | 247.0       |
|         | 820.22           | 822.96           | 2 532 199 | 9,494.3    | 266.71      | 121.2   | 41.20         | 41.00             | 164,191   | 655.3      | 250.5       |
| 72.0    | 635.40           | 629.55           | 2,563,350 | 9,617.9    | 266.52      | 121.6   | 32.59         | 32.43             | 131,574   | 519.3      | 253.3       |
| 72.0    | 035.40           | 621 84           | 2 577 041 | 9.676.6    | 266.32      | 122.0   | 25.39         | 25.27             | 103,860   | 405.5      | 256.1       |
| 76.0    | 637.20           | 610.27           | 2,377,041 | 9.510.6    | 256.07      | 122.4   | 19.63         | 19.53             | 81,296    | 314.0      | 258.8       |



#### February 20, 1993

## Start-Up/Shutdown Profiles

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel

Chemical



#### - Flowrate Profile

|        |                  | Nozzie           |           | _          |                  |         | Nondo-d               | Nozzie             | Venum       | Total Mass | Specific    |
|--------|------------------|------------------|-----------|------------|------------------|---------|-----------------------|--------------------|-------------|------------|-------------|
|        | Headend          | Stagnation       | Vacuum    | Total Mass | Specific         |         | Present               | Preserve           | Threat      | Flow Rate  | Implus      |
| Time   | Pressure         | Pressure         | Thrust    | Flow Rate  | Impluse          | Ime     | riesSUI#              |                    | i i i unari | ibm/sec    | sec-lbf/lbr |
| econds | psia             | peia             | ы         | ibm/sec    | sec-lbt/lbm      | seconds | peia<br>(Nominal en M | pera Pro           | n Rate)     |            |             |
| -      | (Nominal 60 °F   | and 0.368 ips Bu | um Rate)  |            |                  |         |                       | - and 0.006 lpt 81 |             |            |             |
|        | 010.03           | 817 AK           | 3,177 675 | 11.848.3   | 268.20           | 84.0    | 597.97                | 593.55             | 2,430,344   | 9,138.5    | 265.9       |
| 1.0    | 910.95<br>BOR DO | A12 A3           | 3.162.390 | 11.783.2   | 268.38           | 86.0    | 565.47                | 561.54             | 2,304,312   | 8,669.4    | 265.6       |
| 2.0    | 000.00           | 818 74           | 3 194 184 | 11 891 1   | 268.79           | 92.0    | 539.01                | 535.47             | 2,202,168   | 8,289.2    | 265.6       |
| 4.0    | 50.040<br>008.50 | 610./4<br>840 37 | 3,298,001 | 12 243 4   | 269.37           | 96.0    | 515.03                | 511.87             | 2,109,693   | 7,944.9    | 265.5       |
| 8.0    | 000.00           | BAD 01           | 3.314 342 | 12 291 9   | 269.64           | 100.0   | 489.72                | 486.88             | 2,011,079   | 7,577.5    | 265.4       |
| 12.0   | 07.100           | 830.04           | 3 201 178 | 12 305 2   | 269.90           | 104.0   | 459.83                | 457.32             | 1,891,307   | 7,133.3    | 265.1       |
| 16.0   | 679.63           | 817 56           | 3,321,170 | 12.328.8   | 270.16           | 108.0   | 426.35                | 424.15             | 1,756,305   | 6,631.5    | 264.8       |
| 20.0   | 873.85           | 607.00<br>600 0# | 3 108 080 | 11 944 9   | 270.06           | 112.0   | 367.07                | 365.03             | 1,506,404   | 5,727.9    | 262.9       |
| 24.0   | 832.69           | 762.20           | 3,180,000 | 11 160 2   | 269.65           | 114.0   | 264.85                | 263.61             | 1,081,918   | 4,147.6    | 260.8       |
| 28.0   | //8.24           | /53.3/           | 3,000,000 | 10 630 1   | 269.25           | 116.0   | 170.55                | 169.74             | 670,474     | 2,680.9    | 250.0       |
| 32.0   | 736.86           | /16.26           | 2,002,100 | 10,000.1   | 268.87           | 118.0   | 109.72                | 109.20             | 421,968     | 1,731.3    | 243.7       |
| 36.0   | 699.16           | 661.96           | 2,733,022 | D 711 1    | 268.40           | 118.4   | 99.75                 | 99.28              | 383,286     | 1,575.3    | 243.3       |
| 40.0   | 664.90           | 000.01           | 2,012,000 | 0,708 4    | 268.12           | 118.6   | 90.37                 | 89.94              | 346,920     | 1,428.3    | 242.8       |
| 44.0   | 638.28           | 626.28           | 2,519,380 | P.040,9    | 200.12           | 110.2   | 80.02                 | 81.64              | 314.600     | 1,297.5    | 242.4       |
| 48.0   | 615.63           | 605.40           | 2,439,655 | 9,111.0    | 201.11<br>287 A2 | 1196    | 73.60                 | 73.26              | 282,061     | 1,165.4    | 242.0       |
| 52.0   | 594.16           | 585.27           | 2,362,641 | 0,030.1    | 201.94           | 120.0   | 65 33                 | 66.02              | 250.136     | 1,035.5    | 241.5       |
| 56.0   | 600.75           | 592.61           | 2,395,414 | 8,967.5    | 201.23           | 120.4   | 57.39                 | 57.12              | 222,727     | 910.5      | 244.6       |
| 60.0   | 610.67           | 603.19           | 2,443,418 | 9,149.3    | 201.00           | 120.9   | 50.15                 | 49.91              | 197.245     | 798.5      | 247.6       |
| 64.0   | 622.55           | 615.64           | 2,498,140 | 9,360.1    | 200.09           | 120.0   | 41 20                 | 41.00              | 164.191     | 655.3      | 250.5       |
| 68.0   | 629.32           | 622.96           | 2,532,199 | 9,494.3    | 206.71           | 121.2   | -1.4V<br>22 80        | 39 43              | 131 574     | 519.3      | 253.3       |
| 72.0   | 635.40           | 629.55           | 2,563,350 | 9,617.9    | 206.52           | 121.0   | 32.04                 | 0E.40              | 103 860     | 405.5      | 256 1       |
| 76.0   | 637.20           | 631.84           | 2,577,041 | 9,676.6    | 266.32           | 122.0   | 20.34                 | 40.41              | 81 204      | 314 0      | 258 8       |
| 80.0   | 624.26           | 619.37           | 2,530,472 | 9,510.6    | 266.07           | 122.4   | 19.03                 | 19.53              |             |            |             |

### February 14, 1993

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Interfaces

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel

Chemical



### February 14, 1993

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# **Technology Development**

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Englne: Solid Fuel

Chemical

Technology Development

# February 14, 1993 Advanced Development Plan

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel

(

Chemical

Advanced Development Plan

Figure 82.

# Output for NERVA Derived Nuclear Thermal Rocket Propulsion System

NTRND Propulsion System



| 50,000                        | 852.0                           | 784                                            | Liquid Hydrogen | 300             | 387.0       | 119.0         | 9,570        |
|-------------------------------|---------------------------------|------------------------------------------------|-----------------|-----------------|-------------|---------------|--------------|
| Nominal Thrust (Ibf) • Vacuum | Specific Impulse (sec) • Vacuum | Chamber Pressure (psia)<br>(Nozzle Stagnation) | Fuel            | Expansion Ratio | Length (in) | Diameter (in) | Weight (Ibm) |

**Advanced Propulsion Subsystem Concepts Database** 



3/27/93

Advanced Propulsion Subsystem Concepts Database



3/13/93

#### March 30, 1993

## **Background Information**

| Engine Name: | Nuclear Thermal Rocket, NERVA Derivative |  |
|--------------|------------------------------------------|--|
|--------------|------------------------------------------|--|

Class of Engine: Nuclear Thermal

Fission Reactor

Background

Representative background data for the NTPNE will be incorporated at a future date.

- Comments -

No comments.

 References
 Rover/NERVA-Derived Near-Term Nuclear Propulsion, FY92 Final Report, October 22, 1992 (Final report of Rocketdyne contract with NASA-LeRC); Unpublished Rocketdyne data.

 Date:
 Unpublished data as of March 1993.

Entered by: Dan Levack

March 30, 1993

**Propulsion System General Data** 

| Creatio                            | n Date Modi            | fication Date   | r            | Record Number          |    |
|------------------------------------|------------------------|-----------------|--------------|------------------------|----|
| 3/7/93                             | 3/30/9                 | 3               | L            | 10                     |    |
| Engine Name                        | 3                      | Nuclear         | Thermal Ro   | ocket, NERVA Derivativ | /e |
| Class of Engine<br>Propulsion Type |                        | Nuclear         | hermal       | Fission Reactor        |    |
|                                    |                        | Thermod         | namic Exp    | ansion of Hot Gas      |    |
| Acronym                            |                        | NTRND           |              |                        |    |
| Application                        | Acronym<br>Application |                 | ansfer       |                        |    |
| Manufacture                        | r                      | Concept         | al Engine    | (Rocketdyne Study)     |    |
| Program Sta                        | tus                    | Concept         | al Studies   | for NASA-LeHC          |    |
| Manrated                           |                        | Current         | olans are to | manrate this system    |    |
| IOC/Date St                        | udied (Month/Year)     | 2-19-93         |              |                        |    |
| Mixture Rati                       | o – Engine/ Thrust     | Chamber         |              |                        |    |
| - Propellant                       | 3                      |                 |              |                        |    |
| Oxidizer                           | None                   |                 |              |                        |    |
| Fuel                               | Liquid Hydrogen        |                 | 1            |                        |    |
| Engine Desi                        | gn Life (Flights)      | 1               |              |                        |    |
| Restart Cap                        | ability                | 10              |              |                        |    |
| Engine Cyc                         | Engine Cycle           |                 |              |                        |    |
| Nominal Ch                         | amber Pressure         |                 | 784          |                        |    |
|                                    | Dette                  |                 | 300.00       |                        |    |
| Expansion                          |                        | Gimbal          |              |                        |    |
|                                    |                        |                 |              |                        |    |
| Maximum                            | Length (inches)        |                 | 387.00       |                        | i  |
| Maximum                            | Width (inches)         |                 | 119.00       |                        |    |
| Engine Ma                          | ss (ibm)               |                 | 9,570.00     |                        |    |
| Engine Th                          | rust Data, Ibf         |                 |              | Manuar                 | 1  |
|                                    |                        | <u>Sea Leve</u> | 1            | vacuum                 |    |
| Nomi                               | nal                    | -110,75         | 7 C          | 50,000                 |    |
| Maxi                               | mum                    |                 | ] [          |                        |    |
| Minir                              | num                    |                 | ] [          |                        |    |
|                                    |                        |                 |              |                        |    |

# **Engine Performance 1**

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March 7, 1993

| Engine Name:     | Nuclear Thermal Rocket, NERVA Derivative |                 |
|------------------|------------------------------------------|-----------------|
| Class of Engine: | Nuclear Thermai                          | Fission Reactor |

| Fuel Liquid Hydrogen<br>Nominal Chamber Pressure (psia)<br>Expansion Batio          | 784.00                   | Engine Restarts                                                            | 9                                      |
|-------------------------------------------------------------------------------------|--------------------------|----------------------------------------------------------------------------|----------------------------------------|
| Engine Design Life (Flights)<br>Engine Thrust Data<br>Nominal<br>Maximum<br>Minimum | 1<br>Vacuum<br>50,000.00 | Engine Reliability, sec<br>Design<br>Demonstrated                          | 16,200                                 |
| Thrust data in units of lbf<br>Throttle Ratio<br>Maximum                            | Vacuum                   | Nozzie Data<br>Type Bell, Slotted Tubu<br>Length (In)<br>Diameter (sq. in) | lar Wall/Radiation<br>242.00<br>118.00 |
| Specific Impulse Data<br>@Nominal Thrust<br>@MaxImum Thrust<br>@Minimum Thrust      | <u>Vacuum</u><br>852.00  | Throat Area (sq. in)<br>Exit Area (sq. in)<br>Expansion Ratio              | 36.43<br>10,927.8<br>300.00            |
| Specific Impulse data in units of a                                                 | seconds                  |                                                                            |                                        |
## March 7, 1993

# **Engine Performance 2**

| Engine Name:       Nuclear Thermal Rocket, NERVA Derivative         Class of Engine:       Nuclear Thermal                                                                                      | Fission Reactor                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Engine Mass (Ibm)         Total Mass w/TVC       9,570.0         Total Mass wo/TVC       9,530.0                                                                                                | TVC         Method       Gimbal         Mass (Ibm)       40.0         Max Gimbal Angle (deg)       4.0         Max Gimbal Rate (deg/s)       2.0 |
| Type Topping   Pressures, psia   Fuel Turbopump   Min Pump Inlet   32   Turbine Inlet   2,350.0     Envelope   Length   Nominal   387   Stowed   Extended   Maximum Gimbal   Envelope Dimension | Diameter<br>Nozzie Exit 118.0<br>Maximum 119.0<br>Maximum Gimbai 174.0                                                                           |
| Engine Component Masses, Ibm<br>Component Mass, Ibm<br>Reactor Assembly<br>(Includes Pressure Vessel an<br>Internal Shield)<br>Chamber/Nozzle<br>Turbopump<br>Lines and Controls                | 7,310<br>d<br>1,470<br>230<br>560                                                                                                                |

# March 13, 1993 Start-Up/Shutdown Profiles

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal

**Fission Reactor** 





# March 7, 1993 Start-Up/Shutdown Profiles

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal

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**Fission Reactor** 

Thrust Profile



# March 7, 1993 Start-Up/Shutdown Profiles

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal

**Fission Reactor** 



| Impulse Profile |      |
|-----------------|------|
|                 |      |
|                 |      |
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|                 | <br> |
|                 |      |

### March 13, 1993

## Interfaces

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal

**Fission Reactor** 



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# **Technology Development**

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal

**Fission Reactor** 

Technology Development

March 7, 1993

### March 7, 1993

# **Advanced Development Plan**

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal

**Fission Reactor** 

-Advanced Development Plan

Figure 83.

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Field Definitions of the File "Prop System DB"

| Field Name                     | Field Type           | Formula / Entry Option                                                                                                                                                                       |
|--------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Percent Number                 | Number               | Serial Number with Current Value: "11" Increment: "1"                                                                                                                                        |
| Creation Date                  | Date                 | Auto-enter the: "Creation Date"<br>Prevent data that is automatically entered from being changed.                                                                                            |
| Modification Date              | Date                 | Auto-enter the: "Modification Date"<br>Prevent data that is automatically entered from being changed.                                                                                        |
|                                | Text                 |                                                                                                                                                                                              |
| Class of Engine                | Text                 | Value List:<br>Cryogenic Liquid<br>Hydrocarbon Liquid<br>Storable Liquid<br>Solid Fuel<br>Hybrid SRB<br>Metalized Fuels<br>Nuclear Thermal<br>Nuclear Electric<br>Combined Nuclear<br>Exotic |
| Engine Name                    | Text                 |                                                                                                                                                                                              |
| Acronym                        | Text                 |                                                                                                                                                                                              |
| Application                    | Text                 |                                                                                                                                                                                              |
| Manufacturer                   | Text                 |                                                                                                                                                                                              |
| Program Status                 | Text                 |                                                                                                                                                                                              |
| Manrated                       | Text                 |                                                                                                                                                                                              |
| Mixture Ratio (O:F) Engine     | Number               |                                                                                                                                                                                              |
| Mixture Ratio (O:F)<br>Chamber | Number               |                                                                                                                                                                                              |
| IOC/Date Studied               | Text                 |                                                                                                                                                                                              |
| Engine Cycle                   | Text                 |                                                                                                                                                                                              |
| Nominal Chamber Pressure       | Number               |                                                                                                                                                                                              |
| Min Inlet Pressure (Oxid)      | Number               |                                                                                                                                                                                              |
| Expansion Ratio                | Number               |                                                                                                                                                                                              |
| TVC Method                     | Text                 |                                                                                                                                                                                              |
| Maximum Length                 | Number               |                                                                                                                                                                                              |
| Maximum Width                  | Number               |                                                                                                                                                                                              |
| Engine Mass (lbm)              | Number               |                                                                                                                                                                                              |
| Oxidizer                       | Text                 |                                                                                                                                                                                              |
| Fuel                           | Text                 | W (New Yes Thrust - 0 Nom Ves Thrust - 11 545353 *                                                                                                                                           |
| Nom Sea Level Thrust           | Calculation (Number) | = If (Nom Vac Thrust > 0, Nom Vac Thrust > 11.040000<br>NozzleDiameter ^ 2, * ")                                                                                                             |
| Nom Vac Thrust                 | Number               | 14 (14 - Mar Through - 0 May Vee Through - 11 545353 *                                                                                                                                       |
| Max Sea Level Thrust           | Calculation (Number) | = If (Max Vac Thrust > 0, Max Vac Thrust > 11.540000<br>NozzleDiameter ^ 2, " ")                                                                                                             |
| Max Vac Thrust                 | Number               | Water Man Threads, O. Min Mon Thread, 11 545353 *                                                                                                                                            |
| Min Sea Level Thrust           | Calculation (Number) | = If (Min vac Thrust > 0, Min vac Thrust = The toolog<br>NozzleDiameter ^ 2, " ")                                                                                                            |
| Min Vac Thrust                 | Number               | L OL Man Thrush                                                                                                                                                                              |
| lsp Sea Level                  | Calculation (Number) | = Isp SL Nom I nrust                                                                                                                                                                         |
| Isp Vacuum                     | Calculation (Number) |                                                                                                                                                                                              |
| Engine Background              | Text                 |                                                                                                                                                                                              |
| Background Comments            | Text                 |                                                                                                                                                                                              |
| Reference Source               | Text                 |                                                                                                                                                                                              |
| Date of Reference              | Text                 |                                                                                                                                                                                              |
| Entered by                     | Text                 |                                                                                                                                                                                              |

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| Field Name                    | Field Type           | Formula / Entry Option                                                                                                          |
|-------------------------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Engine Design Life Starts     | Number               |                                                                                                                                 |
| Engine Design Life Sec        | Number               |                                                                                                                                 |
| Engine Design Life (Flights)  | Number               |                                                                                                                                 |
| Restart Capability            | Text                 |                                                                                                                                 |
| Engine Design Restarts        | Number               |                                                                                                                                 |
| Engine Demo Restarts          | Number               |                                                                                                                                 |
| Design Rel (Starts)           | Calculation (Number) | = Engine Design Life Starts                                                                                                     |
| Design Rel (Sec)              | Calculation (Number) | ≠ Engine Design Life Sec                                                                                                        |
| Demo Rel (Starts)             | Number               |                                                                                                                                 |
| Demo Rel (Sec)                | Number               |                                                                                                                                 |
| Isp SL Nom Thrust             | Calculation (Number) | = If (Nom Vac Thrust > 0,Isp Vac Nom Thrust * Nom Sea Level<br>Thrust / Nom Vac Thrust, * *)                                    |
| Isp Vac Nom Thrust            | Number               | ······································                                                                                          |
| lsp SL Max Thrust             | Calculation (Number) | If (Max Vac Thrust > 0, If (IspVacMaxThrust > 0, IspVacMaxThrust<br>* Max Sea Level Thrust / Max Vac Thrust, " ")," ")          |
| lspVacMaxThrust               | Number               |                                                                                                                                 |
| lsp SL Min Thrust             | Calculation (Number) | = If (Min Vac Thrust > 0, If (Isp Vac Min Thrust > 0, Isp Vac Min<br>Thrust * Min Sea Level Thrust / Min Vac Thrust, " "), " ") |
| lsp Vac Min Thrust            | Number               |                                                                                                                                 |
| NozzleType                    | Text                 |                                                                                                                                 |
| Nozzle Length                 | Number               |                                                                                                                                 |
| NozzleDiameter                | Number               |                                                                                                                                 |
| Nozzle Throat Area            | Number               |                                                                                                                                 |
| Nozzle Exit Area              | Calculation (Number) | = Nozzle Expansion Ratio * Nozzle Throat Area                                                                                   |
| Nozzle Expansion Ratio        | Number               |                                                                                                                                 |
| Throttle Ratio SL Max         | Number               |                                                                                                                                 |
| Throttle Ratio Vac Max        | Number               |                                                                                                                                 |
| Throttle Ratio SL Min         | Number               |                                                                                                                                 |
| Throttle Ratio Vac Min        | Number               |                                                                                                                                 |
| Max OX Pump Pres              | Number               |                                                                                                                                 |
| Max Fuel Pump Pres            | Number               |                                                                                                                                 |
| Nom OX Turbine Pres           | Number               |                                                                                                                                 |
| TVC Mass                      | Number               |                                                                                                                                 |
| Max Gimbal Angle (deg)        | Number               |                                                                                                                                 |
| Max Gimbal Rate               | Number               |                                                                                                                                 |
| Nominal Length                | Calculation (Number) | = Maximum Length                                                                                                                |
| Stowed Length                 | Number               |                                                                                                                                 |
| Extended Length               | Number               |                                                                                                                                 |
| Extended Length Max<br>Gimbal | Number               |                                                                                                                                 |
| Nozzle Exit Diameter          | Number               |                                                                                                                                 |
| Maximum Diameter              | Number               |                                                                                                                                 |
| Max Diameter Max Gimbal       | Number               |                                                                                                                                 |
| Total Mass TVC                | Numper               |                                                                                                                                 |
| Total Mass w/o TVC            |                      |                                                                                                                                 |
| Start Up Sequence             | Picture/Sound        |                                                                                                                                 |
| Snutdown Sequence             | Picture/Sound        |                                                                                                                                 |
| Inrust Startup Profile        | Picture/Sound        |                                                                                                                                 |
| Inrust Snutdown Protile       | Picture/Sound        |                                                                                                                                 |
| isp Startup Profile           | Ficture/Sound        |                                                                                                                                 |

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| Field Name                | Field Type           | Formula / Entry Option                                                                                                                                                                                                                                                                                                                                                                                                                              |
|---------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Isp Shutdown Profile      | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Flow Startup Profile      | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Flow Shutdown Profile     | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| O/F Startup Profile       | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| O/F Shutdown Profile      | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Technology Development    | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Adv Development Plan      | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Interface 1               | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Interface 2               | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Interface 3               | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Engine Type               | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Nom Fuel Turbine Pres     | Number               |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Min Inlet Pressure (Fuel) | Number               |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Return Where?             | Calculation (Number) | <ul> <li>if(Class of Engine = "Cryogenic Liquid" OH Class of Engine =</li> <li>"Hydrocarbon Liquid" OR Class of Engine = "Storable Liquid", 17,</li> <li>if(Class of Engine = "Solid Fuel", 46, if(Class of Engine = "Hybrid</li> <li>SRB", 75, if(Class of Engine = "Nuclear Thermal" OR Class of</li> <li>Engine = "Nuclear Electric" OR Class of Engine = "Nuclear Electric",</li> <li>104, if(Class of Engine = "Exotic", 133,5)))))</li> </ul> |
| Which Data Entry?         | Calculation (Number) | = if(Class of Engine = "Cryogenic Liquid" OR Class of Engine =<br>"Hydrocarbon Liquid" OR Class of Engine = "Storable Liquid", 8,<br>if(Class of Engine = "Solid Fuel", 12, if(Class of Engine = "Hybrid<br>SRB", 13, if(Class of Engine = "Nuclear Thermal" OR Class of<br>Engine = "Nuclear Electric" OR Class of Engine = "Nuclear Electric",<br>14, if(Class of Engine = "Exotic",15,5)))))                                                     |
| Class Type Calc           | Calculation (Text)   | = Class of Engine                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Engine Component Masses   | Picture/Sound        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Grain Design              | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Noz Submergence Ratio     | Number               |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Material 1           | Calculation (Text)   | = Oxidizer                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Prop Material 2           | Calculation (Text)   | ≖ Fuel                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Prop Material 3           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Material 4           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Material 5           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Material 6           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Material 7           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 1     | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 2     | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 3     | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 4     | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 5     | lext                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 6     | i ext                |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Weight Percent 7     |                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Function 1           | 1 BXI<br>Text        |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Function 2           |                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Function 3           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Function 4           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Prop Function 5           | Text                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                           | Tovt                 | ·                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                           | Number               |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Burn Hate                 | Hambor               |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

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| Field Name               | Field Type           | Formula / Entry Option                                                                                                                                          |
|--------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Burn Rate Temp           | Number               |                                                                                                                                                                 |
| Burn Rate Pressure       | Number               |                                                                                                                                                                 |
| Burn Rate Exp            | Number               |                                                                                                                                                                 |
| Burn Time                | Number               |                                                                                                                                                                 |
| Action Time              | Number               |                                                                                                                                                                 |
| Max Exp Op Press         | Number               |                                                                                                                                                                 |
| Max Op Press             | Number               |                                                                                                                                                                 |
| Burn Time Avg Press      | Number               |                                                                                                                                                                 |
| Action Time Avg Press    | Calculation (Number) | Nominal Chamber Pressure                                                                                                                                        |
| Max Exp Op Thrust Vac    | Number               |                                                                                                                                                                 |
| Max Op Thrust Vac        | Number               |                                                                                                                                                                 |
| Burn Time Avg Thrust Vac | Number               |                                                                                                                                                                 |
| Action Time Avg F Vac    | Calculation (Number) | = Nom Vac Thrust                                                                                                                                                |
| Burn Time Impulse Vac    | Calculation (Number) | = Burn Time Avg Thrust Vac * Burn Time                                                                                                                          |
| Action Time Impulse Vac  | Calculation (Number) | = Action Time Avg F Vac * Action Time                                                                                                                           |
| Action Time Avg F SL     | Calculation (Number) | = If (Action Time Avg F Vac > 0, Action Time Avg F Vac - 11.545555<br>*NozzleDiameter ^ 2, " ")                                                                 |
| Max Exp Op Thrust SL     | Calculation (Number) | If (Max Exp Op Thrust Vac > 0, Max Exp Op Thrust Vac -<br>11.545353 * NozzleDiameter ^ 2," ")                                                                   |
| Max Op Thrust SL         | Calculation (Number) | = If (Max Op Thrust Vac > 0, Max Op Thrust Vac - 11.545353 *<br>NozzleDiameter ^ 2, * ")                                                                        |
| Burn Time Avg Thrust SL  | Calculation (Number) | = If (Burn Time Avg Thrust Vac > 0, Burn Time Avg Thrust Vac -<br>11.545353 * NozzleDiameter ^ 2, " ")                                                          |
| Burn Time Impulse SL     | Calculation (Number) | If (Burn Time Avg Thrust SL > 0, Burn Time Avg Thrust SL * Burn<br>Time, " ")                                                                                   |
| Action Time Impulse SL   | Calculation (Number) | = If (Action Time Avg F SL > 0, Action Time Avg F SL * Action Time,<br>"")                                                                                      |
| Press Startun Profile    | Picture/Sound        | •                                                                                                                                                               |
| Press Shutdown Profile   | Picture/Sound        |                                                                                                                                                                 |
| Burn Time Avg Isp SL     | Calculation (Number) | = If (Burn Time Avg Thrust Vac > 0, If (Burn Time Avg Isp Vac > 0,<br>Burn Time Avg Isp Vac * Burn Time Avg Thrust SL / Burn Time Avg<br>Thrust Vac, " "), " ") |
| Burn Time Avg Isp Vac    | Number               |                                                                                                                                                                 |
| Action Time Avg Isp SL   | Calculation (Number) | # If (Action Time Avg F Vac > 0, If (Action Time Avg Isp Vac ><br>0,Action Time Avg Isp Vac * Action Time Avg F SL / Action Time<br>Avg F Vac," ")," ")         |
| Action Time Avg Isp Vac  | Calculation (Number) | = Isp Vac Nom Thrust                                                                                                                                            |
| Reactor Type             | Text                 |                                                                                                                                                                 |
|                          | Text                 |                                                                                                                                                                 |
| Max Fuel Temp R          | Number               |                                                                                                                                                                 |
| Propellant Temp R        | Number               |                                                                                                                                                                 |
| Impulse Startup Profile  | Picture/Sound        |                                                                                                                                                                 |
| Impulse Shutdown Profile | Picture/Sound        |                                                                                                                                                                 |

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Figure 84.

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# Field Definitions of the File "Prop System DB-Pictures"

| Field Name                         | Field Type         | Formula / Entry Option                                                                                                                                                                                                                                                                                             |
|------------------------------------|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Record Number                      | Number             | Lookup: "Record Number" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: "                                                                                                                                                                                                    |
| Class of Engine                    | Text               | Value List:<br>Cryogenic Liquid<br>Hydrocarbon Liquid<br>Storable Liquid<br>Solid Fuel<br>Hybrid SRB<br>Metalized Fuels<br>Nuclear Thermal<br>Nuclear Electric<br>Combined Nuclear<br>Exotic<br>Lookup: "Class of Engine" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: "" |
| Engine Name                        | Text               |                                                                                                                                                                                                                                                                                                                    |
| Acronym                            | Text               | Lookup: "Acronym" in "Prop System DB" when "Engine Name"<br>matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                                         |
| Engine Type                        | Text               | Lookup: "Engine Type" in "Prop System DB" when "Engine Name"<br>matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                                     |
| Mixture Ratio (O:F)                | Number             | Lookup: "Mixture Ratio (O:F) Engine" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                      |
| Nominal Chamber Pressure<br>(psia) | Number             | Lookup: "Nominal Chamber Pressure" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                        |
| Expansion Ratio                    | Number             | Lookup: "Expansion Ratio" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                                 |
| Nom Sea Level Thrust (lbf)         | Number             | Lookup: "Nom Sea Level Thrust" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: "" ""                                                                                                                                                                                         |
| Nom Vac Thrust                     | Number             | Lookup: "Nom Vac Thrust" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                                  |
| lsp Sea Level (sec)                | Number             | Lookup: "Isp Sea Level" in "Prop System DB" when "Engine Name"<br>matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                                   |
| lsp Vacuum                         | Number             | Lookup: "Isp Vacuum" in "Prop System DB" when "Engine Name"<br>matches "Engine Name"<br>If no match, copy: ""                                                                                                                                                                                                      |
| Maximum Length                     | Number             | Lookup: "Maximum Length" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: "" ""                                                                                                                                                                                               |
| Maximum Width                      | Number             | Lookup: "Maximum Width" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: "" ""                                                                                                                                                                                                |
| Engine Mass                        | Number             | Lookup: "Engine Mass (Ibm)" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: "" ""                                                                                                                                                                                            |
| Engine Drawing                     | Picture/Sound      |                                                                                                                                                                                                                                                                                                                    |
| Engine Balance                     | Picture/Sound      |                                                                                                                                                                                                                                                                                                                    |
| Engine Type Calc                   | Calculation (Text) | = Engine Type                                                                                                                                                                                                                                                                                                      |
| Engine Class Clac                  | Calculation (Text) | = Class of Engine                                                                                                                                                                                                                                                                                                  |

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| Field Name              | Field Type | Formula / Entry Option                                                                                                        |
|-------------------------|------------|-------------------------------------------------------------------------------------------------------------------------------|
| Action Time Avg F SL    | Number     | Lookup: "Action Time Avg F SL" in "Prop System DB" when "Engine<br>Name" matches "Engine Name"<br>If no match, copy: "" ""    |
| Action Time Avg F Vac   | Number     | Lookup: "Action Time Avg F Vac" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: "" "    |
| Action Time Avg Isp SL  | Number     | Lookup: "Action Time Avg Isp SL" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: "" ""  |
| Action Time Avg Isp Vac | Number     | Lookup: "Action Time Avg Isp Vac" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: "" "" |
| Action Time Avg Press   | Number     | Lookup: "Action Time Avg Press" in "Prop System DB" when<br>"Engine Name" matches "Engine Name"<br>If no match, copy: "" ""   |
| Action Time             | Number     | Lookup: "Action Time" in "Prop System DB" when "Engine Name"<br>matches "Engine Name"<br>If no match, copy: "" ""             |
| Fuel                    | Text       | Lookup: "Fuel" in "Prop System DB" when "Engine Name" matches<br>"Engine Name"<br>If no match, copy: "" ""                    |

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Appendix

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Use of Fortran Externals with Resolve<sup>™</sup> and Excel<sup>™</sup>

## **USER GUIDE**

- Subject: External Functions for Claris Resolve for the Macintosh written in FORTRAN complied with Language Systems FORTRAN version 3.0.1 and MPW version 3.2.3
- Written By: David W. Harris Rocketdyne Division Rockwell International PO Box 7922 6633 Canoga Ave. Canoga Park, CA 91309-7922 (818) 718-4677
  Date: March 10, 1993

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**Purpose:** This User guide is to lead a person with limited knowledge of Macintosh programing through the steps necessary to turn a FORTRAN subroutine into an Resolve external function. This guide assumes that the user has a little familiarity with the Language Systems FORTRAN compiler and Claris Resolve. For more detailed information refer to the Language Systems FORTRAN Reference Manual and to the Resolve User Guide and Claris Technical Note.

### INTRODUCTION

Claris Resolve versions 1.1v1 and above have the ability to call external code that can be used as spreadsheet functions. This code is an assembly language code with the proper data handling that allows it to be called or linked to other code. To create a Resolve external function with this guide you must have the following:

- 1. The CHookc.c.o object file
- 2. A FORTRAN subroutine SetUp.f
- 3. A FORTRAN subroutine FHook.f
- 4. Your FORTRAN subroutine
- 5. Funcname application

Because of the required interface between Resolve and an external function an interface program or "hook" had to be written in "C" code. This program handles the setting of variables that Resolve uses to call the external function and the passing of program variables. A hook called CHookc.c.o was created as a generic

interface. This hook calls two FORTRAN subroutines, SetUp.f and FHook.f. The SetUp.f subroutine supplies the CHook with two necessary pieces of information, the name of the function to be used by Resolve and the number of input arguments. The name of the function is not the file name but the function name used in the Resolve script to call the external function. The function name cannot be over 8 characters long. Because the passing of string variables from FORTRAN to C is tricky, an application, Funcname, has been provided to create the SetUp.f file. Executing this program will create a complete SetUp.f file ready for compiling and linking. FHook.f is the front-end for your subroutine. Your subroutine will be called by FHook.f. FHook.f must be written with two arguments, an input array and an output array. Both arrays must be double precision REAL and dimensioned input(\*) and output(100). The generic "C" hook was written to handle infinite input and 100 output variables. FHook.f can be used to manipulate the input and output data to your subroutine. That is do things such as reassign the values to other variable, change from double to single precision, convert the value and so on.

The following is a set of steps that will allow you to create a Resolve external using the CHookc.c.o interface. It is suggested that all of the steps are followed the first time. After that any changes to the FORTRAN code that do not change file names will require only a simple **Build** command and maybe minor changes to the Resolve script.

- **STEP 1** Create a SetUp subroutine. To do this run the program Funcname. This program will create a file SetUp.f that is necessary for the Resolve interface. When Funcname asks for 'Resolve Function Name', enter the name that you what to call the function in Resolve and for 'Number of Input variables', enter the number of input variables to your subroutine.
- STEP 2 Launch MPW
- **STEP 3** Open (**File, Open...**) and change your FORTRAN subroutine so that it meets the programing rules.

#### **Programing Rules**

- No global or static storage: FORTRAN programs can have no COMMON, BLOCK DATA, or SAVE statements and the *-saveall* compiler option cannot be used to force static storage.
- No FORTRAN I/O statements: see the following list. A lack of I/O is a serious limitation, but I/O is often for user interaction which is the function of Resolve.

| ACCEPT    | OPEN   |
|-----------|--------|
| BACKSPACE | PAUSE  |
| CLOSE     | PRINT  |
| DECODE    | READ   |
| ENCODE    | REWIND |
| ENDFILE   | STOP   |
| FORMAT    | TYPE   |
| INQUIRE   | WRITE  |
| NAMELIST  |        |

• No character constants: a statement such as

CHARACTER\*26 myString myString = 'I paid my taxes on April 7.'

```
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```

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will cause a linker error. Using CHARACTER\*1 arrays initialized with DATA statements or char() functions can be used to create a character constant.

**STEP 4** Create (**File**, **New**) a Resolve to FORTRAN interface function. This subroutine must have the name FHOOK.f. The following function can be used as a boiler plate code.

```
SUBROUTINE FHook(args, revals)
      REAL*8 args(*), revals(100)
      REAL*8 arg1, arg2, arg3, arg4, arg5
      REAL*8 arg6, arg7, arg8, arg9, arg10, arg11, arg12
c If your subroutine needs other type of variables (real*4, integer,
  etc.) use the appropriate conversion function to avoid garbage from
С
c being passed. Here are some examples
С
                                    !from real*8 to real*4
      a = SNGL(args(1))
С
                                   !from real*8 to integer*4
      b = IDINT(args(2))
С
                                   !from real*8 to Integer*2
      c = IIDINT(args(3))
С
                                   lany to real*8
      args(4) = DBLE(d)
С
                                 IThis is the setting of the subroutine
      argl = args(1)
                                larguments. Add more statements as
      arg2 = args(2)
                                 las needed.
      arg3 = args(3)
      arg4 = args(4)
      arg5 = args(5)
c Calling your subroutine. Change this call as necessary to match
c your subroutine.
      call yoursub(arg1,arg2,arg3,arg4,arg5,
                    arg6, arg7, arg8, arg9, arg10, arg11, arg12)
      å
                                  !This sets the output array
      revals(1) = arg6
                                  with the appropriate
      revals(2) = arg7
                                  !subroutine arguments.
      revals(3) = arg8
      revals(4) = arg9
       revals(5) = arg10
       revals(6) = argl1
       revals(7) = arg12
       return
       end
```

STEP 5 Create a Build script. Either use the following example Build script file (saved as ResExtern.make) as boiler plate or use the **Create BuildCommands** menu. It is important to include CHookc.c.o in the OBJECTS sections. CHookc.c.o is the Resolve to FORTRAN hook.

| # | File:    | ResExtern.make        |                                    |
|---|----------|-----------------------|------------------------------------|
| # | Target:  | ResExtern             |                                    |
| # | Sources: | FHook.f SetUp.f yours | ub.I                               |
| # | Created: | Friday, March 5, 1993 | 2:21:05 PM                         |
|   |          | Page 3 of 10          | Printed: Wednesday, March 10, 1993 |

FORTRAN external functions for Claris Resolve and Language System FORTRAN

OBJECTS = CHookc.c.o FHook.f.o SetUp.f.o yoursub.f.o ResExtern ff ResExtern.make {OBJECTS} Link -t RsTl -c Rslv  $\partial$ {OBJECTS}  $\partial$ "{Libraries}"Runtime.o  $\partial$ "{Libraries}"Interface.o  $\partial$ "{FLibraries}"FORTRANlib.o  $\partial$ "{FLibraries}"IntrinsicLib.o  $\partial$ -o ResExtern FHook.f.o f ResExtern.make FHook.f FORTRAN FHook.f -opt=1 SetUp.f.o f ResExtern.make SetUp.f FORTRAN SetUp.f -opt=1 yoursub.f.o f ResExtern.make yoursub.f FORTRAN yoursub.f -opt=1

### Running Create Build Commands

- 1. Select Create Build Commands... under the Build menu.
- 2. In **Program Name** type the name of the file used in the *file\_text* argument of the GET EXTERNAL function. In the above example the **Program Name** is ResExtern.
- 3. Click on the **Source Files...** button and select the function and subroutines that will be linked together. These include FHOOK.f and SetUp.f as well as your subroutine.

### 4. Click on **CreateMake**

5. Open the file "Program Name".make (in the above example it would be ResExtern.make) and change the following:

Add CHookc.c.o in the front of the OBJECTS list. Remove : -w -f -srt -ad 4 Change the APPL to RsT1 Change the '????' to Rs1v Remove the lines: Echo "Include d" {FLibraries}Fresources.rd";" > "{FLibraries}Resource.inc" Rez "{FLibraries}Resource.inc" -a -m -o "filename." FSIZE "filename." Remove the following libraries: "{FLibraries}"FSANELib.o d Remove unnecessary libraries noted by the Linker. They will not cause a linker abort, but there will be a warning.

- STEP 6 Run Build... under the Build menu. In the window type the program file name.
- STEP 7 Correct the code to remove any compile and linker errors and repeat STEP 6.
- **STEP 8** Quit MPW

- **STEP 9** Move the compiled function file into the same folder as the Resolve application.
- **STEP 10** Launch Resolve
- STEP 11 Create a Button using button tool from tool palette. Name it Load (Edit, Button info...)
- STEP 12 Open the button script (Script, Button Script) and write: GET EXTERNAL ":ResExtern" Replace the word ResExtern with the name of your compiled function file.
- **STEP 13** Close button script and save.
- STEP 14 Create a Button using button tool from tool palette. Name it Calculate (Edit, Button Info...)
- STEP 15 Open the button script (Script, Button Script) and write a Resolve script that defines your input variables, one output variable and a counter. Because Resolve External Functions can only return one value at a time you will have to create a loop and call your function once for each subroutine return variable you want. Your function call will include each of your input variables and the counter. The counter must be the last item in the list. Assign the return variable to the function (ie. x = function). For the first call to the function the counter must be equal to zero. The return value will be the first return variable. Therefore, the loop counter should go from zero to "the number of return variables"-1. The follow example is for the function FHook in the ResExtern file. FHook has 5 input variables and 7 output variables. The input values are located in cells B1, B2, B3 B4 and B5 on the spreadsheet. The return values will be placed in cells C1, C2, C3, C4, C5, C6 and C7 as directed by the PUT x statement.

```
DEFINE a,b,c,d,e,n,x

a = B1

b = B2

c = B3

d = B4

e = B5

FOR n = 0 TO 6

x = ResExtern:FHook(a,b,c,d,e,n)

PUT x INTO MAKECELL(3,n+1)

END FOR
```

Replace the word ResExtern with the name of your compiled function file and FHOOK for the name you specified when running Funchame.

- **STEP 16** Close button script
- **STEP 17** Press the "Load" button This loads the external function.
- **STEP 18** Press the "Calculate" button to run the function
- **STEP 19** Save worksheet.

After following this procedure you will have two files to keep track of:

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- FORTRAN Function
- Resolve worksheet

To avoid operational problems keep these files in the same folder. Similarly there are FORTRAN files that should be kept together:

- Function source code file
- Any Subroutine source code files
- Function .make file

#### PROBLEMS

The following are some special errors that may occur during the development process and some hints that may help to eliminate these problems.

#### Compiling

No special errors.

#### Linking

1. Cannot modify 32 bit instructions. The object files were complied with the wrong compiler settings. Delete all of the .f.o object files and re-run the **Build**.

#### Resolve

- 1. Invalid argument. CHookc.c.o was written to check for non-numeric input variables. This error means that a non-numeric value has been entered an input cell of the spreadsheet.
- 2. Can not open function.
  - Check the function name in the script to be sure it is the same name as specified in SetUp.f.
    - Check that the function file is in the same folder as the Resolve application.

Use Open · Tool:mySFGetFile external function. See next section for more information.

#### Open · Tool:mySFGetFile

A useful tool for finding a file while running a Resolve script is the external function mySFGetFile. This function will open a standard "Open File" window and allow the user to find the desired file. This function returns the full path name of the file which can be used with file functions to load or open the file. The function mySFGetFile is located in the file Open · Tool. This file comes with Resolve and is located in the folder External Examples within the Resolve Samples folder.

There are many ways to setup your Resolve folder, but for simplicity and this example create a folder named Externals and place it in the same folder as the Resolve application. Move or copy the Open.Tool file into the Externals folder. Now the script line:

GET EXTERNAL ":Externals:Open.Tool"

will load the Open•Tool:mySFGetFile function. The form of the function is:

```
Open.Tool:mySFGetFile(<prompt string>,"<file type1>","<file
type2>","<file type3>","<file type4>")
```

were file type1, file type2, file type3 and file type4 are file type filters (e.g. PICT, APPL, TEXT, etc). These filters will cause files of the type specified to appear in the Open dialog. If no filters are passed, files of all types will appear. In the case of Resolve external functions the file type is RsTI. The following example shows how the script in STEP 15 would be written when the mySFGetFile function is added within an error handling routine (ON ERROR).

```
DEFINE a,b,c,d,e,n,x,fullpath
a = B1
b = B2
c = B3
d = B4
e = B5
GET EXTERNAL ":Externals:Open·Tool"
GET EXTERNAL "ResExtern"
       FOR n = 0 TO 4
              x = ResExtern:FHook(a,b,c,d,e,n)
             PUT x INTO MAKECELL(3, n+1)
       END FOR
ON ERROR
       y = LError()
fullpath = 'Open.Tool:mySFGetFile'("Please find
'ResExtern':","RsTl","","")
              GET EXTERNAL fullpath
       END IF
       IF(y = 12)
                     SOUND EFFECT "Monkey"
                     SOUND EFFECT "Monkey"
                     SOUND EFFECT "Monkey"
                     MESSAGE SError()
                     ABORT
       END IF
END ERROR
```

The mySFGetFile function can also be added to the resource fork of the spreadsheet. To do this requires ResEdit and a knowledge of how to use it. WARNING: Misuse of ResEdit can cause irreparable damage to files and applications.

#### FPU OPTIONAL CODE

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Language System FORTRAN has the option of compiling your code to take advantage of the type of machine and the presence of an FPU. Because this is compiler option Language System FORTRAN will allow for FPU optional code generation. Meaning that the same external function can run on a Plus as well as a Quadra 950 and take advantage of the FPU. To do this requires minimal additional programing.

- **STEP 20** Duplicate your subroutine and give the file a different name than the original.
- **STEP 21** Modify this file by renaming the main subroutine and all lower subroutines and subroutine calls. Failure to do this will cause a linker warning about duplicate names and could cause run time problems.
- **STEP 22** Modify the FHook.f file by adding the following lines between the last declaration and the first operational line:

!!MP Inlines.f

INCLUDE '{MPW}Interfaces:FIncludes:OSUtils.f' INCLUDE '{MPW}Interfaces:FIncludes:Traps.f' POINTER /SysEnvRec/ SysEnvRecPtr SysEnvRecPtr = NewPtr(sizeof(SysEnvRec)) OSErr = SysEnvirons(curSysEnvVers,SysEnvRecPtr)

**STEP 23** Modify the FHook.f file prior to the subroutine call by adding an if-then statement checking the variable SysEnvRecPtr^.hasFPU. In the TRUE section of the if put the call to the new subroutine. In the FALSE section put the original call. Save FHook.f.

The FHook.f program in STEP 4 would now look like this:

SUBROUTINE FHook(args, revals)

REAL\*8 args(\*), revals(100) REAL\*8 arg1,arg2,arg3,arg4,arg5 REAL\*8 arg6,arg7,arg8,arg9,arg10,arg11,arg12

IIMP Inlines.f

INCLUDE '{MPW}Interfaces:FIncludes:OSUtils.f'
INCLUDE '{MPW}Interfaces:FIncludes:Traps.f'

POINTER /SysEnvRec/ SysEnvRecPtr

SysEnvRecPtr = NewPtr(sizeof(SysEnvRec))
OSErr = SysEnvirons(curSysEnvVers,SysEnvRecPtr)

c If your subroutine needs other type of variables (real\*4, integer, c etc.) use the appropriate conversion function to avoid garbage from c being passed. Here are some examples С !from real\*8 to real\*4 a = SNGL(args(1))С !from real\*8 to integer\*4 b = IDINT(args(2))С !from real\*8 to Integer\*2 c = IIDINT(args(3))С lany to real\*8 args(4) = DBLE(d)С This is the setting of the subroutine arg1 = args(1)larguments. Add more statements as arg2 = args(2)las needed. arg3 = args(3)

```
arg4 = args(4)
      arg5 = args(5)
c Calling your subroutine. Change this call as necessary to match
c your subroutine.
      if(SysEnvRecPtr^.hasFPU) then
  Use FPU
С
          call yoursub81(arg1,arg2,arg3,arg4,arg5,
                    arg6, arg7, arg8, arg9, arg10, arg11, arg12)
     £
      else
  NO FPU
С
           call yoursub(arg1,arg2,arg3,arg4,arg5,
                    arg6, arg7, arg8, arg9, arg10, arg11, arg12)
     £
      end if
                                   IThis sets the output array
      revals(1) = arg6
                                  with the appropriate
      revals(2) = arg7
                                  !subroutine arguments.
      revals(3) = arg8
      revals(4) = arg9
      revals(5) = arg10
      revals(6) = arg11
      revals(7) = arg12
      return
      end
```

**STEP 24** Modify the .make file by adding the new subroutine file in the compile list. Do this by copying the old subroutine compile directive and pasting it to the end of the compile list. Change the old subroutine name to the new name. Add to the compiler options of the new subroutine -MC68020 -MC-68881. These new options will take advantage of 68020 and above CPUs with 68881 and above FPUs. This covers most of the Mac IIs and the new high end Macs. The new mid range Macs may or may not have an FPU. Add the new subroutine object file name in the OBJECTS list and save the file.

The Make file in the first STEP 5 would now look like this:

```
ResExtern.make
    File:
#
                ResExtern
    Target:
#
                FHook.f SetUp.f yoursub.f
    Sources:
#
                Friday, March 5, 1993 2:21:05 PM
#
    Created:
OBJECTS = CHookc.c.o FHook.f.o SetUp.f.o yoursub.f.o yoursub81.f.o
ResExtern ff ResExtern.make {OBJECTS}
      Link -t RsTl -c Rslv \partial
             {OBJECTS} ∂
              {Libraries} "Runtime.o ∂
             "{Libraries}"Interface.0 d
             "{FLibraries}"FORTRANLib.0 \partial
             "{FLibraries}"IntrinsicLib.0 ∂
             -o ResExtern
FHook.f.o f ResExtern.make FHook.f
```

```
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```

FORTRAN external functions for Claris Resolve and Language System FORTRAN

FORTRAN FHook.f -opt=1 SetUp.f.o f ResExtern.make SetUp.f FORTRAN SetUp.f -opt=1 yoursub.f.o f ResExtern.make yoursub.f FORTRAN yoursub.f -opt=1 yoursub81.f.o f ResExtern.make yoursub81.f FORTRAN yoursub81.f -opt=1 -MC68020 -MC68881

STEP 25 Re-run the make file by using the **Build...** under the **Build** menu.

This new external function will work on all Macs. If the Mac has an FPU the performance of the function will be increased over the original function created in **STEP 1** through **STEP 19**.

FORTRAN external functions for Claris Resolve and Language System FORTRAN

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## **USER GUIDE**

Subject: External Functions for Claris Resolve for the Macintosh written in FORTRAN complied with Absoft MacFortran II version 3.1 and MPW version 3.2

Written By: David W. Harris Rocketdyne Division Rockwell International PO Box 7922 6633 Canoga Ave. Canoga Park, CA 91309-7922 (818) 718-4677
Date: February 10, 1993

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**Purpose:** This User guide is to lead a person with limited knowledge of Macintosh programing through the steps necessary to turn a FORTRAN subroutine into an Resolve external function. This guide assumes that the user has a little familiarity with the Absoft FORTRAN compiler and Claris Resolve. For more detailed information refer to the MacFortran II Reference Manual and to the Resolve User Guide and Claris Technical Note.

### INTRODUCTION

Claris Resolve versions 1.1v1 and above have the ability to call external code that can be used as spreadsheet functions. This code is an assembly language code with the proper data handling that allows it to be called or linked to other code. To create a Resolve external function with this guide you must have the following:

- 1. The CHookc.c.o object file
- 2. A FORTRAN subroutine SetUp.f
- 3. A FORTRAN subroutine FHook.f
- 4. Your FORTRAN subroutine
- 5. Funchame application

Note: The Absoft MacFortran II compiler creates code that requires an FPU. Therefore, the code development described here will not work on some of the older Mac's (Plus,SE) and some of the newer ones without FPUs (Classic, LC, SI, Centris).

Because of the required interface between Resolve and an external function an interface program or "hook" had to be written in "C" code. This program handles the setting of variables that Resolve uses to call the external function and the passing of program variables. A hook called CHookc.c.o was created as a generic interface. This hook calls two FORTRAN subroutines, SetUp.f and FHook.f. The SetUp.f subroutine supplies the CHook with two necessary pieces of information, the name of the function to be used by Resolve and the number of input arguments. The name of the function is not the file name but the function name used in the Resolve script to call the external function. The function name cannot be over 8 characters long. Because the passing of string variables from FORTRAN to C is tricky, an application, Funchame, has been provided to create the SetUp.f file. Executing this program will create a complete SetUp.f file ready for compiling and linking. FHook.f is the front-end for your subroutine. Your subroutine will be called by FHook.f. FHook.f must be written with two arguments, an input array and an output array. Both arrays must be double precision REAL and dimensioned input(\*) and output(100). The generic "C" hook was written to handle infinite input and 100 output variables. FHOOK. f can be used to manipulate the input and output data to your subroutine. That is do things such as reassign the values to other variable, change from double to single precision, convert the value and so on.

The following is a set of steps that will allow you to create a Resolve external using the CHookc.c.o interface. It is suggested that all of the steps are followed the first time. After that any changes to the FORTRAN code that do not change file names will require only a simple **Build** command and maybe minor changes to the Resolve script.

- **STEP 1** Create a SetUp subroutine. To do this run the program Funcname. This program will create a file SetUp.f that is necessary for the Resolve interface. When Funcname asks for 'Resolve Function Name', enter the name that you what to call the function in Resolve and for 'Number of Input variables', enter the number of input variables to your subroutine.
- STEP 2 Launch MPW
- **STEP 3** Open (**File, Open...**) and change your FORTRAN subroutine so that it meets the programing rules.

### **Programing Rules**

- No global or static storage: FORTRAN programs can have no COMMON, BLOCK DATA, or SAVE statements and the -s compiler option cannot be used to force static storage.
- No FORTRAN I/O statements: see the following list. A lack of I/O is a serious limitation, but I/O is often for user interaction which is the function of Resolve.

| ACCEPT    | OPEN   |
|-----------|--------|
| BACKSPACE | PAUSE  |
| CLOSE     | PRINT  |
| DECODE    | READ   |
| ENCODE    | REWIND |
| ENDFILE   | STOP   |
| FORMAT    | TYPE   |
| INOUIRE   | WRITE  |
| NAMELIST  |        |

- No run time error messages: some compiler options such as the "Check array boundaries" option, -C, and the subprogram folding options, -z and -Z, can generate a run time error message. A CASE statement with a missing CASE DEFAULT can also cause a run time error unless the -N4 option is used.
- No character constants: a statement such as

```
CHARACTER*26 myString myString = 'I paid my taxes on April 7.'
```

will cause a linker error. Using CHARACTER\*1 arrays initialized with DATA statements or char() functions can be used to create a character constant.

**STEP 4** Create (**File, New**) a Resolve to FORTRAN interface function. This subroutine must have the name FHOOK.f. The following function can be used as a boiler plate code.

SUBROUTINE FHook(args, revals)

```
REAL*8 args(*), revals(100)
REAL*8 arg1,arg2,arg3,arg4,arg5
REAL*8 arg6,arg7,arg8,arg9,arg10,arg11,arg12
```

```
c If your subroutine needs other type of variables (real*4, integer,
c etc.) use the appropriate conversion function to avoid garbage from c being passed. Here are some examples
С
                                    !from real*8 to real*4
      a = SNGL(args(1))
С
                                   from real*8 to integer*4
      b = IDINT(args(2))
С
                                   !from real*8 to Integer*2
      c = IIDINT(args(3))
С
                                   !any to real*8
      args(4) = DBLE(d)
С
                                 IThis is the setting of the subroutine
      argl = args(1)
                                 larguments. Add more statements as
      arg2 = args(2)
                                 las needed.
      arg3 = args(3)
      arg4 = args(4)
      arg5 = args(5)
c Calling your subroutine. Change this call as necessary to match
c your subroutine.
      call yoursub(arg1,arg2,arg3,arg4,arg5,
                    arg6,arg7,arg8,arg9,arg10,arg11,arg12)
      £
                                  !This sets the output array
      revals(1) = arg6
                                  with the appropriate
      revals(2) = arg7
                                  Isubroutine arguments.
      revals(3) = arg8
      revals(4) = arg9
      revals(5) = arg10
       revals(6) = argll
       revals(7) = arg12
       return
       end
```

FORTRAN external functions for Claris Resolve and Absoft MacFortran II

STEP 5 Create a Build script. Either use the following example Build script file (saved as ResExtern.make) as boiler plate or use the **Create BuildCommands** menu. It is important to include CHookc.c.o in the OBJECTS sections. CHookc.c.o is the Resolve to FORTRAN hook.

| # # #<br>#      | File:<br>Target:<br>Sources:<br>Created:                                                                                        | ResExtern.make<br>ResExtern<br>FHook.f SetUp.f<br>Monday, January 18, 1993 9:16:12 AM                                                                                                                                                                             |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| OB              | JECTS = CHOON                                                                                                                   | c.c.o FHook.f.o SetUp.f.o yoursub.f.o                                                                                                                                                                                                                             |
| FFI             | LAGS = -q -k                                                                                                                    | -N14                                                                                                                                                                                                                                                              |
| Re:<br>FH<br>Se | sExtern ff Re<br>Link -t<br>{OI<br>"{1<br>"{1<br>"{2<br>-O<br>cok.f.o f Re<br>f77comp<br>tUp.f.o f Re<br>f77comp<br>ursub.f.o f | <pre>SExtern.make {OBJECTS} 'RsTl' -c Rslv d BJECTS} d Libraries}"Runtime.o d Libraries}"Interface.o d FLibraries}"f77math.o d ResExtern SExtern.make FHook.f iler {FFLAGS} FHook.f iler {FFLAGS} SetUp.f ResExtern.make yoursub.f iler {FFLAGS} your.sub.f</pre> |

### Running Create BuildCommands

- 1. Select Create BuildCommands... under the MacFortran menu.
- 2. In **Program Name** type the name of the file used in the *file\_text* argument of the GET EXTERNAL function. In the above example the **Program Name** is ResExtern.
- 3. Click on the **Source Files...** button and select the function and subroutines that will be linked together. These include FHOOK.f and SetUp.f as well as your subroutine.
- 4. Click on CreateMake
- 5. Open the file "Program Name".make (in the above example it would be ResExtern.make) and change the following:

Add -N14 -k next to FFLAGS -q, separated with only a space. Add CHookc.c.o in the front of the OBJECTS list. Remove the line: *filename ff filename*.make Duplicate -r -y "{FLibraries}F77mrwe.o" *filename* Change the APPL to 'RsTl' Change the '????' to 'Rslv'

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Remove -f -model far

Remove the following libraries:

- "{FLibraries}"F77mrwe.o  $\partial$ "{FLibraries}"frt0.o  $\partial$ "{FLibraries}"f77io.o  $\partial$
- Remove unnecessary libraries noted by the Linker. They will not cause a linker abort, but there will be a warning.

If Linker reports 32K jump errors add -N8 and -N11 to the FFLAGS list.

- Run Build... under the MacFortran menu. In the window type the program **STEP 6** file name.
- Correct the code to remove any compile and linker errors and repeat STEP 6. **STEP 7**
- **Ouit MPW STEP 8**
- Move the compiled function file into the same folder as the Resolve application. STEP 9
- **STEP 10** Launch Resolve
- Create a Button using button tool from tool palette. Name it Load (Edit, Button STEP 11 Info...)
- Open the button script (Script, Button Script) and write: **STEP 12** GET EXTERNAL ":ResExtern" Replace the word ResExtern with the name of your compiled function file.
- Close button script and save. STEP 13
- Create a Button using button tool from tool palette. Name it Calculate (Edit, **STEP 14 Button Info...**)
- Open the button script (Script, Button Script) and write a Resolve script that STEP 15 defines your input variables, one output variable and a counter. Because Resolve External Functions can only return one value at a time you will have to create a loop and call your function once for each subroutine return variable you want. Your function call will include each of your input variables and the counter. The counter must be the last item in the list. Assign the return variable to the function (ie. x =function). For the first call to the function the counter must be equal to zero. The return value will be the first return variable. Therefore, the loop counter should go from zero to "the number of return variables"-1. The follow example is for the function FHook in the ResExtern file. FHook has 5 input variables and 7 output variables. The input values are located in cells B1, B2, B3 B4 and B5 on the spreadsheet. The return values will be placed in cells C1, C2, C3, C4, C5, C6 and C7 as directed by the PUT x statement.

DEFINE a,b,c,d,e,n,x a = B1b = B2c = B3d = B4e = B5

FORTRAN external functions for Claris Resolve and Absoft MacFortran II

```
FOR n = 0 TO 6
    x = ResExtern:FHook(a,b,c,d,e,n)
    PUT x INTO MAKECELL(3,n+1)
END FOR
```

Replace the word ResExtern with the name of your compiled function file and FHOOK for the name you specified when running Funchame.

- **STEP 16** Close button script
- STEP 17 Press the "Load" button This loads the external function.
- **STEP 18** Press the "Calculate" button to run the function
- **STEP 19** Save worksheet.

After following this procedure you will have two files to keep track of:

- FORTRAN Function
- Resolve worksheet

To avoid operational problems keep these files in the same folder. Similarly there are FORTRAN files that should be kept together:

- Function source code file
- Any Subroutine source code files
- Function .make file

#### PROBLEMS

The following are some special errors that may occur during the development process and some hints that may help to eliminate these problems.

#### Compiling

No special errors.

#### Linking

- 1. Cannot modify 32 bit instructions. The object files were complied with the wrong compiler settings. Delete all of the .f.o object files and re-run the **Build**.
- 2. Cannot make 32K jump. Add -N8 and -N11 to the FFLAGS list. Delete all of the .f.o object files and re-run the **Build**.

#### Resolve

- 1. Invalid argument. CHookc.c.o was written to check for non-numeric input variables. This error means that a non-numeric value has been entered an input cell of the spreadsheet.
- 2. Can not open function.
  - Check the function name in the script to be sure it is the same name as specified in SetUp.f.

Check that the function file is in the same folder as the Resolve application. Use Open.Tool:mySFGetFile external function. See next section for more information.

#### Open · Tool:mySFGetFile

A useful tool for finding a file while running a Resolve script is the external function mySFGetFile. This function will open a standard "Open File" window and allow the user to find the desired file. This function returns the full path name of the file which can be used with file functions to load or open the file. The function mySFGetFile is located in the file Open · Tool. This file comes with Resolve and is located in the folder External Examples within the Resolve Samples folder.

There are many ways to setup your Resolve folder, but for simplicity and this example create a folder named Externals and place it in the same folder as the Resolve application. Move or copy the Open.Tool file into the Externals folder. Now the script line:

```
GET EXTERNAL ":Externals:Open.Tool"
```

will load the Open•Tool:mySFGetFile function. The form of the function is:

```
Open.Tool:mySFGetFile(<prompt string>,"<file type1>","<file
type2>","<file type3>","<file type4>")
```

were file type1, file type2, file type3 and file type4 are file type filters (e.g. PICT, APPL, TEXT, etc). These filters will cause files of the type specified to appear in the Open dialog. If no filters are passed, files of all types will appear. In the case of Resolve external functions the file type is RsTI. The following example shows how the script in STEP 15 would be written when the mySFGetFile function is added within an error handling routine (ON ERROR).

```
DEFINE a,b,c,d,e,n,x,fullpath
a = B1
b = B2
c = B3
d = B4
e = B5
GET EXTERNAL ":Externals:Open.Tool"
GET EXTERNAL "ResExtern"
      FOR n = 0 TO 4
             x = ResExtern:FHook(a,b,c,d,e,n)
             PUT x INTO MAKECELL(3, n+1)
      END FOR
ON ERROR
      y = LError()
fullpath = 'Open.Tool:mySFGetFile'("Please find
'ResExtern':","RsTl","","")
             GET EXTERNAL fullpath
       END IF
       IF(y = 12)
```

```
Page 7 of 8
```

FORTRAN external functions for Claris Resolve and Absoft MacFortran II

SOUND EFFECT "Monkey" SOUND EFFECT "Monkey" SOUND EFFECT "Monkey" MESSAGE SError() ABORT

END IF END ERROR

The mySFGetFile function can also be added to the resource fork of the spreadsheet. To do this requires ResEdit and a knowledge of how to use it. WARNING: Misuse of ResEdit can cause irreparable damage to files and applications.

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## **USER GUIDE**

**Subject:** External Functions for Microsoft Excel for the Macintosh written in FORTRAN complied with Absoft MacFortran II version 3.1 and MPW version 3.2

Written By: David W. Harris Rocketdyne Division Rockwell International PO Box 7922 6633 Canoga Ave. Canoga Park, CA 91309-7922 (818) 718-4677
Date: August 12 1992

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**Purpose:** This User guide is to lead a person with limited knowledge of Mac programing through the steps necessary to turn a FORTRAN subroutine into an Excel external function. This guide assumes that the user has a little familiarity with the Absoft FORTRAN compiler and Microsoft Excel. For more information refer to the MacFortran II Reference Manual and to the Excel User Guide, Function Reference and Microsoft Application Note: ME0333.

### INTRODUCTION

Microsoft Excel versions 2.2 and above have the ability to call external code resources that can be used as spreadsheet functions. A "Code Resource" is an assembly language code with the proper data handling that allows it to be called or linked to other code. There are many different types of code resources but for this application the resource needs to be type CODE. Apple Technical Note #256 has additional information on code resources but it is not necessary to read if the examples of this note are followed.

Note: The Absoft MacFortran II compiler creates code that requires an FPU. Therefore, the code development described here will not work on some of the older Mac's (Plus,SE) and some of the newer ones without FPUs (Classic, LC, SI, Centris).

Page 1 of 6

- Launch MPW STEP 1
- Open (File, Open...) and change your FORTRAN subroutine so that it meets the STEP 2 programing rules.

### **Programing Rules**

- No global or static storage: FORTRAN programs can have no COMMON, BLOCK DATA, or SAVE statements and the -s compiler option cannot be used to force static storage.
- No FORTRAN I/O statements: see the following list. A lack of I/O is a serious limitation, but I/O is often for user interaction which is the function of Excel.

| ACCEPT    | OPEN   |
|-----------|--------|
| BACKSPACE | PAUSE  |
| CLOSE     | PRINT  |
| DECODE    | READ   |
| FNCODE    | REWIND |
| ENDFILE   | STOP   |
| FORMAT    | TYPE   |
| TNOUTRE   | WRITE  |
| NAMELIST  |        |

- No run time error messages: some compiler options such as the "Check array boundaries" option, -C, and the subprogram folding options, -z and -Z, can generate a run time error message. A CASE statement with a missing CASE DEFAULT can also cause a run time error unless the -N4 option is used.
- · No character constants: a statement such as

CHARACTER\*26 myString myString = 'I paid my taxes on April 7.'

will cause a linker error. Using CHARACTER\*1 arrays initialized with DATA statements or char() functions can be used to create a character constant.

Create (File, New) an Excel to FORTRAN interface function. The following **STEP 3** function can be used as a boiler plate code. This example program is saved as xfunc.f.

PASCAL INTEGER\*4 FUNCTION MAIN(in)

c This function works as a Integer function in EXCEL with "KK" type\_text.

| STRUCTURE /inlist/<br>INTEGER*2 row<br>INTEGER*2 col<br>REAL*8 ary(100)<br>END STRUCTURE  | !This is the input list from Excel.                    |
|-------------------------------------------------------------------------------------------|--------------------------------------------------------|
| STRUCTURE /outlist/<br>INTEGER*2 row<br>INTEGER*2 col<br>REAL*8 ary(100)<br>END STRUCTURE | !This is the output list from the<br>!FORTRAN program. |
RECORD /inlist/ in RECORD /outlist/ out

c This is the declaration of arguments for the FORTRAN subroutine.

real\*8 arg1,arg2,arg3,arg4,arg5,arg6

c If your subroutine needs other type of variables (real\*4, integer, c etc.) use the appropriate conversion function to avoid passing garbage c Here are some examples C ifrom real\*8 to real\*4 a = SNGL(ary(1))С !from real\*8 to integer\*4 b = IDINT(ary(2))С ifrom real\*8 to Integer\*2 c = IIDINT(ary(3))С lany to real\*8 ary(4) = DBLE(d)С !This is the setting of the subroutine arg1 = in.ary(1)larguments. Add more statements as arg2 = in.ary(2)las needed. arg3 = in.ary(3)c Calling your subroutine. Change this call as necessary to match c your subroutine. call yoursub(arg1,arg2,arg3,arg4,arg5,arg6) IThis sets the worksheet area. out.row = 3

| out.col = 1                                                      | Adjust as needed.                                                             |
|------------------------------------------------------------------|-------------------------------------------------------------------------------|
| <pre>out.ary(1) = arg4 out.ary(2) = arg5 out.ary(3) = arg6</pre> | IThis sets the output array<br>with the appropriate<br>Isubroutine arguments. |

c The last thing to do is set the function values to the structure c pointer. No need to change this statement.

```
MAIN = LOC(out)
return
end
```

The STRUCTURE in this function would be good for any combination of arguments where row\*columns <= 100. The RECORD declaration is necessary to assign the name "in" to the structure "inlist". The variables are now referred to with the prefix "in." (in.row, in.col, in.ary(1), ...). The values in ary are arranged as such:

```
ary(1) = row<sub>1</sub>,col<sub>1</sub>
ary(2) = row<sub>1</sub>,col<sub>2</sub>
.
ary(m) = row<sub>1</sub>,col<sub>m</sub>
ary(m+1) = row<sub>2</sub>,col<sub>1</sub>
.
ary(n*m) = row<sub>p</sub>,col<sub>m</sub>
```

**STEP 4** Create a Build script. Either use the following example Build script file (save as xfunc.make) as boiler plate or use the **Create BuildCommands** menu.

| # # # #  | File:<br>Target:<br>Sources:<br>Created: | xfunc.make<br>xfunc<br>xfunc.f yoursub.f                                                     |
|----------|------------------------------------------|----------------------------------------------------------------------------------------------|
| #<br>OBJ | Add to this<br>TECTS = xfunc             | OBJECTS list all necessary subroutines<br>.f.o yoursub.f.o                                   |
| FFI      | $\Delta GS = -q - N$                     | .4 -k                                                                                        |
| χſι      | inc ff xfunc.<br>Link -t X<br>{OI        | make {OBJECTS}<br>LLB -c XCEL -rt CODE=128 -m MAIN -sg main $\partial$<br>SJECTS} $\partial$ |
| #        | This library                             | I list can be modified to remove unnecessary                                                 |
| #        | libraries                                |                                                                                              |
|          | " {1                                     | Libraries "Runtime.o $\sigma$                                                                |
|          | " {]                                     | Libraries   "E77stubs 0 d                                                                    |
|          | " {]                                     | "Libraries) F//Stubs.0 0                                                                     |
|          | " { I                                    | (Libraries) fiction of                                                                       |
|          | ۲ (۱<br>۱۱ (۲                            | $f_{1}$                                                                                      |
|          | 1                                        | sting                                                                                        |
|          | ung fof yf                               | unc.make xfunc.f                                                                             |
| XT.      | f77comp                                  | iler {FFLAGS} xfunc.f                                                                        |
| #        | Repeat the                               | next two lines for each subroutine and change                                                |
| #        | yoursub to                               | each of the subroutine names                                                                 |
| yo       | ursub.f.o f                              | xfunc.make yoursub.f                                                                         |
| -        | f77comp                                  | iler {FFLAGS} yoursub.f                                                                      |

## Running Create BuildCommands

- 1. Select Create BuildCommands... under the MacFortran menu.
- 2. In **Program Name** type the name of the file used in the *file\_text* argument of the REGISTER or CALL function. In the above example the **Program Name** is xfunc.
- 3. In the Program Type box select Code Resource
- 4. In the box next to **Creator** put **HCEL**. (Note characters must be all upper case.)
- 5. In the box next to **Type** put **HLLB**. (Note characters must be all upper case.)
- 6. In the box next to **Main Entry Point** type the name of the FORTRAN function. Must be all upper case. This is the name used in the *resource\_text* argument of the REGISTER or CALL function. In the above example the **Main Entry Point** is MAIN.

- 7. In the box next to **Resource Type** put **CODE=128**
- 8. Click on the **Source Files...** button and select the function and subroutines that will be linked together. The main function (the one called by Excel) must be first. In the above example xfunc.f is the main program and yoursub.f is a subroutine.
- 9. Click on **CreateMake**
- 10. Open the file "Program Name".make (in the above example it would be xfunc.make) and change the following:

Add -N14 -k next to FFLAGS -q, separated with only a space.

Change the word next to -sg to the same name as the -m option only all lower case. When this link is run any unnecessary libraries will cause a warning message. They will not cause a linker abort, but there will be a warning. The unnecessary libraries can be removed for the library list. (See above example)

- **STEP 5** Run **Build...** under the **MacFortran** menu. In the window type the program file name.
- **STEP 6** Correct the code to remove any compile and linkers errors and repeat **STEP 5**.
- **STEP 7** Quit MPW
- **STEP 8** Move the compiled function file into the Excel folder.
- **STEP 9** Launch Excel
- **STEP 10** Open a new Macro sheet. (File, New...)
- **STEP 11** Create the following macro:

|   | A                              |
|---|--------------------------------|
| 1 | load                           |
| 2 | =REGISTER("xfunc","MAIN","KK") |
| 3 | =RETURN()                      |

Replace the word **Hfunc** with the name of your compiled function file.

- **STEP 12** Select cell A1 and then select **Define Name** under the **Formula** Menu. Select the **Command** button and type p in the box next to **Key:.** Click **OK.** Now pressing "option  $+ \mathbf{4} + p$ " will load the external function.
- STEP 13 Save this Macro sheet as **load.xfunc** using **Saue As...**
- **STEP 14** Press "option  $+ \mathbf{\bullet} + \mathbf{p}$ ". This loads the external function.
- **STEP 15** Press "  $\bigstar$  + ` ". In A2 a number should be there, if not there is something wrong with the REGISTER arguments, the Build script or the interface code. Check for

FORTRAN external functions for Microsoft Excel and Absoft MacFortran II

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consistency between names and arguments. Press "  $\bigstar$  + ` " again to return to normal display.

**STEP 16** Create your worksheet and select the appropriate output range for your function and type in a CALL function with **load.xfunc!\$A\$2** as the *register text* and the appropriate input range. Enter the function by pressing "**c** + enter" (This entry method is necessary for any Excel array function). The following is an example for a function that has a 3 cell input range and a 1-by-3 (rows by columns) output range:

|   | A                              |   |
|---|--------------------------------|---|
| 1 |                                | 1 |
| 2 |                                | 2 |
| 3 |                                | 3 |
| 4 |                                |   |
| 5 | =CALL(load.xfunc!\$A\$2,A1:A3) |   |
| 6 |                                |   |
| 7 |                                |   |

The double box is the selected area. Cells A5, A6 and A7 are now the return array.

- **STEP 17** Save the worksheet.
- STEP 18Select Define Name under Formula menu<br/>In the Name: box type auto\_load<br/>In the Refers to: box type load.xfunc!load<br/>Click Add<br/>Click Ok
- **STEP 19** Save worksheet. Now when the worksheet is opened the Macro sheet will automatically be opened and executed, loading the external function.

After following this procedure you will have three files to keep track of:

- FORTRAN Function
- Excel worksheet
- Excel Macro sheet

To avoid operational problems keep these files in the same folder. Similarly there are FORTRAN files that should be kept together:

- Function source code file
- Any Subroutine source code files
- Function .make file

|                                                                                                                                                                      | REPORT DO                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       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The fixed point do<br>the STME, F-1, F-1A, J-<br>Further parametric model<br>SUBJECT TERMS<br>Propulsion, Database, Ro                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | and Workingsolutionz So<br>TATEMENT<br>was to produce a propulsi<br>omprehensive in the level<br>parametric data using the<br>fixed point design propuls<br>has models for LOX/H <sub>2</sub> ar<br>ellants, a hybrid rocket bo<br>atabase has extensive form<br>2, J-2S, SSME, RD-170,<br>s and specific engine data<br>pocket Engine | ftware were team n<br>on system database<br>of detail available.<br>Macintosh spreadsl<br>ion systems using<br>d LOX /RP liquid<br>poster, and a NERV<br>natting and reportin<br>IME, RSRM, and<br>will be incorporate  | e which is eas<br>Two separate<br>heet Resolve 1<br>the Macintosh<br>engines, solid<br>/A derived nuc<br>g options and<br>a nuclear eng<br>d in the next y | is effort.<br>THON CODE<br>By to use and<br>databases were<br>1.1, and one to<br>database<br>1 rocket boosters<br>clear thermal rocket<br>contains data on<br>jine.<br>year.<br>NUMBER OF PAGES<br>290<br>PRICE CODE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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