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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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Rocketdyne Division

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3/6

Table of Contents

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

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" must 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 requires 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_2 as oxidizer and HTPB and escorez as fuel – pressure fed
- Cryogenic Engines
  - Large (100k-2M lbf) LOX/H_2 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_2 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_2 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_2 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_2 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_2, 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_2 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_2) being studied. For divergence losses, a curve-fit 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_2, 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.

Weight. The weight for the LOX/H_2 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_2 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_2 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
2. Go to the "Script" item in the menu bar and select "Unload Script" and "Library"
   If "Unload Script" is grayed in the menu bar then skip this step
3. Go to the "Script" item in the menu bar and select "Open Script..."
4. Use the resulting dialog box to find and open the file "Library"
5. Make the desired changes
6. Go to the "File" item in the menu bar and select "Save"
7. Go to the "File" item in the menu bar and select "Close"
8. Go to the "Script" item in the menu bar and select "Worksheet Script"
9. Highlight the following four lines with the cursor:

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

10. Go to the "Edit" item in the menu bar and select "Copy"
11. Go to the "Edit" item in the menu bar and select "Select All"
12. Press "Delete" key
13. Go to the "Edit" item in the menu bar and select "Paste"
14. Go to the "File" item in the menu bar and select "Close"
15. Press any active button which forces the program to attach the file "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, all 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 relook-ups are not automatic in FileMaker Pro.

References

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

Parametric Propulsion

Database Figures

TA3–0427

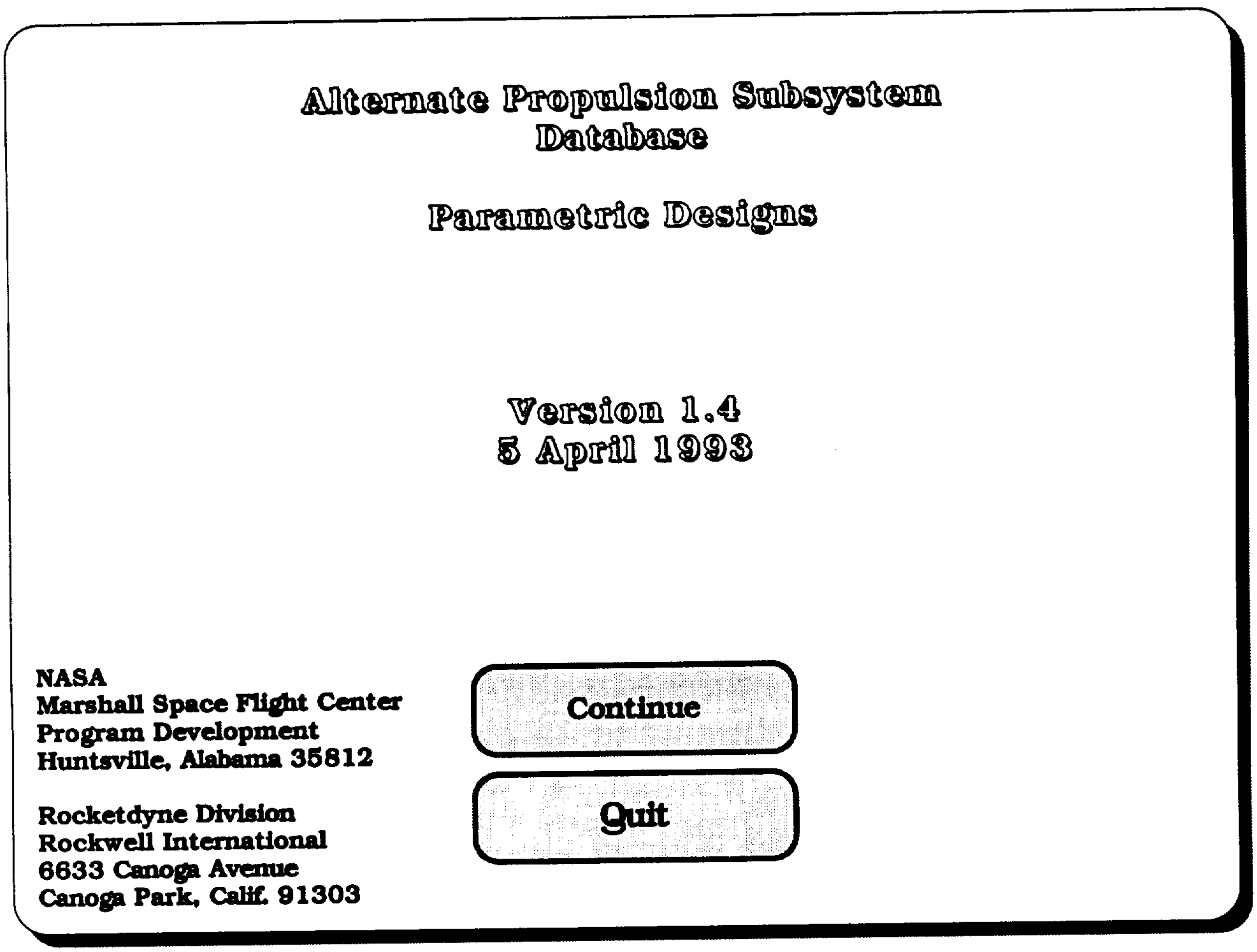

Figure 1. Parametric Database Opening Screen

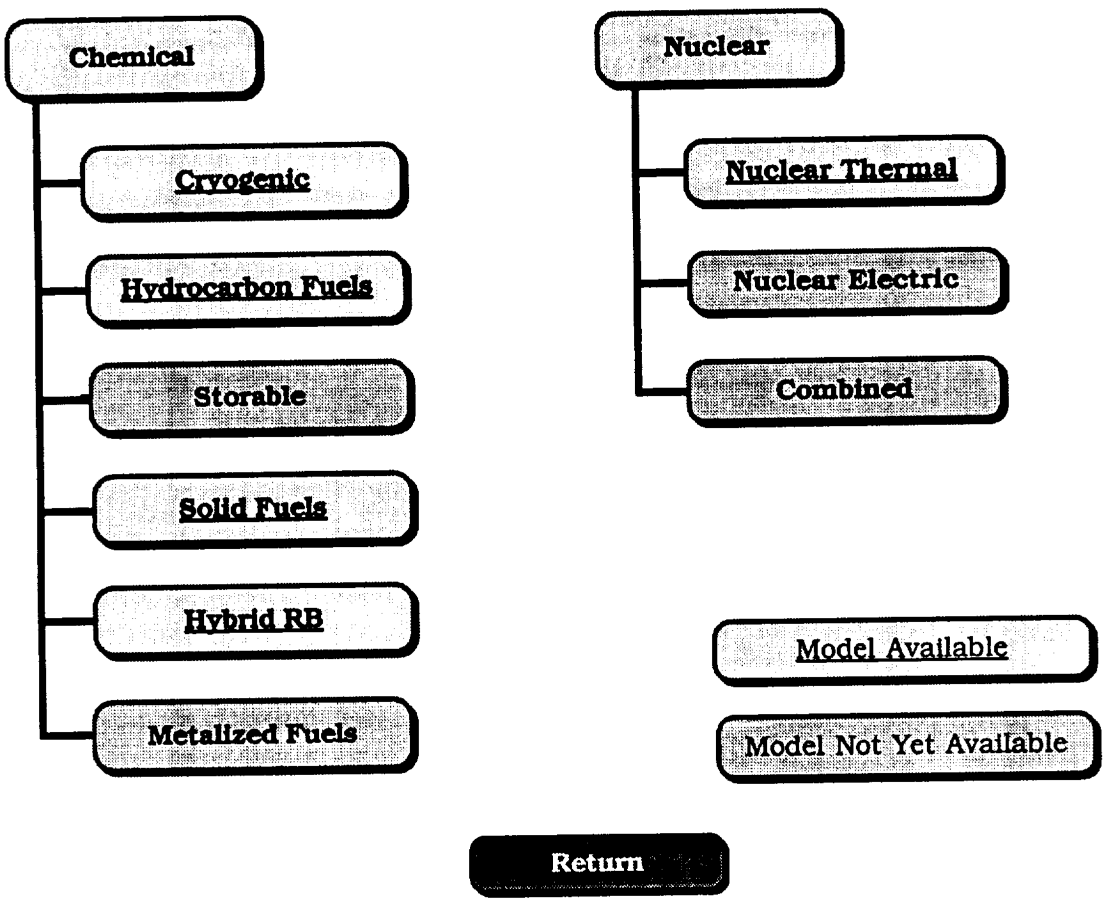

Figure 2. Main Navigation Screen

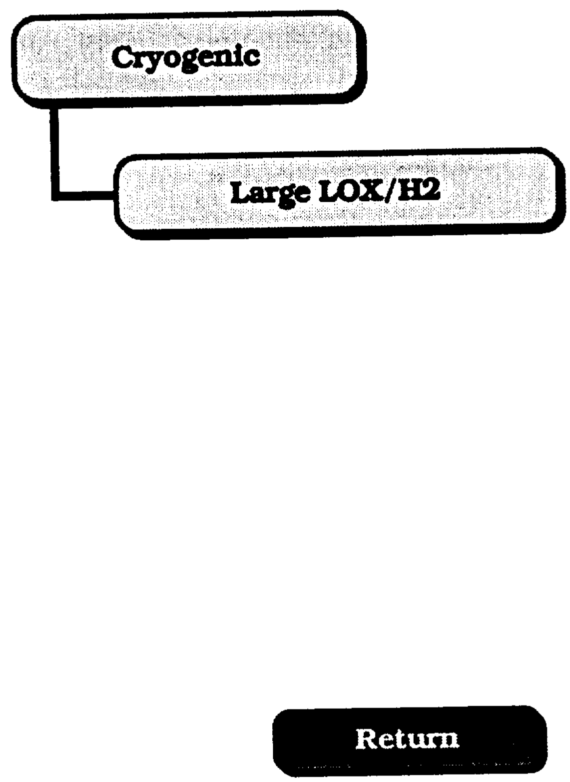

Figure 3. Current Cryogenic Models

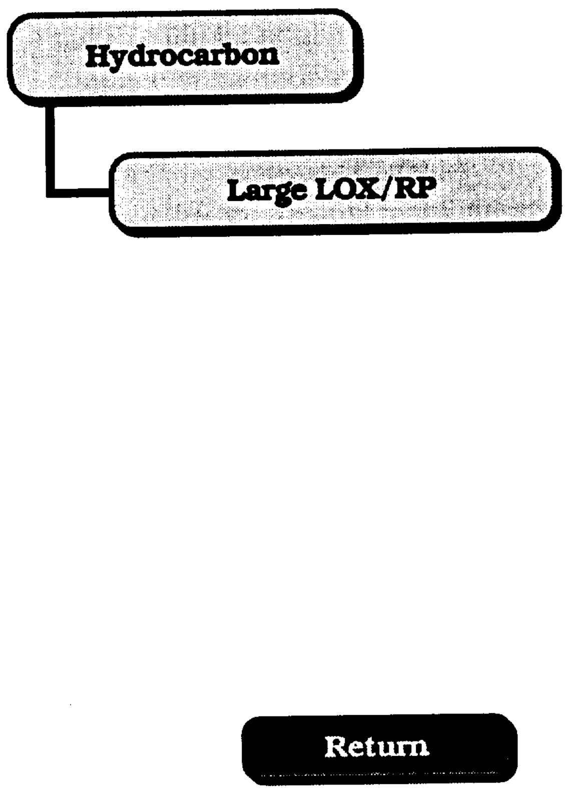

Figure 4. Current Hydrocarbon Models

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OF POOR QUALITY

Return | English Units | Print (Report) | Print (Briefing)

Calculate - LOX/H2 | Page Down | Graphs

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* Efficiency	0.98450	0.85 to 0.999
Fuel Inlet Enthalpy, kcal/mole	-1.270	-2.154 to 1.856

Performance	Value
Vacuum Thrust, klbf	512.845
Vacuum Isp, sec-lbf/lbm	452.983
SL Thrust, klbf	418.772
SL Isp, sec-lbf/lbm	369.891
ODE C-Star, ft/sec	7,753.620
L-Star, in	30.399
ODE Isp, sec-lbf/lbm	468.923
Energy Release Efficiency	0.984
Kinetic Efficiency	1.000
Divergence Efficiency	0.993
Boundary Layer Efficiency	0.989
Engine Efficiency	0.967

Dimensions	Value
Throat Diameter, in	10.3
Throat Area, in^2	83.2
Chamber Length, in	12.3
Nozzle Exit Diameter, in	90.3
Engine Diameter, in	96.0
Nozzle Length, in	119.5
Engine Length, in	168.0

Weights, lbm	Value
Turbomachinery	1,725.0
Preburners	229.0
PB Hot Gas Manifold	558.0
Thrust Chamber	859.0
Nozzle	1,250.0
Gimbal Bearing	105.0
Valves 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

Return | Page Up

Figure 5. Input/Output Table for Liquid Models

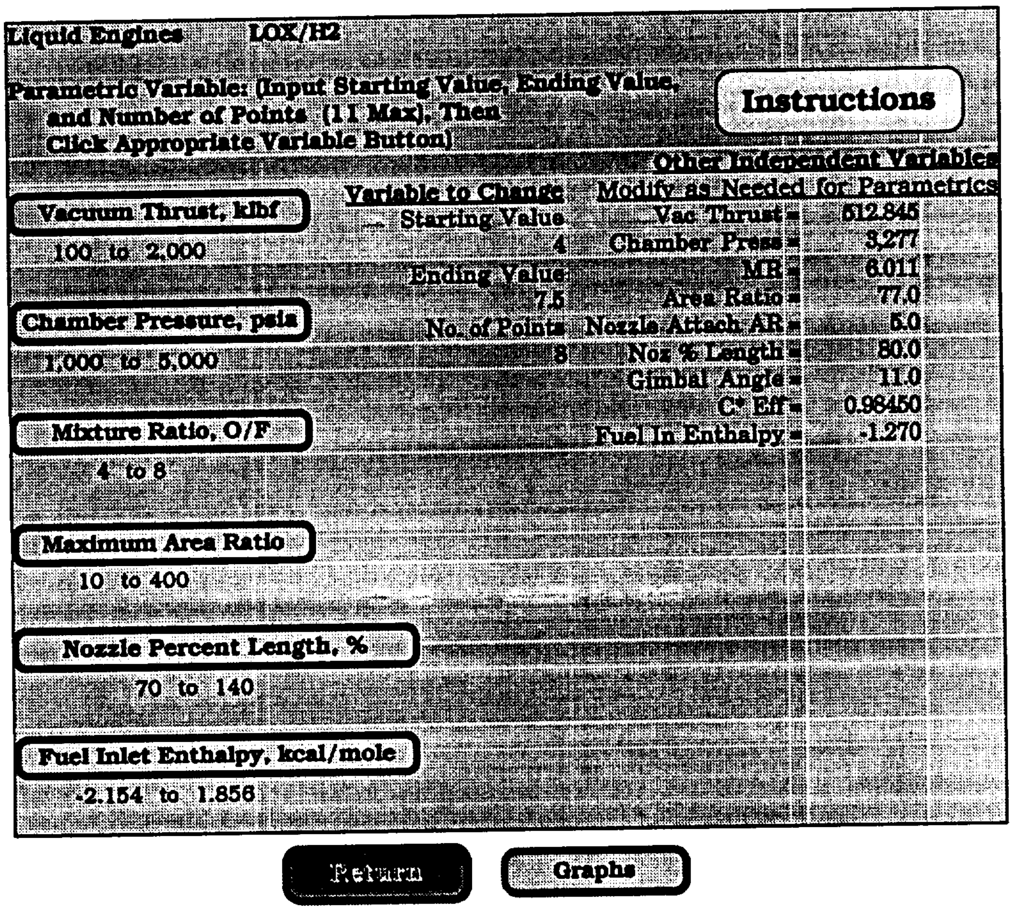


Figure 6. Parametric Data Generation Screen – Liquid Engines

Weight Lengths Performance Print

Return Page Down Use the Yellow Buttons to See the Graphs

Independent Variables	LOX/H2 –Liquid Engines							
Vacuum Thrust, lbf =	512.845	512.845	512.845	512.845	512.845	512.845	512.845	512.845
Chamber Press, psi =	3,277	3,277	3,277	3,277	3,277	3,277	3,277	3,277
Mixture Ratio, O/F =	4.000	4.500	5.000	5.500	6.000	6.500	7.000	7.500
Max 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	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	-1.270	-1.270
Weights, lbm								
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
Preburners =	383.3	329.4	288.0	255.5	229.5	208.3	190.7	164.7
PB Hot Gas Man =	660.7	627.4	600.1	577.5	558.4	541.6	527.0	505.3
Thrust Chamber =	988.9	945.9	911.3	883.2	859.5	838.8	820.9	795.0
Nozzle =	1,298.1	1,285.1	1,272.7	1,261.2	1,250.2	1,239.4	1,229.1	1,214.5
Gimbal Bearing =	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
Valves & Cont =	789.6	769.1	751.3	735.9	722.3	709.9	698.7	681.7
Cont & Mount =	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
POGO System =	94.6	94.7	94.6	94.3	94.0	93.6	93.1	92.5
Prop Ducts =	1,116.5	1,037.0	971.1	915.9	868.7	827.5	791.6	735.5
Pres Sys =	93.6	92.3	91.1	90.0	89.0	88.0	87.1	85.7
Other Engine Sys =	276.7	261.6	248.7	237.8	228.2	219.7	212.2	200.1
Total Dry Weight =	7,984.7	7,611.1	7,300.5	7,039.9	6,816.3	6,619.4	6,446.2	6,180.6
Dimensions								
Throat Dia, in =	10.5	10.5	10.4	10.3	10.3	10.2	10.2	10.1
Throat Area, in^2 =	86.8	85.8	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 Exit Dia, in =	92.2	91.7	91.2	90.8	90.3	89.9	89.5	88.9
Engine Dia, in =	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0
Noz Length, in =	122.0	121.3	120.7	120.1	119.5	118.9	118.4	117.6
Engine Length, in =	171.4	170.5	169.6	168.8	168.0	167.2	166.5	165.4
Performance								
SL Thrust, klbf =	414.74	415.82	416.87	417.83	418.75	419.66	420.53	421.75
V Thrust, klbf =	512.84	512.84	512.84	512.84	512.84	512.84	512.84	512.84
SL Isp, sec-lbf/lbm =	366.75	369.26	370.35	370.47	369.91	368.28	365.84	358.85
V Isp, sec-lbf/lbm =	453.50	455.42	455.62	454.71	453.03	450.06	446.15	436.36
ODE C*, ft/sec =	8,095	8,039	7,956	7,861	7,756	7,631	7,495	7,233
L-Star, in =	30.7	30.6	30.6	30.5	30.4	30.3	30.3	30.2
ODE Isp =	469.44	471.42	471.62	470.69	468.97	465.93	461.97	453.24
Energy Rel Eff =	0.98450	0.98450	0.98450	0.98450	0.98450	0.98450	0.98450	0.98450
Kinetic Eff =	0.99999	0.99999	0.99999	0.99999	0.99994	0.99986	0.99968	0.99660
Divergence Eff =	0.99283	0.99283	0.99283	0.99283	0.99283	0.99283	0.99283	0.99283
BL Eff =	0.98904	0.98904	0.98904	0.98904	0.98904	0.98904	0.98904	0.98904
Engine Eff =	0.96672	0.96672	0.96672	0.96672	0.96666	0.96658	0.96642	0.96344

Return Page Up

Figure 7. Parametric Results Table – Liquid Engines

Independent Variables		LOX/H2 –Liquid Engines							
Vacuum Thrust, lbf	=	512.844	512.844	512.844	512.844	512.844	512.844	512.844	512.844
Chamber Press, psi	=	3,277	3,277	3,277	3,277	3,277	3,277	3,277	3,277
Mixtrue Ratio, O/F	=	4.000	4.500	5.000	5.500	6.000	6.500	7.000	7.500
Max 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	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	-1.270	-1.270
Weights, lbm									
Turbomachinery	=	2,092.8	1,978.6	1,881.6	1,798.6	1,726.5	1,662.5	1,605.9	1,515.6
Preburners	=	383.3	329.4	288.0	255.5	229.5	208.3	190.7	164.7
PB Hot Gas Man	=	660.7	627.4	600.1	577.5	558.4	541.6	527.0	505.3
Thrust Chamber	=	988.9	945.9	911.3	883.1	859.5	838.8	820.9	795.0
Nozzle	=	1,298.1	1,285.1	1,272.7	1,261.2	1,250.2	1,239.4	1,229.1	1,214.5
Gimbal Bearing	=	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
Valves & Cont	=	789.6	769.1	751.3	735.9	722.3	709.9	698.7	681.7
Cont & Mount	=	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
POGO System	=	94.6	94.7	94.6	94.3	94.0	93.6	93.1	92.5
Prop Ducts	=	1,116.5	1,037.0	971.1	915.9	868.7	827.5	791.6	735.5
Pres Sys	=	93.6	92.3	91.1	90.0	89.0	88.0	87.1	85.7
Other Engine Sys	=	276.7	261.6	248.7	237.8	228.2	219.7	212.2	200.1
	=								
	=								
	=								
	=								
	=								
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									
Throat Dia, in	=	10.5	10.5	10.4	10.3	10.3	10.2	10.2	10.1
Throat Area, in^2	=	86.8	85.8	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 Exit Dia, in	=	92.2	91.7	91.2	90.8	90.3	89.9	89.5	88.9
Engine Dia, in	=	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0
Noz Length, in	=	122.0	121.3	120.7	120.1	119.5	118.9	118.4	117.6
Engine Length, in	=	171.4	170.5	169.6	168.8	168.0	167.2	166.5	165.4
Performance									
SL Thrust, klbf	=	414.74	415.82	416.87	417.83	418.75	419.66	420.52	421.75
V Thrust, klbf	=	512.84	512.84	512.84	512.84	512.84	512.84	512.84	512.84
SL Isp, sec-lbf/lbm	=	366.75	369.26	370.35	370.47	369.91	368.28	365.84	358.85
V Isp, sec-lbf/lbm	=	453.50	455.42	455.62	454.71	453.03	450.06	446.15	436.36
ODE C*, ft/sec	=	8,095	8,039	7,956	7,861	7,756	7,631	7,495	7,233
L-Star, in	=	30.7	30.6	30.6	30.5	30.4	30.3	30.3	30.2
ODE Isp	=	469.44	471.42	471.62	470.69	468.97	465.93	461.97	453.24
Energy Rel Eff	=	0.98450	0.98450	0.98450	0.98450	0.98450	0.98450	0.98450	0.98450
Kinetic Eff	=	0.99999	0.99999	0.99999	0.99999	0.99994	0.99986	0.99968	0.99660
Divergence Eff	=	0.99283	0.99283	0.99283	0.99283	0.99283	0.99283	0.99283	0.99283
BL Eff	=	0.98904	0.98904	0.98904	0.98904	0.98904	0.98904	0.98904	0.98904
Engine Eff	=	0.96672	0.96672	0.96672	0.96672	0.96666	0.96659	0.96642	0.96344

Figure 8. Printed Version of Parametric Results Chart - Liquid Engines

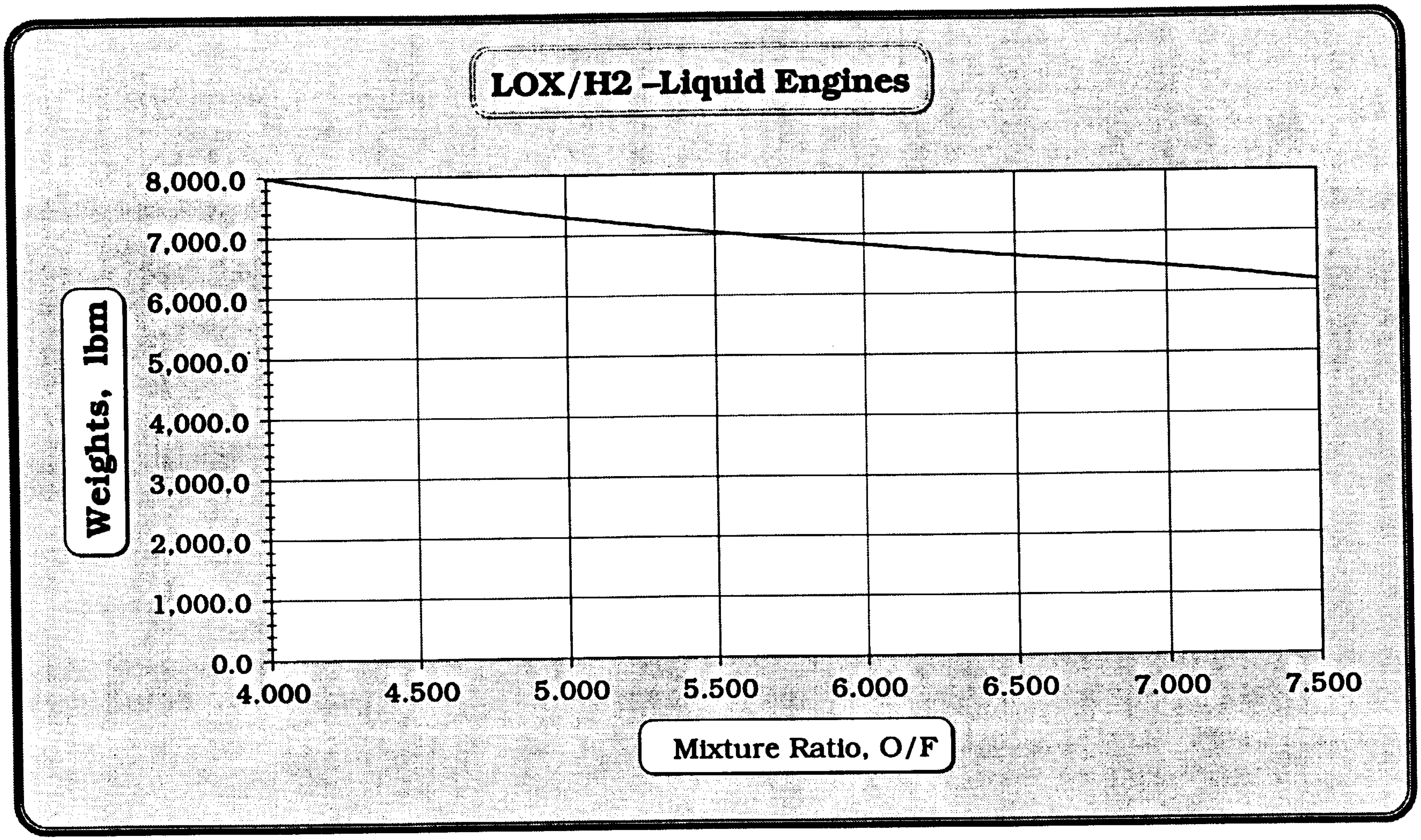


Figure 9. Printed Version of Weight Chart – Liquid Models

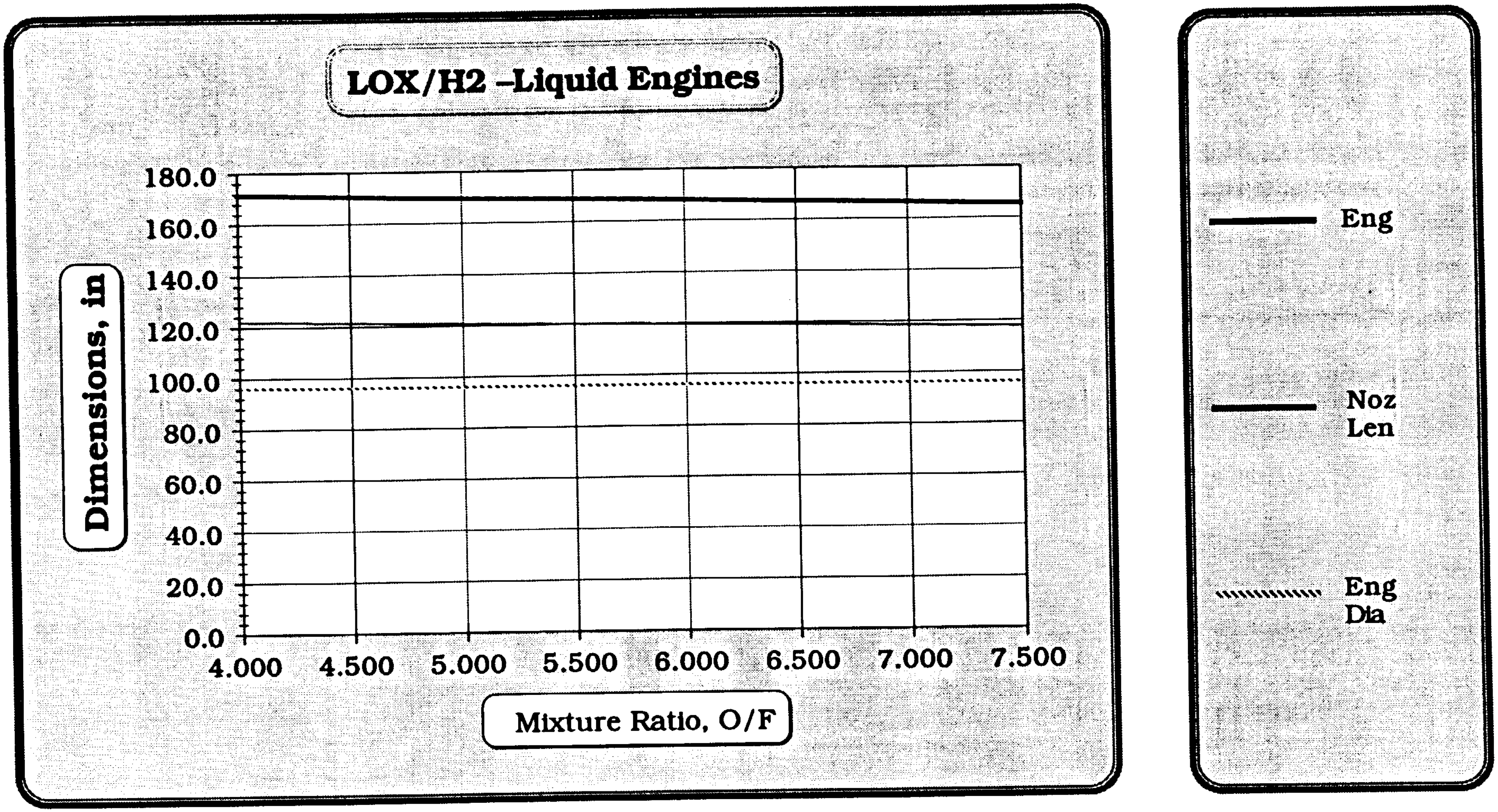


Figure 10. Printed Version of Lengths Chart – Liquid Models

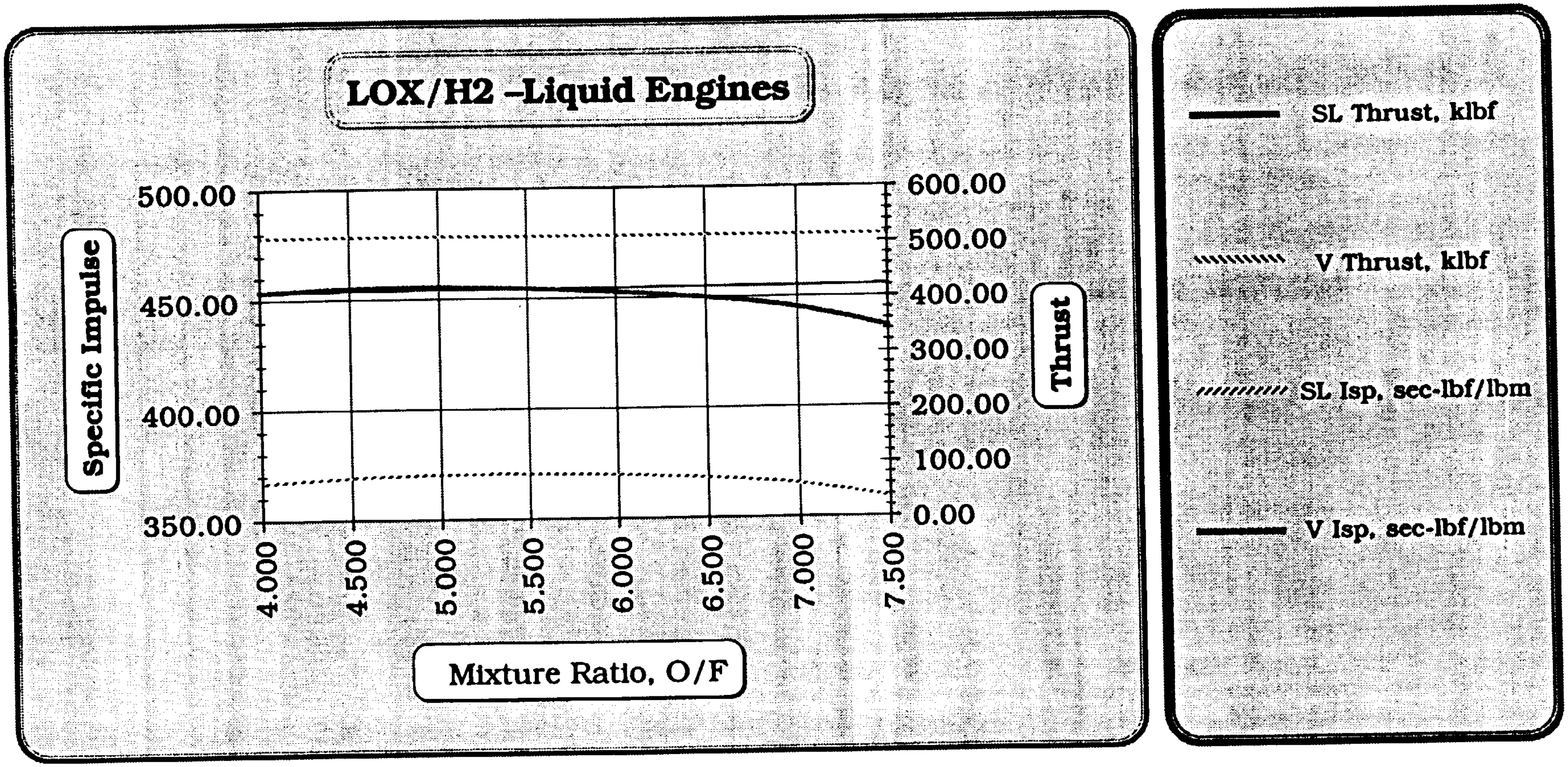
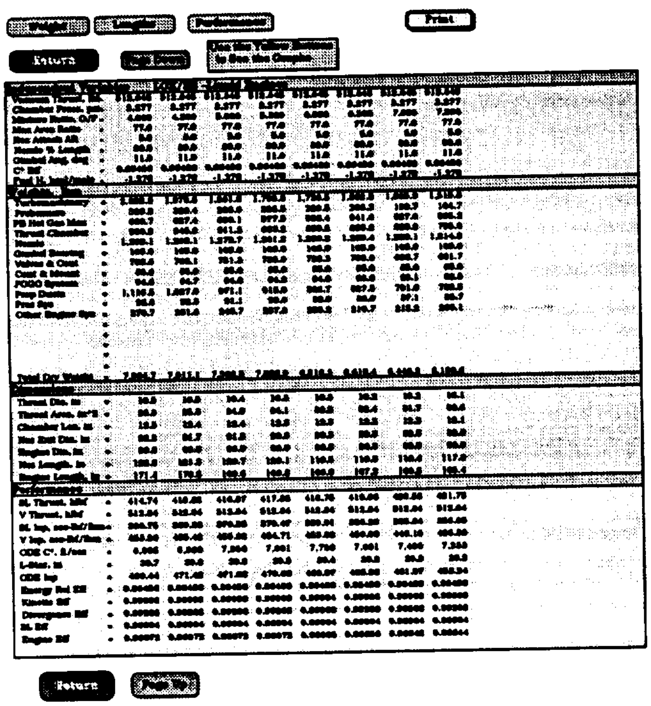
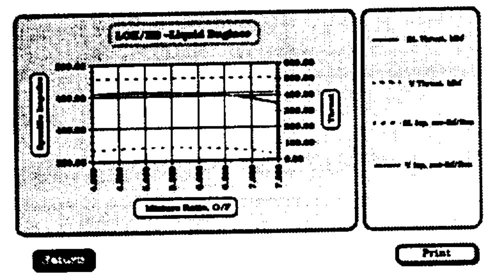
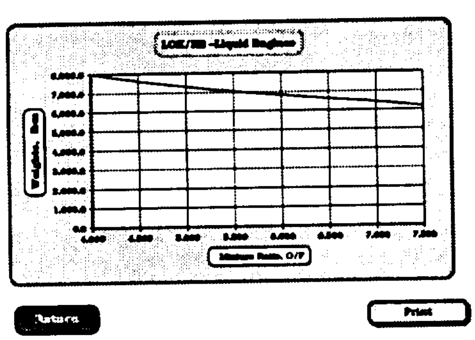


Figure 11. Printed Version of Performance Chart – Liquid Models







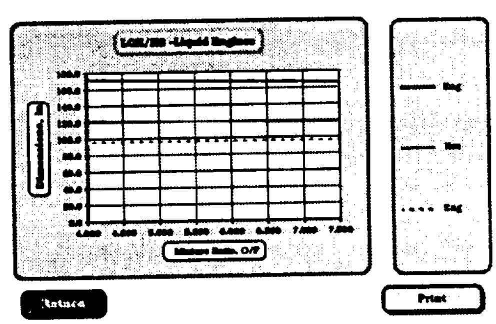


Figure 12. Parametric Data Available – Liquid Engines

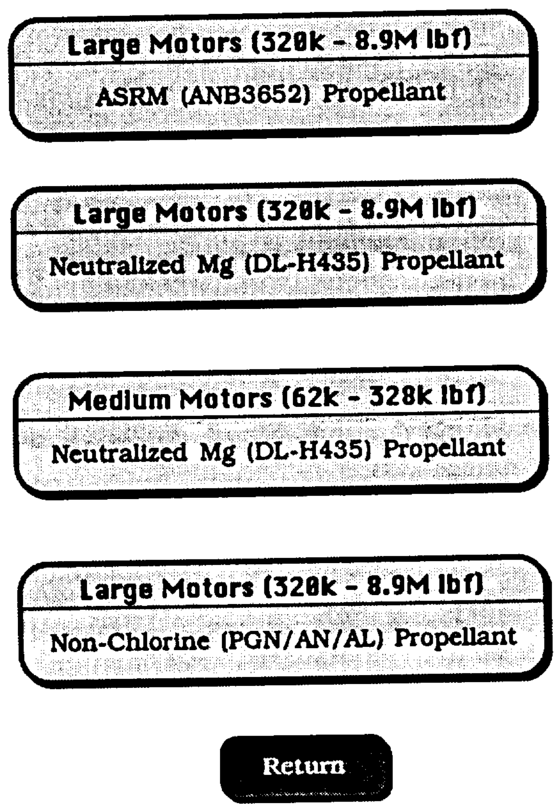


Figure 13. Solid Fuel Models Available

Return | English Units | Print (Report) | Print (Briefing)

Page Down

Graphs

Large Motors — ASRM (ANB3652) Propellant

14 January 1993

Independent Terms			Range
Meop, psia	=	1,000	200 To 2000
Initial Area Ratio, Ei	=	7.0	5 To 19
(Favg)vac, lbf	=	2,590,000	320 K To 8.9 M
Burn Time, Tb, seconds	=	111	60 To 178
Dcase, in	=	146	80 To 255
Push Weight, lbm	=	1,000,000	
Nose Cone L/D	=	1.30	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.334 and 0.806 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results			RMSE
Rbo, in/sec	=	0.530	0.002
(Isp)sl, sec-lbf/lbm	=	246.54	N/A
(Isp)vac, sec-lbf/lbm	=	269.57	N/A
(A throat)avg, in^2	=	2,243.0	10.7
(R throat)avg, in	=	26.7	N/A
(Favg)sl, lbf	=	2,368,679	N/A
(Favg)vac, lbf	=	2,590,000	N/A
L case, in	=	1,187.9	5.3
L/D case	=	8.14	Note 1
L nozzle, in	=	167.5	3.6
Nozzle Exit O.D., in	=	138.5	N/A
Total Length, in	=	1,545.3	N/A
W propellant, lbm	=	1,066,466	Note 4
W nozzle, lbm	=	12,500.2	1,025
W insulation, lbm	=	6,716.0	105
W case, lbm	=	26,124.3	933
W igniter, lbm	=	633.6	29
W nose cone, lbm	=	3,742.3	N/A
W ext insul, lbm	=	763.5	N/A
W fwd skirt, lbm	=	2,965.0	N/A
W aft skirt, lbm	=	14,659.7	N/A
W separation, lbm	=	1,246.8	N/A
W misc, lbm	=	980.4	N/A
W SRM, lbm	=	1.112E+06	
W stage, lbm	=	2.436E+04	
W SRB, lbm	=	1.137E+06	
V ideal, ft/sec	=	5.997E+03	N/A
Mass Fraction	=	9.381E-01	N/A
(Impulse)sl, lbf-sec	=	2.629E+08	
(Impulse)vac, lbf-sec	=	2.875E+08	

Return | Page Up

Figure 14. Solid Motor Model

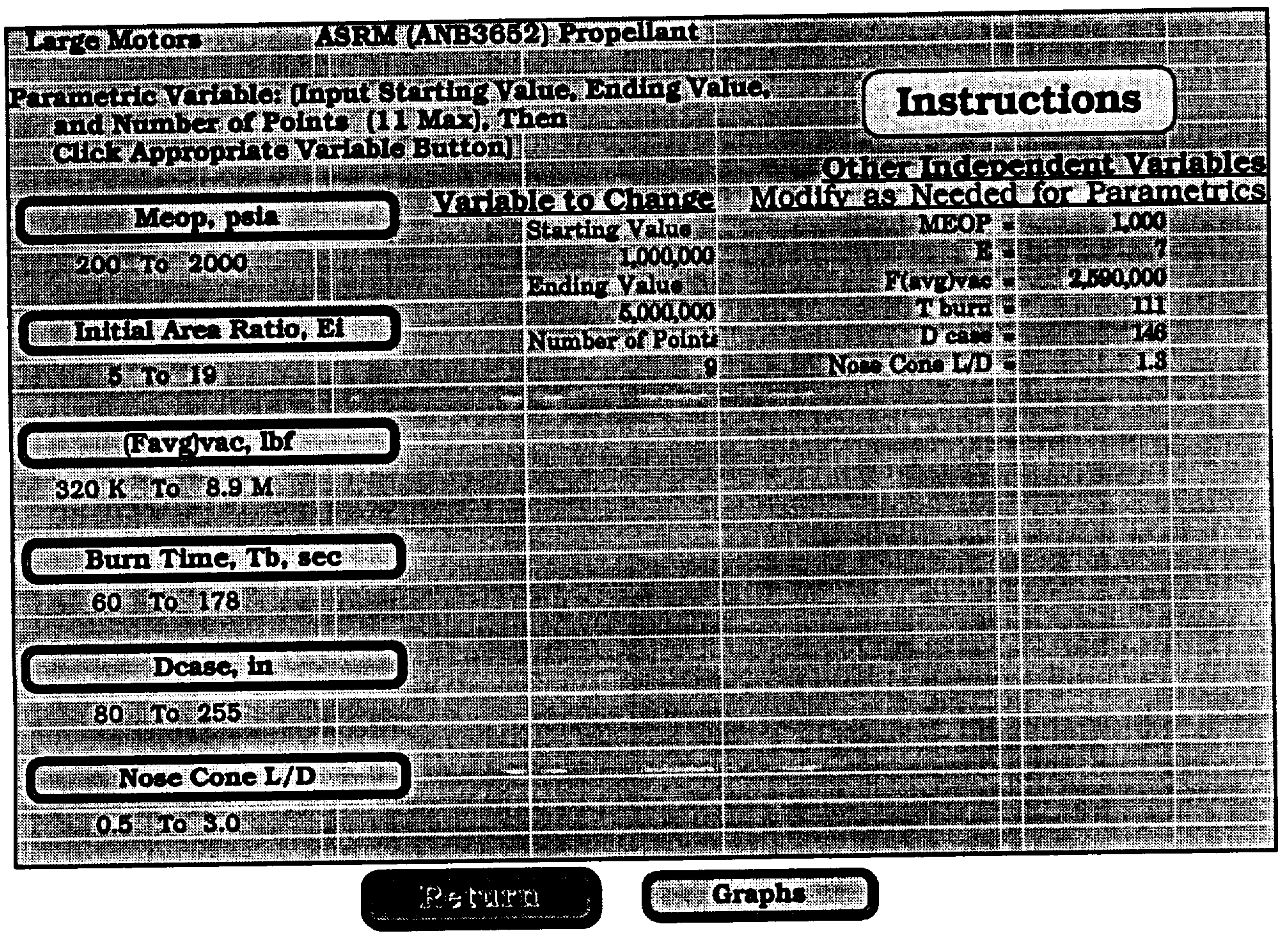


Figure 15. Parametric Generation Screen – Solid Boosters

Weights | Lengths | Print
Mass Fraction | Performance
Return | Page Down | Page Right
Use the Yellow Buttons to See the Graphs
Return | Page Down | Page Left

Independent Variables	ASRM (ANB3652) Propellant — Large Motors									
Meop, psia	=	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Initial Area Ratio, El	=	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
(Favg)vac, lbf	=	1,000,000	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	=	111.0	111.0	111.0	111.0	111.0	111.0	111.0	111.0	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, lbm	=	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
Nose Cone L/D	=	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Weights, lbm										
Nozzle	=	4,731.3	7,108.0	9,545.6	12,045.3	14,590.5	17,174.3	19,791.5	22,430.0	25,119.0
Insulation	=	4,005.6	4,904.9	5,830.0	6,580.5	7,270.9	7,901.3	8,490.3	9,045.4	9,571.9
Case	=	10,893.6	15,829.0	20,614.6	25,291.5	29,894.7	34,408.6	38,874.5	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	=	413,600	619,233	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	=	14,650.7	14,650.7	14,650.7	14,650.7	14,650.7	14,650.7	14,650.7	14,650.7	14,650.7
Separation System	=	485.9	725.7	965.0	1,203.9	1,442.4	1,680.7	1,918.7	2,156.6	2,394.3
Misc	=	137.3	418.8	683.3	935.9	1,179.7	1,416.5	1,647.8	1,873.6	2,096.4
SRM	=	433,441	647,484	860,966	1,074,111	1,286,942	1,499,537	1,711,934	1,924,163	2,136,243
Stage	=	22,754	23,275	23,779	24,270	24,753	25,228	25,697	26,161	26,620
Total (SRB)	=	456,195	670,759	884,767	1,098,382	1,311,695	1,524,765	1,737,631	1,950,323	2,162,863
Lengths, in										
Case	=	475.6	702.4	926.4	1,148.2	1,368.3	1,587.0	1,804.6	2,021.1	2,236.6
Nozzle	=	90.2	123.9	146.3	164.3	181.7	196.0	212.3	227.6	241.3
L/D Case	=	3.3	4.8	6.3	7.9	9.4	10.9	12.4	13.8	15.3
Total	=	764.6	1,016.2	1,261.4	1,502.3	1,739.9	1,974.9	2,207.6	2,438.5	2,667.8
Misc Results										
Rbo, in/sec	=	0.530	0.530	0.530	0.530	0.530	0.530	0.530	0.530	0.530
(A throat)avg, in^2	=	880.2	1,317.7	1,748.0	2,169.9	2,590.5	3,011.1	3,431.9	3,851.9	4,271.3
(R throat)avg, in	=	16.8	20.5	23.6	26.3	28.7	31.0	33.1	35.0	36.9
Nozzle Exit Dia, in	=	86.1	105.4	121.7	136.0	149.0	160.9	172.0	182.5	192.3
Mass Fraction	=	0.907	0.923	0.932	0.937	0.941	0.944	0.946	0.948	0.949
(Favg)sl, lbf	=	914,337	1,371,661	1,828,903	2,286,351	2,743,741	3,201,163	3,658,618	4,116,104	4,573,630
(Favg)vac, lbf	=	1,000,000	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	=	245.36	245.86	246.22	246.49	246.72	246.91	247.07	247.22	247.35
(Isp)vac, sec-lbf/lbm	=	268.37	268.86	269.25	269.55	269.79	269.96	270.13	270.27	270.41
(Impulse)sl, lbf-sec	=	101,491,445	152,254,419	203,018,262	253,784,964	304,555,227	355,329,100	406,108,573	456,887,527	507,671,926
(Impulse)vac, lbf-sec	=	111,000,000	166,500,000	222,000,000	277,500,000	333,000,000	388,500,000	444,000,000	499,500,000	555,000,000
V ideal, ft/sec	=	2,886	4,006	4,965	5,851	6,628	7,335	7,974	8,564	9,100

Return | Page Up | Page Right
Return | Page Up | Page Left

Figure 16. Parametric Results Table – Solid Boosters

Independent Variables		ASRM (ANB3652) Propellant – Large Motors								
Meop, psia	=	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Initial Area Ratio, Ei	=	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
(Favg)vac, lbf	=	1,000,000	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	=	111.0	111.0	111.0	111.0	111.0	111.0	111.0	111.0	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, lbm	=	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
Nose Cone L/D	=	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Weights, lbm										
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	7,901.3	8,490.3	9,045.4	9,571.9
Case	=	10,893.6	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	=	475.6	702.4	926.4	1,148.2	1,368.3	1,587.0	1,804.6	2,021.1	2,236.6
Nozzle	=	99.3	123.9	145.2	164.3	181.7	198.0	213.2	227.6	241.3
L/D Case	=	3.3	4.8	6.3	7.9	9.4	10.9	12.4	13.8	15.3
Total	=	764.6	1,016.2	1,261.4	1,502.3	1,739.9	1,974.8	2,207.6	2,438.5	2,667.8
Misc Results										
Rbo, in/sec	=	0.530	0.530	0.530	0.530	0.530	0.530	0.530	0.530	0.530
(A throat)avg,in^2	=	890.2	1,317.7	1,743.0	2,166.9	2,589.5	3,011.1	3,431.9	3,851.9	4,271.2
(R throat)avg, in	=	16.8	20.5	23.6	26.3	28.7	31.0	33.1	35.0	36.9
Nozzle Exit Dia, in	=	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, lbf	=	1,000,000	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	=	245.38	245.88	246.22	246.49	246.72	246.91	247.07	247.22	247.35
(Isp)vac, sec-lbf/lbm	=	268.37	268.88	269.25	269.53	269.76	269.95	270.12	270.27	270.41
(Impulse)sl, lbf-sec	=	101,491,445	152,254,419	203,018,262	253,784,994	304,555,227	355,329,100	406,106,572	456,887,527	507,671,826
(Impulse)vac, lbf-sec	=	111,000,000	166,500,000	222,000,000	277,500,000	333,000,000	388,500,000	444,000,000	499,500,000	555,000,000
V ideal, ft/sec	=	2,884	4,005	4,983	5,849	6,626	7,329	7,971	8,561	9,106

Figure 17. Printed Output of Parametric Results - Solid Motors

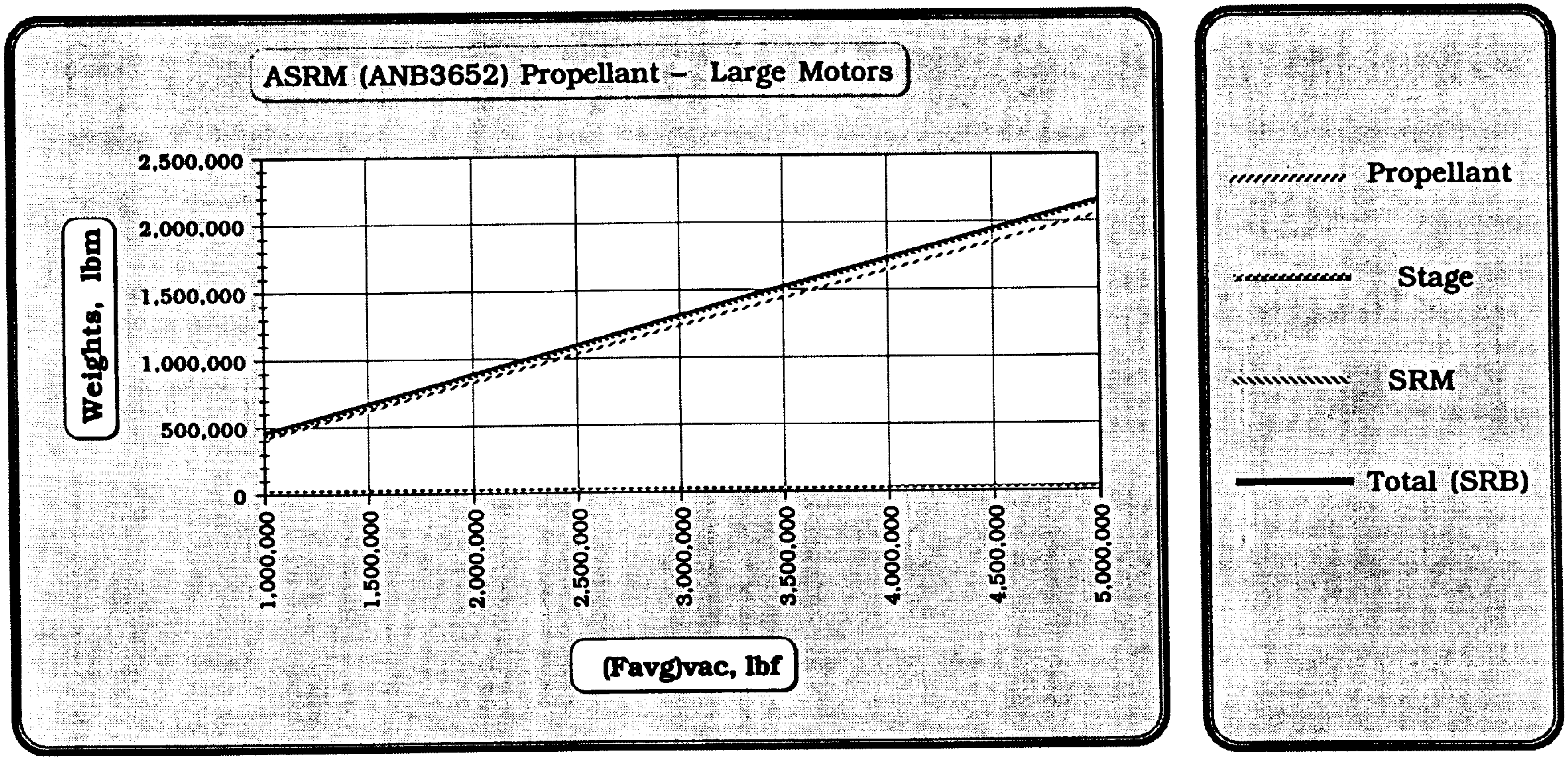


Figure 18. Printed Version of Weights Chart – Solid Rocket Boosters

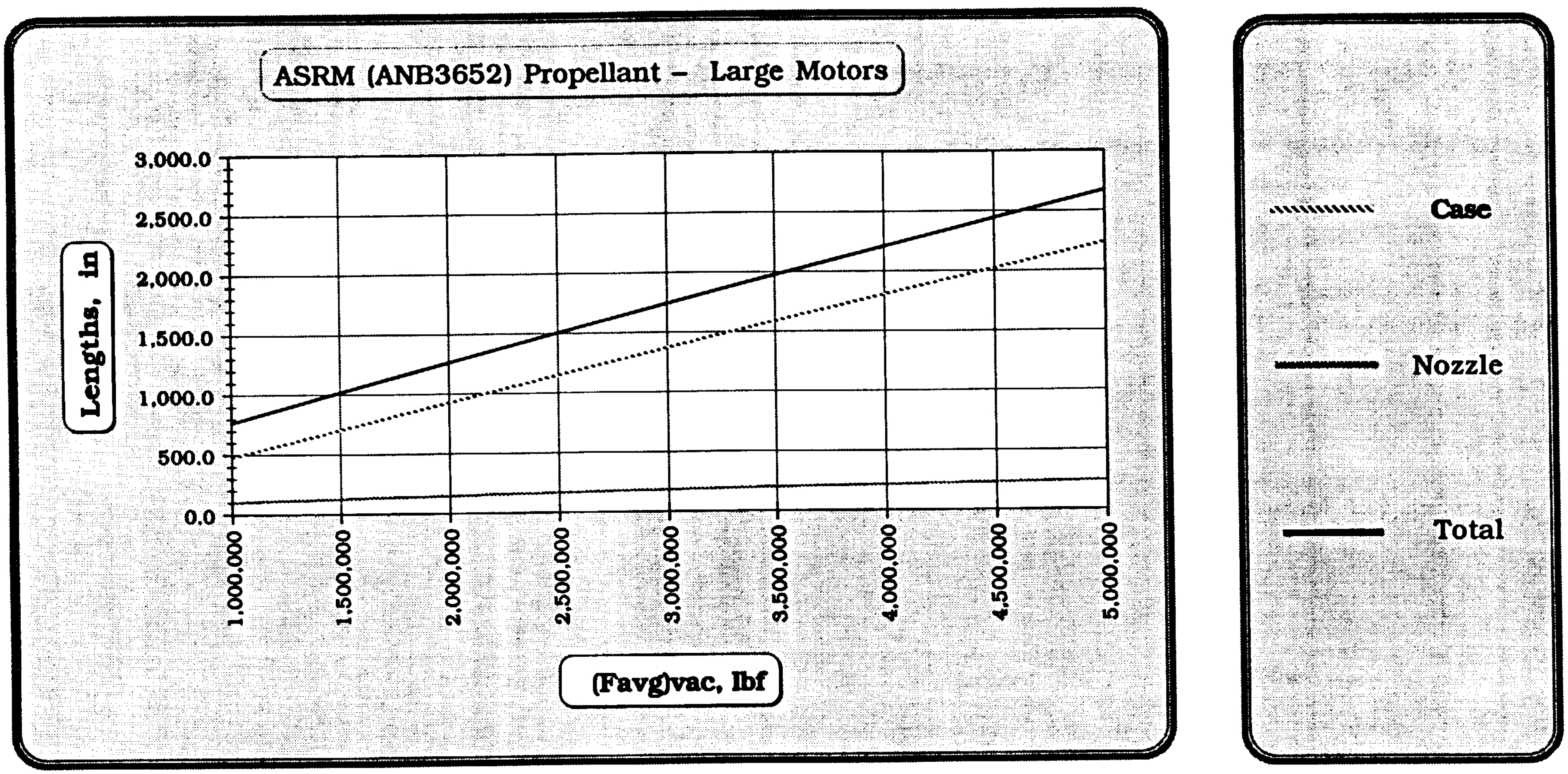


Figure 19. Printed Version of Lengths Chart – Solid Rocket Boosters

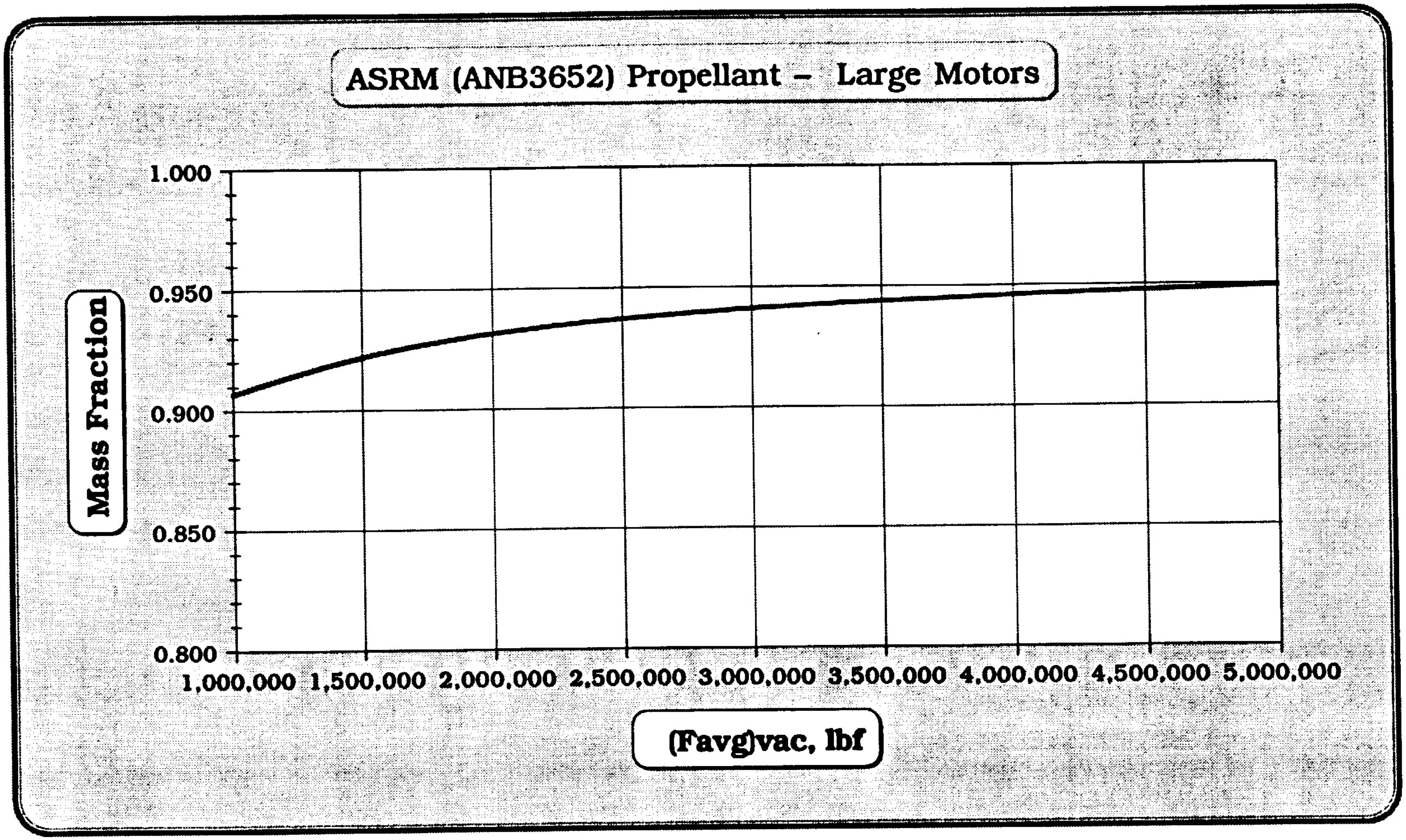


Figure 20. Printed Version of Mass Fraction Chart – Solid Rocket Boosters

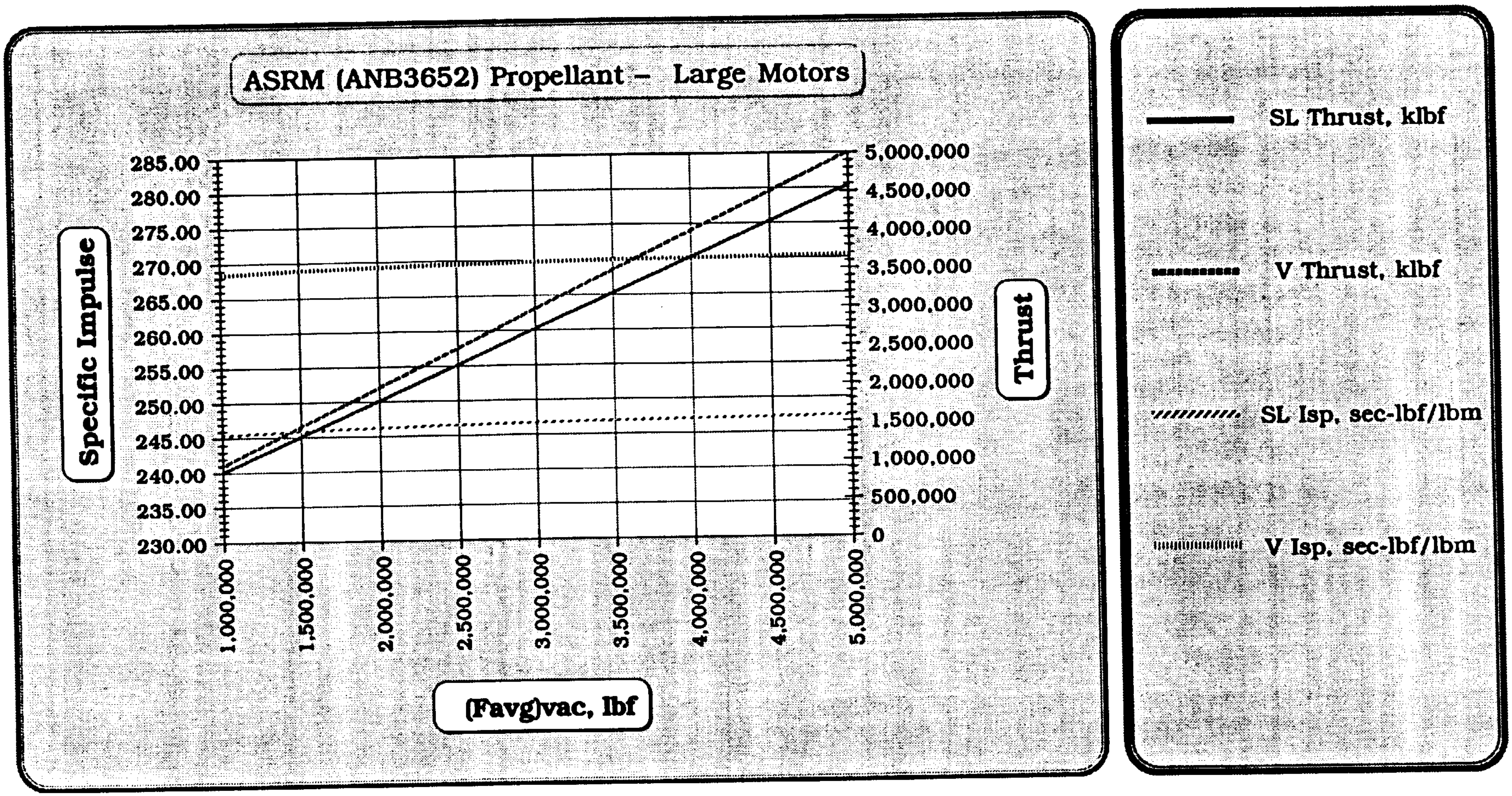


Figure 21. Printed Version of Performance Chart – Solid Rocket Boosters

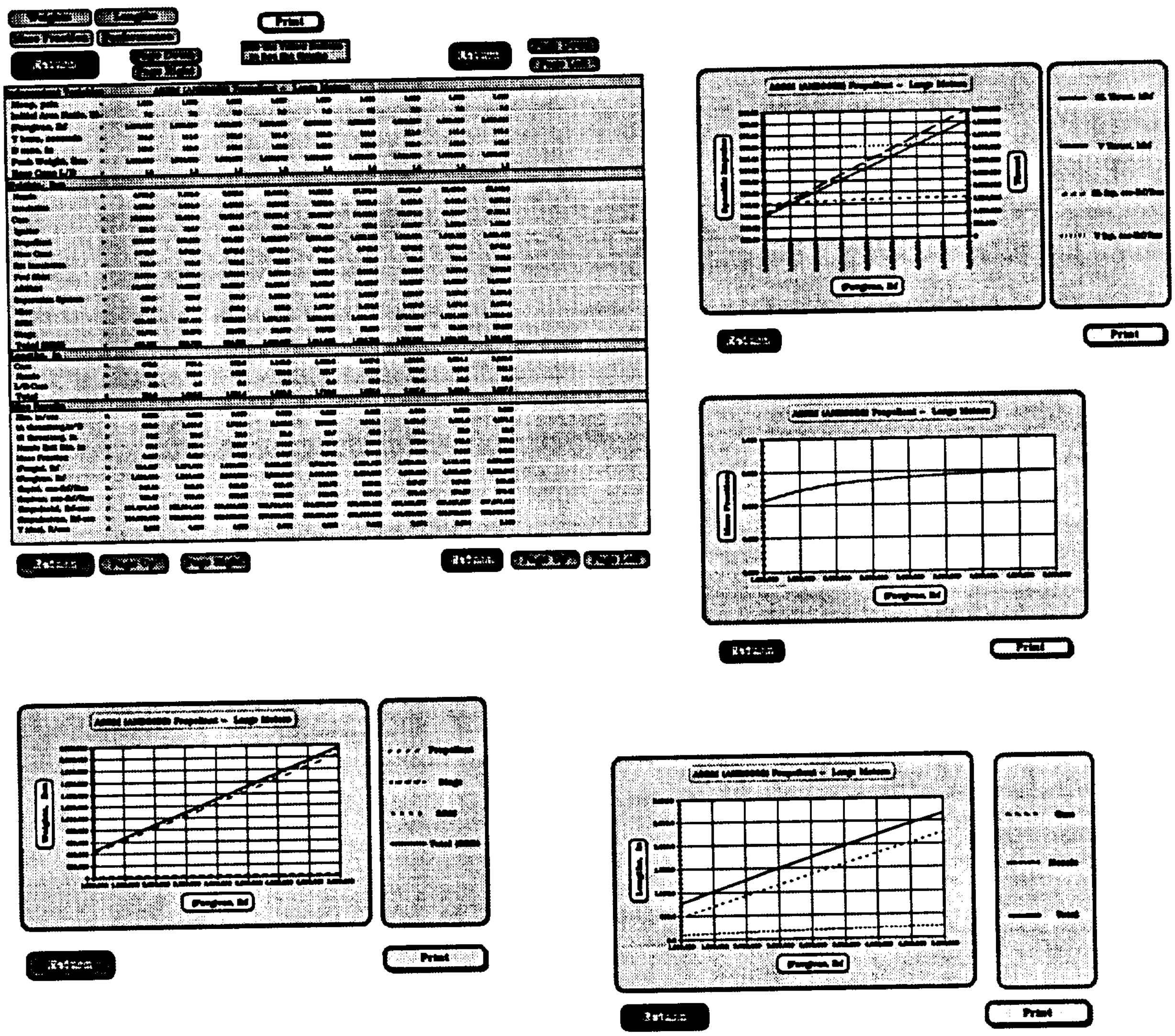


Figure 22. Parametric Results Available – Solid Rocket Boosters

Return | English Units | Print (Report) | Print (Briefing)

Page Down

Graphs

Large Motors | **Hybrid Propellants**

23 March 1993

Independent Terms			Range
Meop, psia	=	500	500 To 1500
Initial Area Ratio, Ei	=	8	8 To 20
(Favg)vac, lbf	=	1,267,506	280 K To 21 M
Burn Time, Tb, seconds	=	45	45 To 200
Nose Cone L/D	=	1.3	0.5 To 3.0
Max Ox Flux, lbm/s-in^2	=	0.2	0.2 To 1.0
Avg MR, O/F	=	1.8	1.8 To 2.8
Push Weight, lbm	=	1,000,000	

Dependent Terms

Note 1: Data is being extrapolated below range of regression.

Note 2: Data is being extrapolated above range of regression.

Results			RMSE
D nozzle exit, in	=	132.8	N/A
(Isp)sl, sec-lbf/lbm	=	238.76	N/A
(Isp)vac, sec-lbf/lbm	=	284.48	1.9
(A throat)avg, in^2	=	1,765.4	N/A
(R throat)avg, in	=	23.7	0.9
(Favg)sl, lbf	=	1,063,817	N/A
(Favg)vac, lbf	=	1,267,506	N/A
L tank & case, in	=	803.5	71
L/D case	=	4.91	N/A
L nozzle, in	=	125.7	53
D motor, in	=	163.5	3
Total Length, in	=	1,141.9	N/A
W oxidizer, lbm	=	128,454	N/A
W fuel, lbm	=	71,363	N/A
W propellant, lbm	=	199,818	N/A
W nose cone, lbm	=	6,307.4	N/A
W ext insul, lbm	=	921.5	N/A
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	=	1,666	N/A
W HRM, lbm	=	232,514	
W stage, lbm	=	3.712E+04	
W HRB, lbm	=	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

Return | Page Up

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

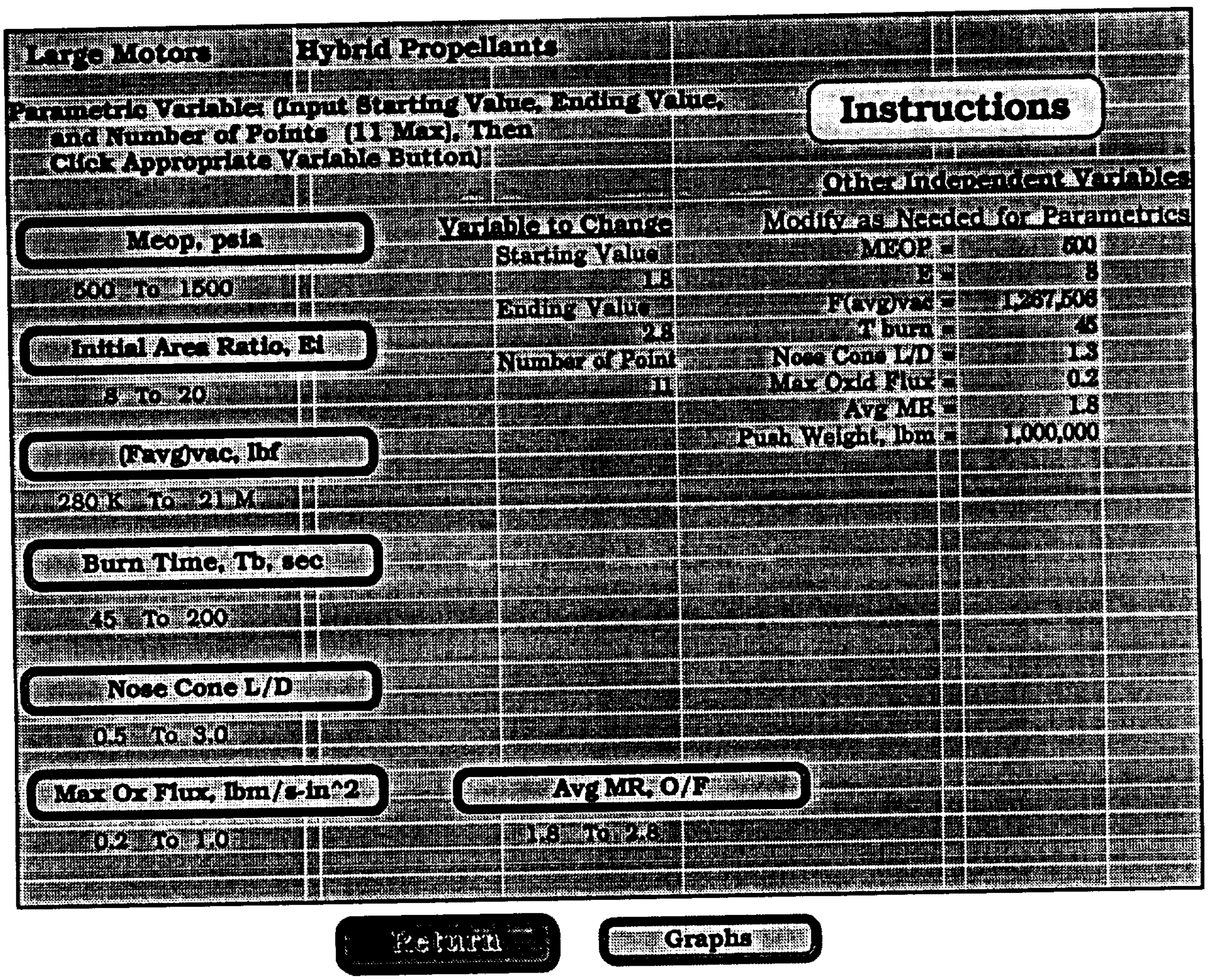


Figure 24. Parametric Data Generation Screen – Hybrid Motors

Weights | Lengths | Print
Mass Fraction | Performance
Return | Page Down | Page Right
Use the Yellow Buttons to See the Graphs
Return | Page Down | Page Left

Independent Variables		Hybrid Propellants -- Large Motors										
Meop, psia	=	500	500	500	500	500	500	500	500	500	500	500
Initial Area Ratio, El	=	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
(Favg)vac, lbf	=	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	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	=	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Max Ox Flux, lbf/s-in^2	=	0.30	0.30	0.30	0.20	0.30	0.20	0.30	0.30	0.30	0.30	0.30
Avg MR, O/F	=	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80
Push Weight, lbm	=	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	1,000,000	1,000,000
Weights, lbm												
	=											
Oxidiser	=	128,454	129,886	131,169	132,320	133,357	134,290	135,120	135,860	136,575	137,199	137,751
Fuel	=	71,363	68,361	65,564	63,010	60,617	58,367	56,308	54,356	52,528	50,812	49,197
Nose Cone	=	6,307	6,307	6,307	6,307	6,307	6,307	6,307	6,307	6,307	6,307	6,307
Ext Insulation	=	881.5	881.5	881.5	881.5	881.5	881.5	881.5	881.5	881.5	881.5	881.5
Fwd Skirt	=	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724
AftSkirt	=	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240
Separation System	=	261	259	257	256	254	253	253	250	249	249	247
Misc	=	1,660	1,622	1,583	1,546	1,511	1,478	1,448	1,419	1,392	1,366	1,341
HRM	=	232,514	231,006	229,573	228,203	226,893	225,637	224,433	223,278	222,169	221,069	220,054
Stage	=	37,120	37,075	37,034	36,996	36,950	36,925	36,895	36,863	36,834	36,807	36,781
	=											
Total (HRB)	=	269,634	268,083	266,607	265,198	263,851	262,562	261,326	260,138	258,996	257,896	256,835
Lengths, in												
Tank & Case	=	808.5	787.4	772.4	758.4	745.2	732.8	721.3	710.4	700.0	690.3	680.9
Nozzle	=	135.7	135.7	125.7	135.7	125.7	135.7	135.7	135.7	135.7	125.7	125.7
L/D (Tank & Case)	=	4.9	4.8	4.7	4.6	4.6	4.5	4.4	4.3	4.3	4.3	4.2
Total	=	1,141.9	1,125.7	1,110.7	1,096.7	1,083.6	1,071.3	1,059.6	1,048.7	1,038.3	1,028.5	1,019.2
Misc Results												
(A throat)avg,in^2	=	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765
(R throat)avg, in	=	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
Motor Dia, in	=	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5
Nozzle Exit Dia, in	=	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8
Mass Fraction	=	0.860	0.858	0.857	0.856	0.855	0.854	0.853	0.852	0.851	0.850	0.850
(Favg)sl, lbf	=	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	1,063,817
(Favg)vac, lbf	=	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	1,267,506
(Isp)sl, sec-lbf/lbm	=	238.76	240.66	242.46	244.25	245.96	247.61	249.23	250.77	252.29	253.76	255.20
(Isp)vac, sec-lbf/lbm	=	284.48	286.73	288.91	291.01	293.05	295.03	296.93	298.78	300.60	302.35	304.06
(Impulse)sl, lbf-sec	=	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	47,871,761
(Impulse)vac, lbf-sec	=	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	57,037,770
V ideal, ft/sec	=	1,568	1,569	1,570	1,570	1,571	1,572	1,573	1,574	1,574	1,575	1,576

Return | Page Up | Page Right
Return | Page Up | Page Left

Figure 25. Parametric Results Table – Hybrid Rocket Boosters

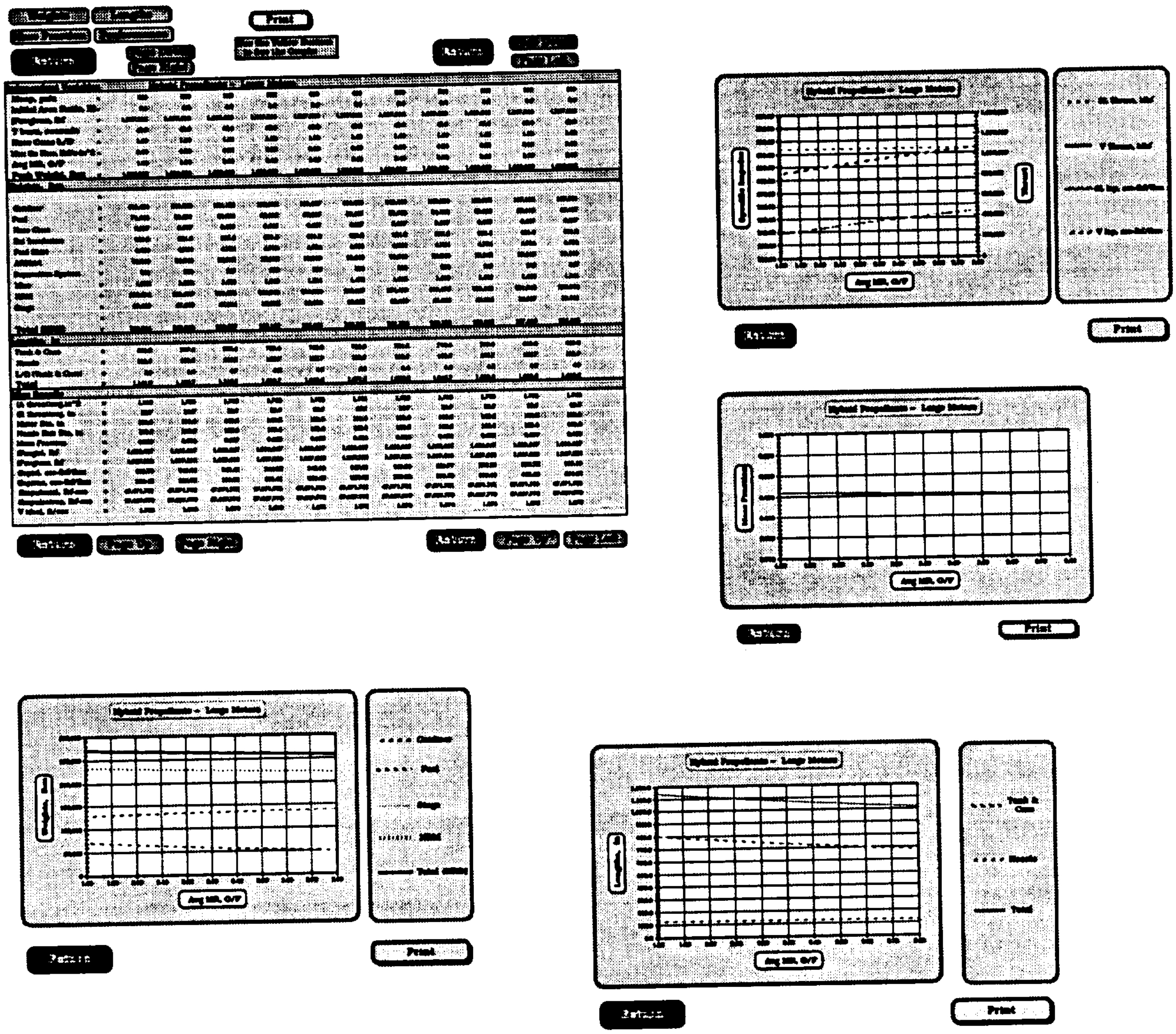


Figure 26. Parametric Data Available - Hybrid Rocket Boosters

Independent Variables		Hybrid Propellants – Large Motors										
Mcop, psia	=	500	500	500	500	500	500	500	500	500	500	500
Initial Area Ratio, El	=	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
(Favg)vac, lbf	=	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	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	=	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Max Ox Flux, lbf/s-in^2	=	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Avg MR, O/F	=	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80
Push Weight, lbm	=	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	1,000,000	1,000,000
Weights, lbm												
	=											
Oxidizer	=	128,454	129,885	131,168	132,320	133,357	134,290	135,132	135,890	136,575	137,193	137,751
Fuel	=	71,363	68,361	65,584	63,010	60,617	58,387	56,305	54,356	52,529	50,812	49,197
Nose Cone	=	6,307	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	=	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724	4,724
AftSkirt	=	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240	23,240
Separation System	=	261	259	257	256	254	253	252	250	249	248	247
Misc	=	1,666	1,623	1,583	1,546	1,511	1,478	1,448	1,419	1,392	1,366	1,341
HRM	=	232,514	231,008	229,573	228,203	226,893	225,637	224,433	223,275	222,162	221,089	220,054
Stage	=	37,120	37,075	37,034	36,995	36,959	36,925	36,893	36,863	36,834	36,807	36,781
	=											
Total (HRB)	=	269,634	268,083	266,607	265,198	263,851	262,562	261,326	260,138	258,996	257,896	256,835
Lengths, in												
Tank & Case	=	803.5	787.4	772.4	758.4	745.2	732.9	721.3	710.4	700.0	690.2	680.9
Nozzle	=	125.7	125.7	125.7	125.7	125.7	125.7	125.7	125.7	125.7	125.7	125.7
L/D (Tank & Case)	=	4.9	4.8	4.7	4.6	4.6	4.5	4.4	4.3	4.3	4.2	4.2
Total	=	1,141.9	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	=	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765	1,765
(R throat)avg, in	=	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
Motor Dia, in	=	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5	163.5
Nozzle Exit Dia, in	=	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8	132.8
Mass Fraction	=	0.859	0.858	0.857	0.856	0.855	0.854	0.853	0.852	0.851	0.850	0.850
(Favg)sl, lbf	=	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	1,063,817
(Favg)vac, lbf	=	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	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
(Isp)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	=	47,871,761	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	47,871,761
(Impulse)vac, lbf-sec	=	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	57,037,770
V ideal, ft/sec	=	1,568	1,569	1,570	1,570	1,571	1,572	1,573	1,574	1,574	1,575	1,576

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

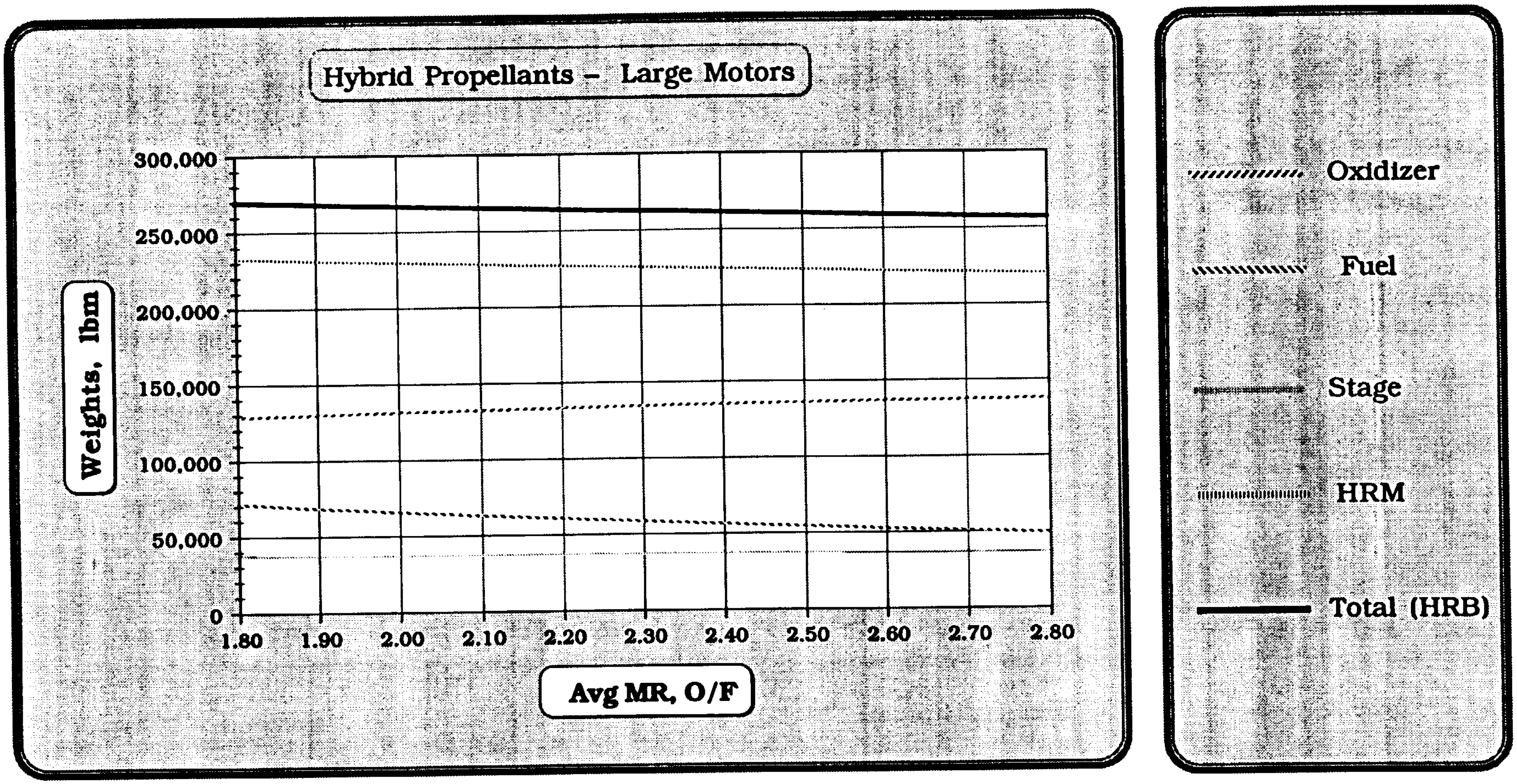


Figure 28. Printed Version of Weights Chart – Hybrid Rocket Motors

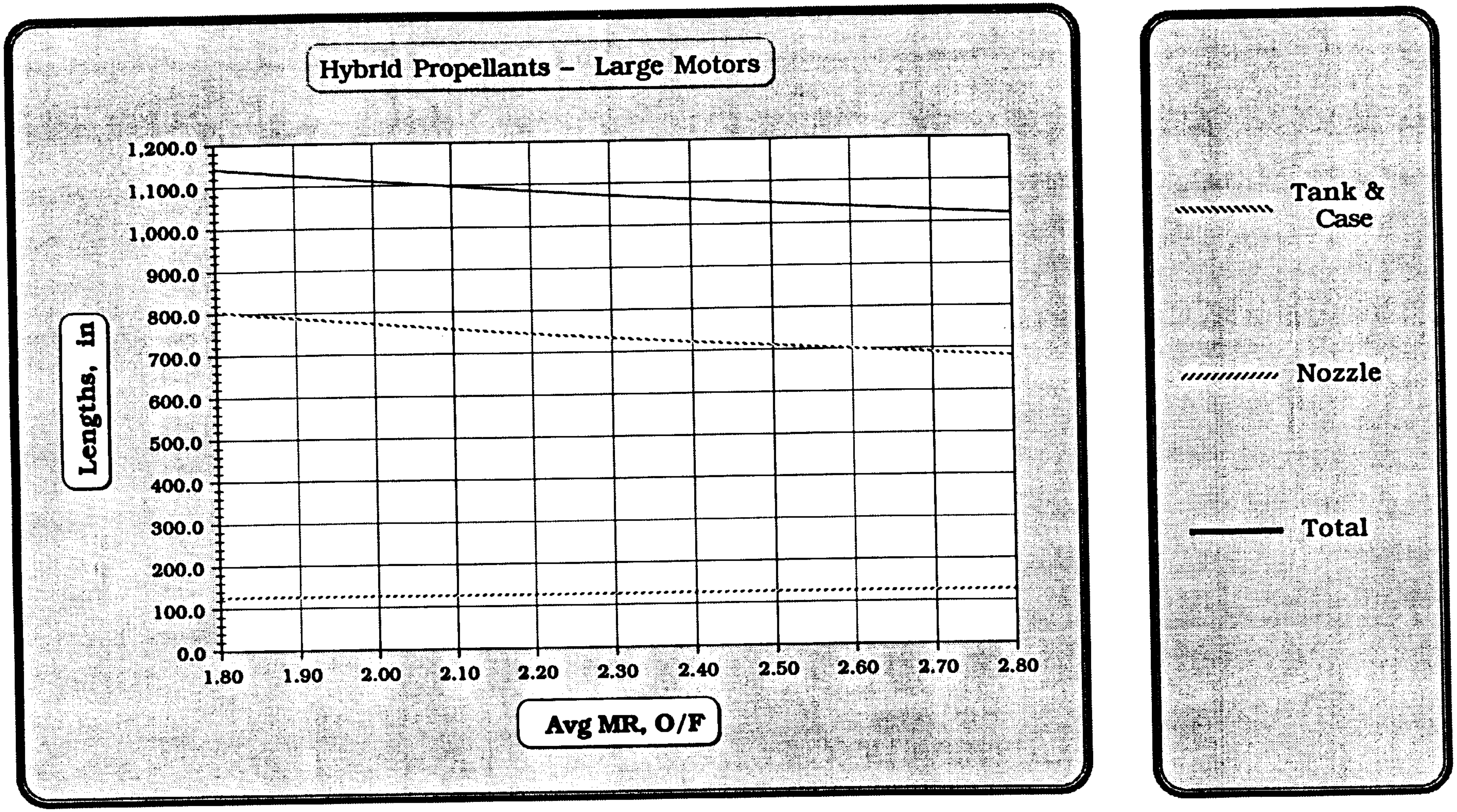


Figure 29. Printed Version of Lengths Chart – Hybrid Rocket Motors

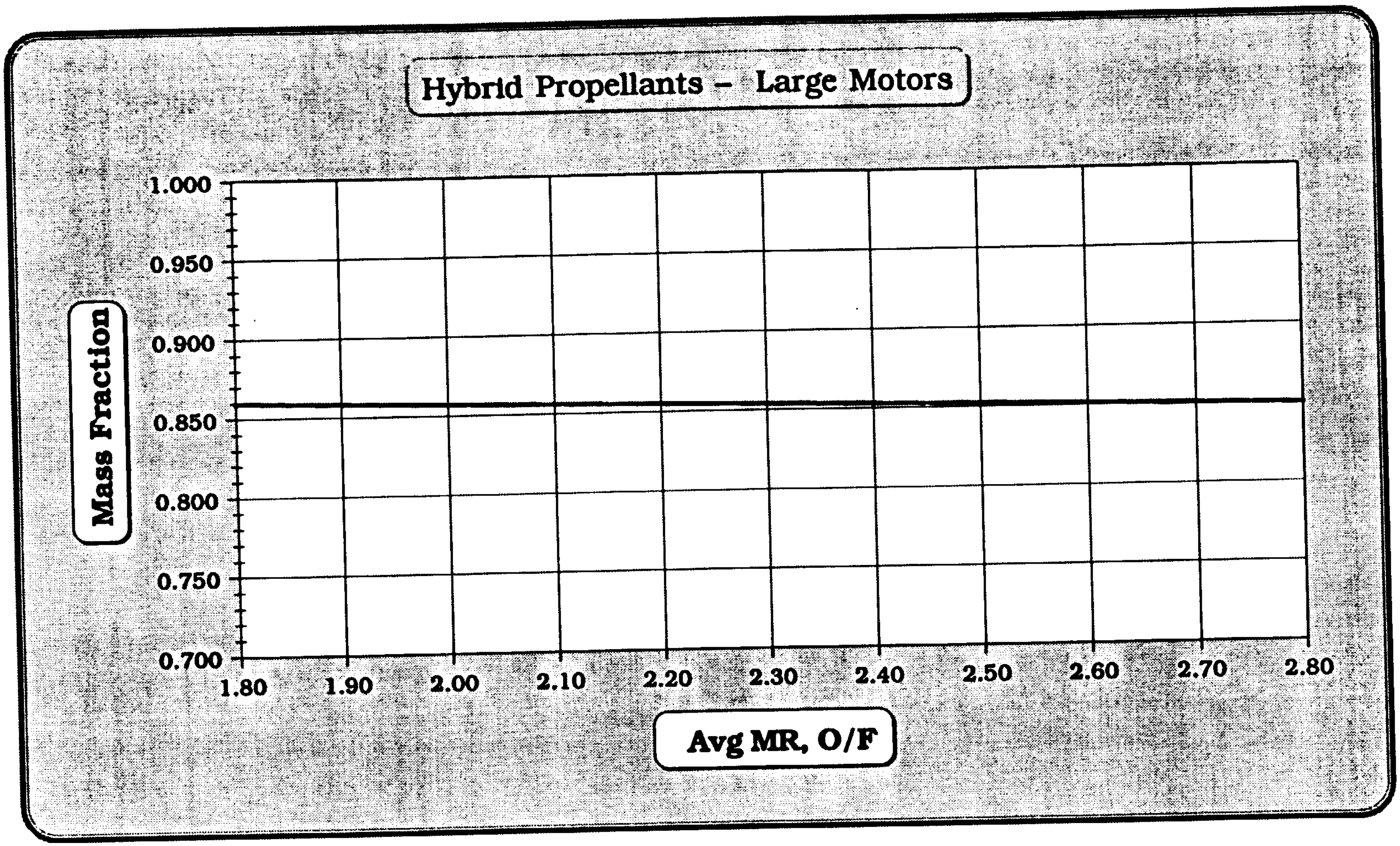


Figure 30. Printed Version of Mass Fraction Chart – Hybrid Rocket Motors

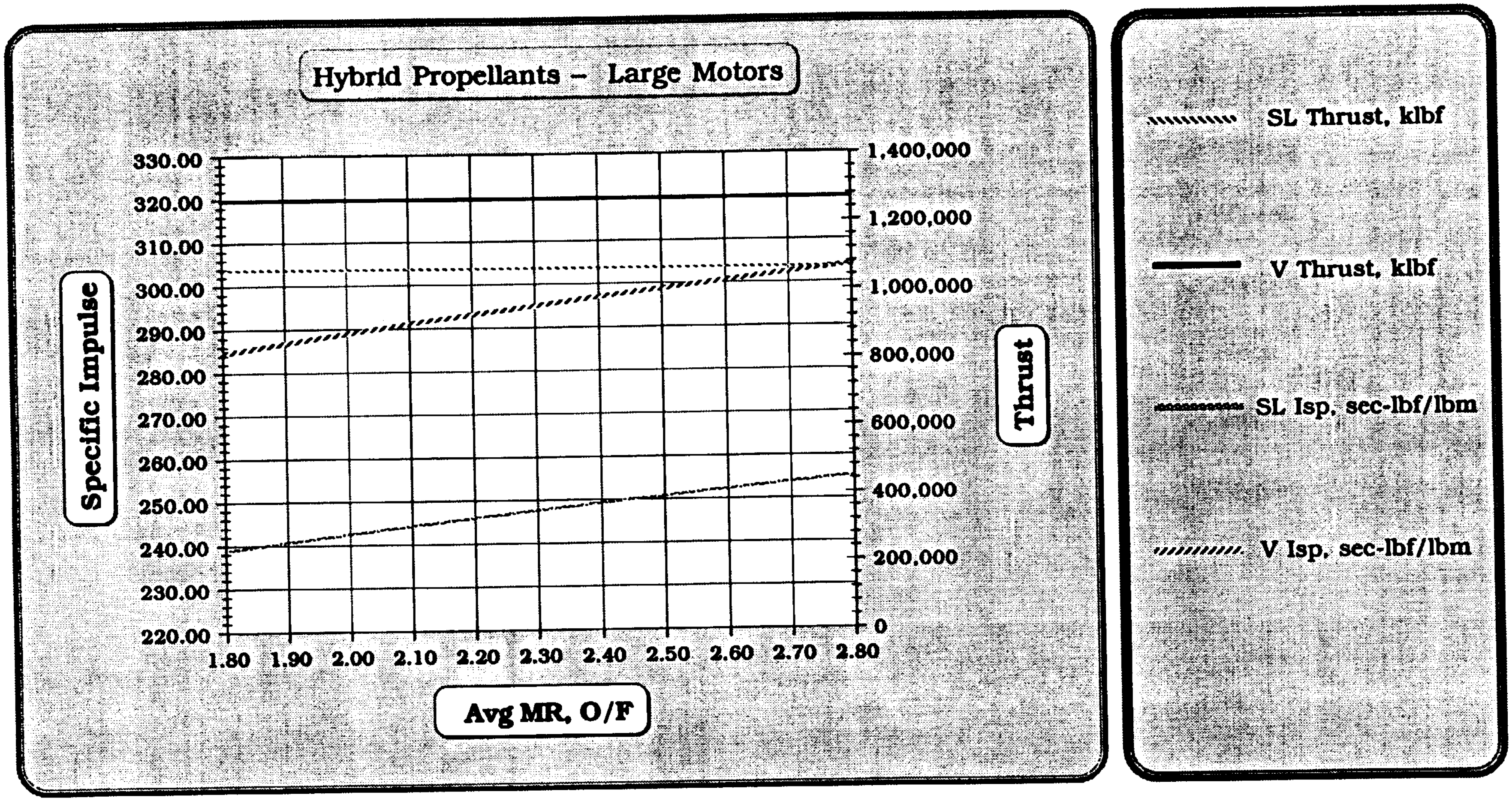


Figure 31. Printed Version of Performance Chart – Hybrid Rocket Motors

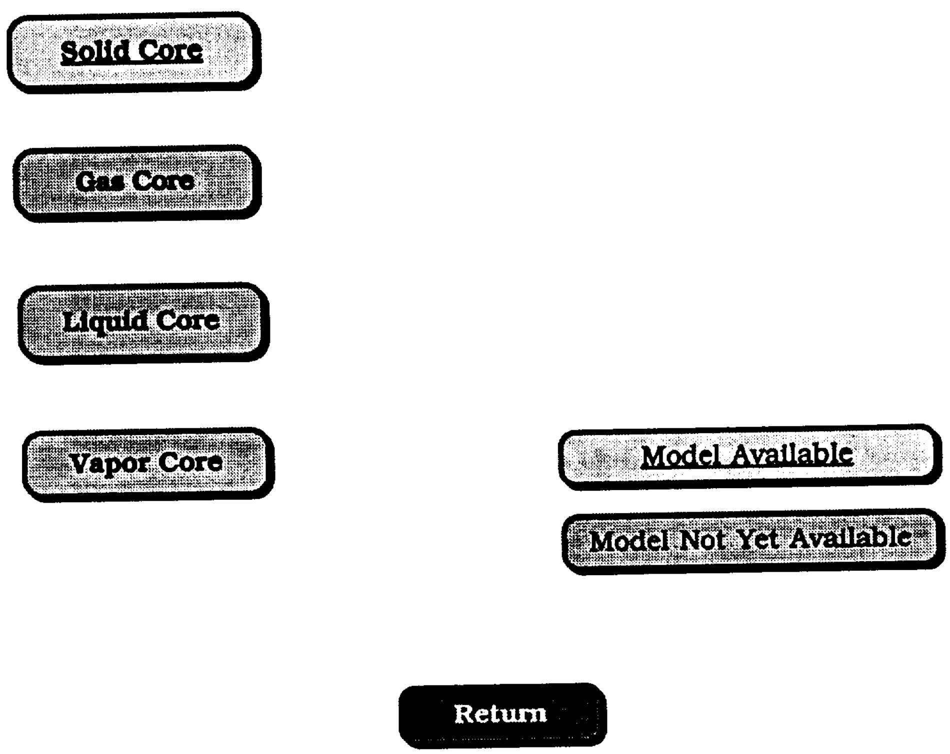


Figure 32. Reactor Choices

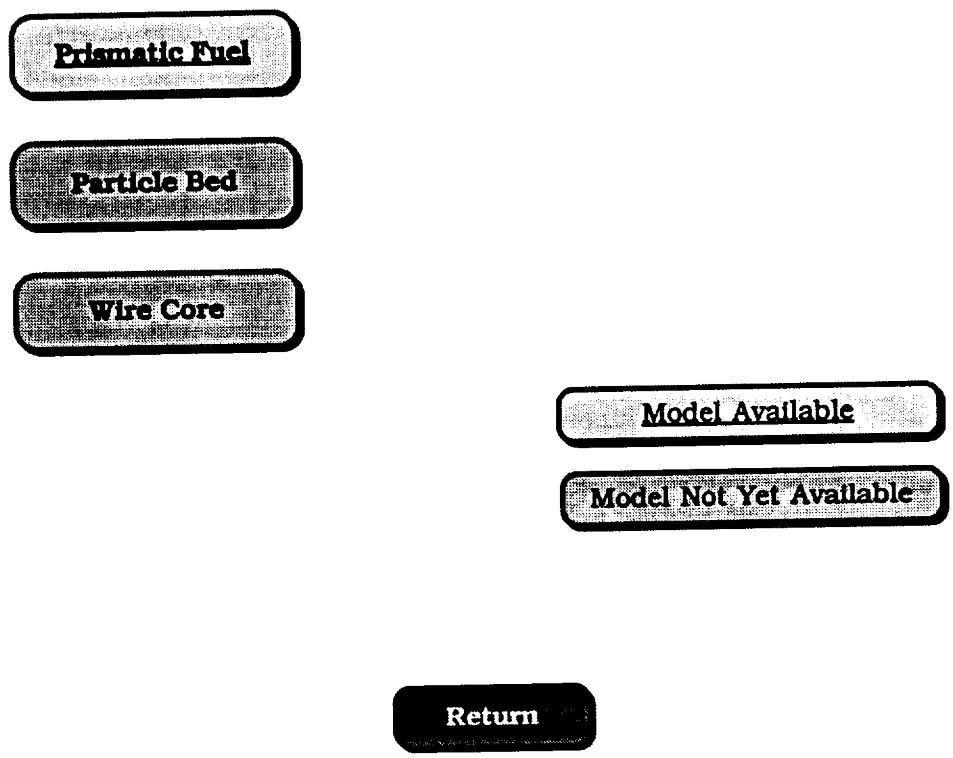


Figure 33. Fuel Form Choices

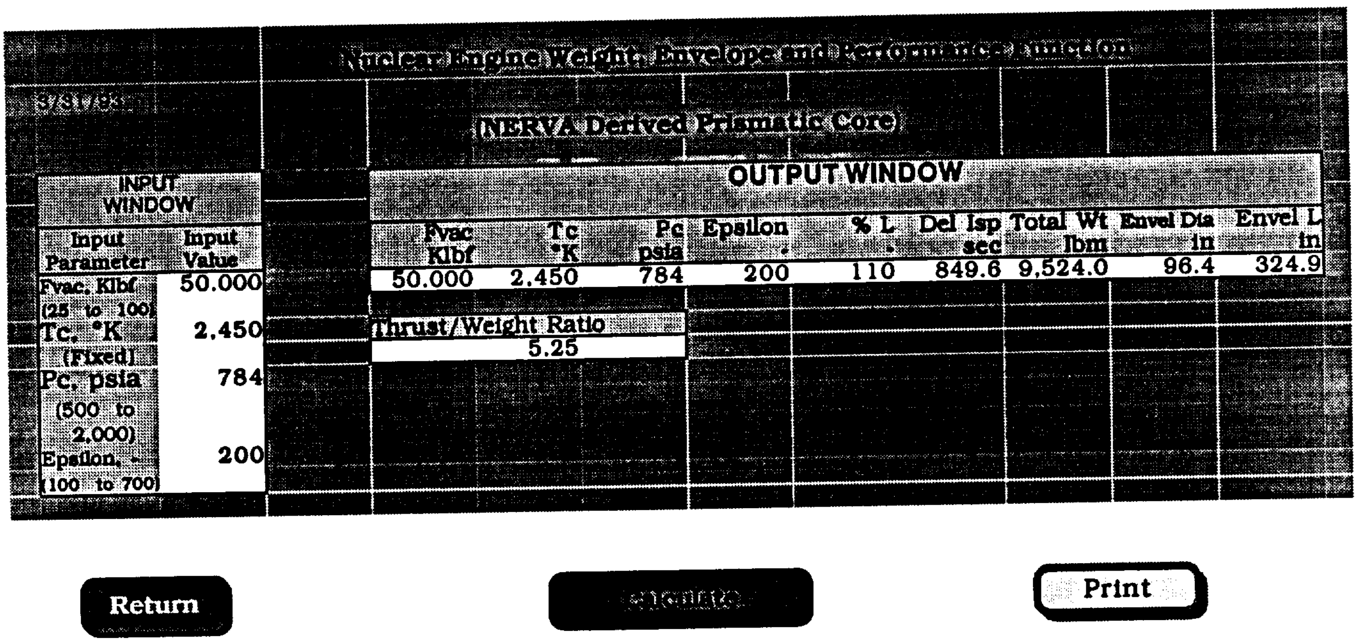


Figure 34. Nuclear Thermal Rocket Model

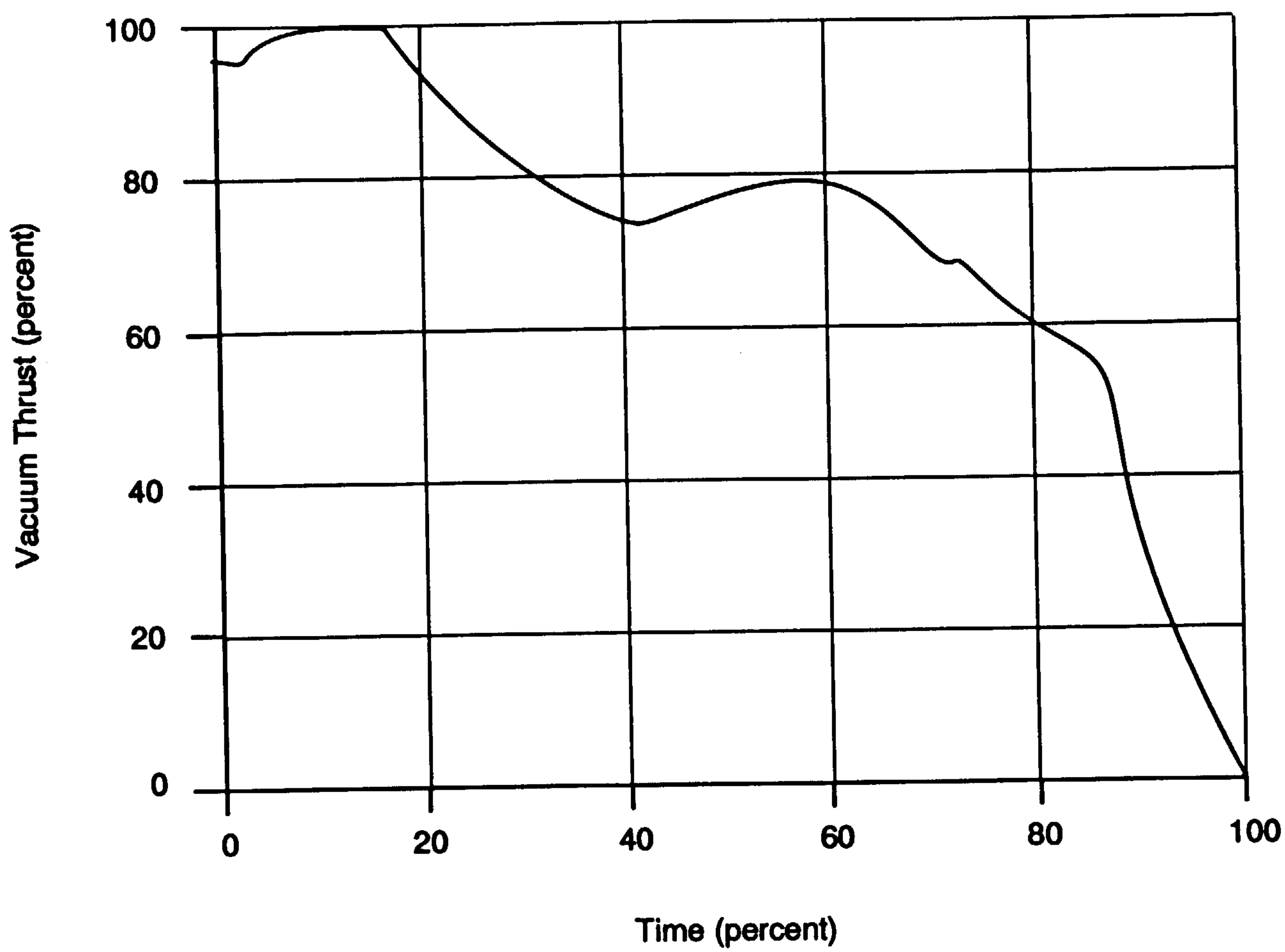


Figure 35. Characteristic Thrust Trace for Solid Rocket Booster Models

TA3–0420Fig

Ingredient	Weight Percent
Al	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 Propellant

Exhaust Product	Mass Fraction
CO (g)	0.2081
CO2 (g)	0.02786
CL (g)	0.00285
HCl (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

TA3–0322

Large Motors **ASRM (ANB3652) Propellant**

14 January 1993

Independent Terms			Range
Meop, psia	-	1,000	200 To 2000
Initial Area Ratio, Ei	-	7.0	5 To 19
(Favg)vac, lbf	-	2,590,000	320 K To 8.9 M
Burn Time, Tb, seconds	-	111	60 To 178
Dcase, in	-	146	80 To 255
Push Weight, lbm	-	1,000,000	
Nose Cone L/D	-	1.30	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.334 and 0.806 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results			RMSE
Rbo, in/sec	-	0.530	0.002
(Isp)sl, sec-lbf/lbm	-	246.54	N/A
(Isp)vac, sec-lbf/lbm	-	269.57	N/A
(A throat)avg, in^2	-	2,243.0	10.7
(R throat)avg, in	-	26.7	N/A
(Favg)sl, lbf	-	2,368,679	N/A
(Favg)vac, lbf	-	2,590,000	N/A
L case, in	-	1,187.9	5.3
L/D case	-	8.14	Note 1
L nozzle, in	-	167.5	3.6
Nozzle Exit O.D., in	-	138.5	N/A
Total Length, in	-	1,545.3	N/A
W propellant, lbm	-	1,066,466	Note 4
W nozzle, lbm	-	12,500.2	1,025
W insulation, lbm	-	6,716.0	105
W case, lbm	-	26,124.3	933
W igniter, lbm	-	633.6	29
W nose cone, lbm	-	3,742.3	N/A
W ext insul, lbm	-	763.5	N/A
W fwd skirt, lbm	-	2,965.0	N/A
W aft skirt, lbm	-	14,659.7	N/A
W separation, lbm	-	1,246.8	N/A
W misc, lbm	-	1,522.1	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	-	9.377E-01	N/A
(Impulse)sl, lbf-sec	-	2.629E+08	
(Impulse)vac, lbf-sec	-	2.875E+08	

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

Large Motors **ASRM (ANB3652) Propellant**

14 January 1993

Independent Terms			Range
Meop, psia	-	1,000	200 To 2000
Initial Area Ratio, Ei	-	7.0	5 To 19
(Favg)vac, lbf	-	2,590,000	320 K To 8.9 M
Burn Time, Tb, seconds	-	111	60 To 178
Dcase, in	-	146	80 To 255
Push Weight, lbm	-	1,000,000	
Nose Cone L/D	-	1.30	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.334 and 0.806 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results			RMSE
Rbo, cm/sec	-	1.345	0.00508
(Isp)sl, sec-N/kg	-	2,417.70	N/A
(Isp)vac, sec-N/kg	-	2,643.60	N/A
(A throat)avg, cm^2	-	14,471.2	69.0321
(R throat)avg, cm	-	67.9	N/A
(Favg)sl, N	-	10,535,884	N/A
(Favg)vac, N	-	11,520,320	N/A
L case, cm	-	3,017.4	13.462
L/D case	-	8.14	Note 1
L nozzle, cm	-	425.6	9.144
Nozzle Exit O.D., cm	-	351.7	N/A
Total Length, cm	-	3,925.0	N/A
W propellant, kg	-	483,643	Note 4
W nozzle, kg	-	5,668.9	464.838
W insulation, kg	-	3,045.7	47.6175
W case, kg	-	11,847.4	423.116
W igniter, kg	-	287.3	13.1515
W nose cone, kg	-	1,697.1	N/A
W ext insul, kg	-	346.2	N/A
W fwd skirt, kg	-	1,344.6	N/A
W aft skirt, kg	-	6,648.2	N/A
W separation, kg	-	565.4	N/A
W misc, kg	-	690.3	N/A
W SRM, kg	-	5.045E+05	
W stage, kg	-	1.129E+04	
W SRB, kg	-	5.158E+05	
V ideal, m/sec	-	1.827E+03	N/A
Mass Fraction	-	9.377E-01	N/A
(Impulse)sl, N-sec	-	1.169E+09	
(Impulse)vac, N-sec	-	1.279E+09	

Figure 39. Printed Output - "Briefing" - Metric Units

Figure 40. Equations for ASRM Propellant Model

TA3-0325

Equations for Stage Components

Variable to be Calculated	Equation

Nose Cone Weight, lbm

$$W_{Nose\ Cone} = 3395 - 2098N_{l/d} - 0.4705(D_c/2)^2 + 2.533x10^{-5}\{(D_c/2)\sqrt{(D_c/2)^2 + (N_{l/d}D_c)^2}\ \}^2$$

External Insulation Weight, lbm

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

Fwd Skirt and Attach Weight, lbm

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

Aft Skirt and Attach Weight, lbm

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

Separation System Weight, lbm

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

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 ASRM Propellant

Variable to be Calculated	Equation	Method & 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, lbm	$W_p = 0.004530\bar{F}_v^{+0.9953} T_b^{1.0024} E_i^{-0.07282}$	RMSE = 2,809 (198k-3.01M)
Vacuum specific Impulse, lbf-sec/lbm	$Isp_v = \frac{\bar{F}_v T_b}{W_p}$	Analytical Equation
Average Nozzle Throat Area, in²	$\bar{A}_t = -14.5 + 172.8 W_p^{0.9902} Meop^{-0.9551} T_b^{-0.9776} + 1.039E-5\bar{F}_v + 0.3131 T_b$	RMSE = 10.7 (315-6830)
Average Nozzle Throat Radius, in	$\bar{R}_t = \sqrt{\frac{\bar{A}_t}{\pi}}$	Analytical Equation
Diameter of Nozzle @ Exit, in	$D_n = 2\sqrt{(\bar{R}_t - 0.005T_b)^2 E_i}$	Analytical Equation
Average Sea Level Thrust, lbf	$\bar{F}_{sl} = \bar{F}_v - 3.675\pi D_n^2$	Analytical Equation
Sea Level Specific Impulse, lbf-sec/lbm	$Isp_{vsl} = \frac{Isp_v \bar{F}_{sl}}{\bar{F}_v}$	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 to Nozzle Exit), in	$L_n = 1.096\bar{A}_t^{+0.5665} E_i^{0.3385}$	RMSE = 3.6 (52-373)
Case length to Diameter Ratio, dim	$L/D_c = \frac{L_c}{D_c}$	Analytical Equation
Booster Total Length, in	$L_{total} = L_c + L_n + N_{l/d} D_c$	Analytical Equation
Igniter Weight, lbm	$W_{ign} = 19.1 + 164.3\dot{M}^{1.273} Meop^{-1.076} D_c^{-0.5851} - 0.07182\bar{A}_t^{+0.5124}$	RMSE = 29 (77-1,748)
Nozzle Weight, lbm	$W_n = 400.6 + 0.02310\sqrt{\bar{A}_t}\,(1+E_i)L_n + 0.1004\bar{A}_t^{+0.6699} W_p^{0.4374} E_i^{0.1699}$	RMSE = 1,025 (1,880-46,900)
Internal Case Insulation, lbm	$W_i = -18.3 + 0.2467 W_p^{0.7199} T_b^{0.3134} L_c^{-0.1737} - 0.07211\bar{A}_t$	RMSE = 105 (1,690-16,800)
Empty Case Weight, lbm	$W_c = -183.1 + 4.795e-4\bar{F}_v + 6.142e-6 L_c^{0.8219} Meop^{0.7691} \bar{F}_v^{+0.1140} D_c^{1.869}$	RMSE = 933 (2,650-107k)
Total Rocket Motor Weight, lbm	$W_{srm} = W_p + W_n + W_i + W_c + W_{ign}$	Analytical Equation
Total Stage Component Weight, lbm	$W_{stg} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$	Analytical Eq. (4,200-193K)
Total Booster weight, lbm	$W_{srb} = W_{srm} + W_{stg}$	Analytical Equation
Booster Ideal Velocity, ft/sec	$V_{ideal} = Isp_v \ln\left(\frac{W_{push} + W_{srb}}{W_{push} + W_{srb} - W_{prop}}\right) 32.18$	Analytical Equation
Booster Mass Fraction, dim	$Mf_{srb} = \frac{W_p}{W_{srb}}$	Analytical Equation
Total Impulse Sea Level, lbf-sec	$I_{sl} = \bar{F}_{sl} T_b$	Analytical Eq. (45M-728M)
Total Impulse vacuum, lbm-sec	$I_v = \bar{F}_v T_b$	Analytical Eq. (51M-865M)

1/14/93

Figure 41. Script for ASRM Propellant Model

TA3–0328

```
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 "=If(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
```

```
{(Isp)vac}
Put "=(C128*C129/(G138/L123))*L125" Into G128
Put "N/A" Into H128
Put "" Into I128

{(A throat)avg}
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 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 "=(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 case}
Put "=G133/(C130*L122)" Into G134
Put "=If(G134>5.6,""Note 1"",""N/A"")" Into H134
Put "" Into I134

{L nozzle}
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

{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 "=((0.004530*C128^0.9953)*(C129^1.0024)*(C127^(-0.07282)))*L123" Into G138
Put "=If(G138>198000*L123,""Note 4"",If(G138<3010000*L123,""Note 3"",2809*L123))" Into H138
Put "" Into I138
```

```
{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

{W igniter}
Put "=(19.1+(164.3*(G138/(C129*L123))^1.273)*(C126^(-1.076))*(C130^(-0.5851))
     -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

{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
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 I150

{W SRB}
Put "=G149+G150" Into G151
Put "" Into H151
Put "" Into I151

{V ideal}
Put "=(32.18*(G128/L125)*Ln((C131+(G151/L123))/(C131+(G151/L123)-(G138/L123))))*L124" Into G15
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<45000000*L126,""Note 3"",If(G154>728000000*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>865000000*L126,""Note 4"",""""))" Into H155
Put "" Into I155


{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
```

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

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

Figure 42. Nominal Composition of Magnesium Clean Propellant

Exhaust Product	Mass Fraction
CO (g)	0.2860
CO2 (g)	0.0162
CL (g)	0.0002
HCl (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-H435) Propellant**

14 January 1993

Independent Terms			Range		
Meop, psia	=	1,000	200	To	2000
Initial Area Ratio, Ei	=	7.0	5	To	19
(Favg)vac, lbf	=	2,590,000	320 K	To	8.9 M
Burn Time, Tb, seconds	=	111	60	To	178
Dcase, in	=	146	80	To	255
Push Weight, lbm	=	1,000,000			
Nose Cone L/D	=	1.30			

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.34 and 0.81 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results			RMSE
Rbo, in/sec	=	0.534	0.002
(Isp)sl, sec-lbf/lbm	=	243.05	N/A
(Isp)vac, sec-lbf/lbm	=	266.17	N/A
(A throat)avg, in^2	=	2,278.9	11
(R throat)avg, in	=	26.9	N/A
(Favg)sl, lbf	=	2,365,069	N/A
(Favg)vac, lbf	=	2,590,000	N/A
L case, in	=	1,337.3	5
L/D case	=	9.16	Note 1
L nozzle, in	=	169.7	3
Nozzle Exit O.D., in	=	139.6	N/A
Total Length, in	=	1,696.8	N/A
W propellant, lbm	=	1,080,110	Note 4
W nozzle, lbm	=	12,648.0	1,184
W insulation, lbm	=	7,128.9	107
W case, lbm	=	28,823.5	1,066
W igniter, lbm	=	630.7	28
W nose cone, lbm	=	3,742.3	N/A
W ext insul, lbm	=	763.5	N/A
W fwd skirt, lbm	=	2,965.0	N/A
W aft skirt, lbm	=	14,659.7	N/A
W separation, lbm	=	1,265.8	N/A
W misc, lbm	=	1,920.0	N/A
W SRM, lbm	=	1.129E+06	
W stage, lbm	=	2.532E+04	
W SRB, lbm	=	1.155E+06	
V ideal, ft/sec	=	5.959E+03	N/A
Mass Fraction	=	9.354E-01	N/A
(Impulse)sl, lbf-sec	=	2.625E+08	
(Impulse)vac, lbf-sec	=	2.875E+08	

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

Large Motors **Neutralizing Mg (DL-H435) Propellant**

14 January 1993

Independent Terms		Value	Range
Mcop, psia	-	1,000	200 To 2000
Initial Area Ratio, Ei	-	7.0	5 To 19
(Favg)vac, lbf	-	2,590,000	320 K To 8.9 M
Burn Time, Tb, seconds	-	111	60 To 178
Dcase, in	-	146	80 To 255
Push Weight, lbm	-	1,000,000	
Nose Cone L/D	-	1.30	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.34 and 0.81 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results		Value	RMSE
Rbo, cm/sec	-	1.356	0.00508
(Isp)sl, sec-N/kg	-	2,383.53	N/A
(Isp)vac, sec-N/kg	-	2,610.21	N/A
(A throat)avg, cm^2	-	14,702.3	70.9676
(R throat)avg, cm	-	68.4	N/A
(Favg)sl, N	-	10,519,828	N/A
(Favg)vac, N	-	11,520,320	N/A
L case, cm	-	3,396.6	12.7
L/D case	-	9.16	Note 1
L nozzle, cm	-	431.2	7.62
Nozzle Exit O.D., cm	-	354.5	N/A
Total Length, cm	-	4,309.9	N/A
W propellant, kg	-	489,830	Note 4
W nozzle, kg	-	5,735.9	536.944
W insulation, kg	-	3,233.0	48.5245
W case, kg	-	13,071.5	483.431
W igniter, kg	-	286.0	12.698
W nose cone, kg	-	1,697.1	N/A
W ext insul, kg	-	346.2	N/A
W fwd skirt, kg	-	1,344.6	N/A
W aft skirt, kg	-	6,648.2	N/A
W separation, kg	-	574.0	N/A
W misc, kg	-	870.7	N/A
W SRM, kg	-	5.122E+05	
W stage, kg	-	1.148E+04	
W SRB, kg	-	5.236E+05	
V ideal, m/sec	-	1.816E+03	N/A
Mass Fraction	-	9.354E-01	N/A
(Impulse)sl, N-sec	-	1.168E+09	
(Impulse)vac, N-sec	-	1.279E+09	

Figure 45. Printed Output - "Briefing" - Metric Units

Figure 46. Equations for Mg Clean Propellant Model

TA3–0326

Equations for Stage Components

Variable to be Calculated	Equation

Nose Cone Weight, lbm

$$W_{Nose\ Cone} = 3395 - 2098N_{l/d} - 0.4705(D_c/2)^2 + 2.533x10^{-5}\{(D_c/2)\sqrt{(D_c/2)^2 + (N_{l/d}D_c)^2}\ \}^2$$

External Insulation Weight, lbm

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

Fwd Skirt and Attach Weight, lbm

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

Aft Skirt and Attach Weight, lbm

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

Separation System Weight, lbm

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

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 Calculated	Equation	Method & Range
Burning Rate @ 1000 psia, ips	$Rbo = 4.957(D_c/T_b)^{0.9788} Meop^{-0.3614}$	RMSE = 0.002 (0.34-0.81)
Propellant Weight, lbm	$W_p = 0.005028 \overline{F}_v^{+0.9953} T_b^{1.0027} E_i^{-0.06843} Meop^{-0.01470}$	RMSE = 3,466 (198k-3.01M)
Vacuum specific Impulse, lbf-sec/lbm	$Isp_v = \frac{\overline{F}_v T_b}{W_p}$	Analytical Equation
Average Nozzle Throat Area, in²	$\overline{A}_t = -15.2 + 157.4 W_p^{0.9899} Meop^{-0.9404} T_b^{-0.9776} + 1.027E-5\overline{F}_v + 0.3134T_b$	RMSE = 11 (329-6,820)
Average Nozzle Throat Radius, in	$\overline{R}_t = \sqrt{\frac{\overline{A}_t}{\pi}}$	Analytical Equation
Diameter of Nozzle @ Exit, in	$D_n = 2\sqrt{(\overline{R}_t - 0.005T_b)^2 E_i}$	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, lbf-sec/lbm	$Isp_{vsl} = \frac{Isp_v \overline{F}_{sl}}{\overline{F}_v}$	Analytical Equation
Boss-Boss Case Length, in	$L_c = -0.3 + 28.23\left[\frac{W_p}{D_c^2}\right]^{0.9794} + 8.696E-4\dot{M} + 0.009766Meop$	RMSE = 5 (492-1,825)
Nozzle Length (Aft Case Boss to Nozzle Exit), in	$L_n = -14.87 + 1.8468E_i^{0.2966}\overline{A}_t^{+0.5225} - 0.002486Meop + 0.4242E_i - 0.02445T_b$	RMSE = 3 (46-374)
Case length to Diameter Ratio, dim	$L/D_c = \frac{L_c}{D_c}$	Analytical Equation
Booster Total Length, in	$L_{total} = L_c + L_n + N_{l/d}D_c$	Analytical Equation
Igniter Weight, lbm	$W_{ign} = 21.0 + 0.2218Meop^{0.1277}\overline{A}_t^{+1.3314}D_c^{-0.6535}$	RMSE =28 (76-1,754)
Nozzle Weight, lbm	$W_n = 588.7 + 0.02444\sqrt{\overline{A}_t}\,(1+E_i)L_n + 0.06048\overline{A}_t^{+0.6750}W_p^{0.4703}E_i^{0.1592}$	RMSE = 1184 (1,944-47,600)
Internal Case Insulation, lbm	$W_i = -19.5 + 0.2395W_p^{0.7022}T_b^{0.3056}L_c^{-0.1211} - 0.06024\overline{A}_t$	RMSE = 107 (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 (2,840-117k)
Total Rocket Motor Weight, lbm	$W_{srm} = W_p + W_n + W_i + W_c + W_{ign}$	Analytical Equation
Total Stage Component Weight, lbm	$W_{stg} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$	Analytical Eq. (4,300-193K)
Total Booster weight, lbm	$W_{srb} = W_{srm} + W_{stg}$	Analytical Equation
Booster Ideal Velocity, ft/sec	$V_{ideal} = Isp_v \ln\left(\frac{W_{push}+W_{srb}}{W_{push}+W_{srb}-W_{prop}}\right)32.18$	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. (44M-716M)
Total Impulse vacuum, lbm-sec	$I_v = \overline{F}_v T_b$	Analytical Eq. (51M-854M)

1/14/93

Figure 47. Script for Mg Clean
Propellant Model
(Large Motors)

TA3–0329

```
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 "N/A" Into H127
Put "" Into I127

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

```
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 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
```

```
{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

{W igniter}
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

{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
```

```
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 I151

{V ideal}
Put "=(32.18*(G128/L125)*Ln((C131+(G151/L123))/(C131+(G151/L123)-(G138/L123))))*L124" Into G15?
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 I155

{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
```

Medium Motors **Neutralizing Mg (DL-H435) Propellant**

18 August 1992

Independent Terms			Range
Meop, psia	-	2,000	900 To 2000
Initial Area Ratio, Ei	-	10	7 To 19
(Favg)vac, lbf	-	250,000	62K to 328K
Burn Time, Tb, seconds	-	40	30 To 105
Dcase, in	-	70	30 To 105
Push Weight, lbm	-	200,000	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.34 and 0.81 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results			RMSE	
Rbo, in/sec	-	0.573	Note 4	2.995
(Isp)sl, sec-lbf/lbm	-	253.43	N/A	N/A
(Isp)vac, sec-lbf/lbm	-	271.88	0.595	0.217
(A throat)avg, in^2	-	115.4	1.57	0.872
(R throat)avg, in	-	6.1	N/A	N/A
(Favg)sl, lbf	-	233,035	N/A	N/A
(Favg)vac, lbf	-	250,000	N/A	N/A
L case, in	-	217.5	1.519	0.466
L/D case	-	3.11	N/A	N/A
L nozzle, in	-	24.7	0.94	2.282
Nozzle Exit O.D., in	-	38.3	N/A	N/A
Total Length, in	-	347.2	N/A	N/A
W propellant, lbm	-	36,781	N/A	N/A
W nozzle, lbm	-	540.7	21	2.358
W insulation, lbm	-	567.2	13.42	1.33
W case, lbm	-	403.5	66.95	2.64
W igniter, lbm	-	24.3	2.9	5.74
W SRM, lbm	-	38,317	71.7	
W stage, lbm	-	1,556	94.8	4.3
W SRB, lbm	-	39,873	121.5	
V ideal, ft/sec	-	1,456	N/A	N/A
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

Medium Motors **Neutralizing Mg (DL-H435) Propellant**

18 August 1992

Independent Terms		Value	Range
Meop, psia	-	2,000	900 To 2000
Initial Area Ratio, Ei	-	10	7 To 19
(Favg)vac, lbf	-	250,000	62K to 328K
Burn Time, Tb, seconds	-	40	30 To 105
Dcase, in	-	70	30 To 105
Push Weight, lbm	-	200,000	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.34 and 0.81 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results		Value	RMSE	
Rbo, cm/sec	-	1.454	Note 4	2.995
(Isp)sl, sec-N/kg	-	2,485.28	N/A	N/A
(Isp)vac, sec-N/kg	-	2,666.21	5.83496	0.217
(A throat)avg, cm^2	-	744.6	10.129	0.872
(R throat)avg, cm	-	15.4	N/A	N/A
(Favg)sl, N	-	1,036,540	N/A	N/A
(Favg)vac, N	-	1,112,000	N/A	N/A
L case, cm	-	552.5	3.85826	0.466
L/D case	-	3.11	N/A	N/A
L nozzle, cm	-	62.8	2.3876	2.282
Nozzle Exit O.D., cm	-	97.4	N/A	N/A
Total Length, cm	-	882.0	N/A	N/A
W propellant, kg	-	16,683	N/A	N/A
W nozzle, kg	-	245.2	9.5235	2.358
W insulation, kg	-	257.2	6.08597	1.33
W case, kg	-	183.0	30.3618	2.64
W igniter, kg	-	11.0	1.31515	5.74
W SRM, kg	-	17,379	32.516	
W stage, kg	-	706	42.9918	4.3
W SRB, kg	-	18,085	55.1003	
V ideal, 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)vac, N-sec	-	4.448E+07	N/A	N/A

Figure 49. Printed Output - "Briefing" - Metric Units

Figure 50. Script for Mg Clean Propellant Model (Medium Motors)

TA3–0330

```
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
```

```
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}

{Rbo}
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 I67

{(Isp)sl}
Put "=G72*C70/G79" Into G68
Put "N/A" Into H68
Put "N/A" Into I68

{(Isp)vac}
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 I71

{(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

{L case}
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

{L nozzle}
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 I76
```

```
{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

{W nozzle}
Put "=(36.9679+0.000011857*M82+0.1818*M94+1.41166*C70+9.22776*G76/L2)*L3" Into G80
Put "=If(G80<221*L3,""Note 3"",If(G80>1819*L3,""Note 4"",21*L3))" Into H80
Put 2.358 Into I80

{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 I81

{W case}
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 I82

{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 I83

{W SRM}
Put "=Sum(G79..G83)" Into G84
Put "=71.7*L3" Into H84
Put " " Into I84

{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 I85

{W SRB}
Put "=G84+G85" Into G86
Put "=121.5*L3" Into H86
Put " " Into I86

{V ideal}
Put "=((G69/L5)*32.18*M100)*L4" Into G87
Put "N/A" Into H87
Put "N/A" Into I87
```

{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
Al	25.0
AN**	40.0

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

Figure 51. Nominal Composition of Non-Chlorine Clean Propellant

Exhaust Product	Mass Fraction
CO (g)	0.236
CO2 (g)	0.0175
AlOH	0.00001
AlO2H	0.00001
Al2O3 (l & s)	0.472
OH (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

TA3–0324

Large Motors **Non-Chlorine (PGN/AN/AL) Clean Propellant**

14 January 1993

Independent Terms			Range
Meop, psia	-	1,000	200 To 2000
Initial Area Ratio, Ei	-	7.0	5 To 19
(Favg)vac, lbf	-	2,590,000	320 K To 8.9 M
Burn Time, Tb, seconds	-	111	60 To 178
Dcase, in	-	146	80 To 255
Push Weight, lbm	-	1,000,000	
Nose Cone L/D	-	1.30	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.33 and 0.818 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results			RMSE
Rbo, in/sec	-	0.540	0.002
(Isp)sl, sec-lbf/lbm	-	244.10	N/A
(Isp)vac, sec-lbf/lbm	-	267.69	N/A
(A throat)avg, in^2	-	2,312.2	11
(R throat)avg, in	-	27.1	N/A
(Favg)sl, lbf	-	2,361,706	N/A
(Favg)vac, lbf	-	2,590,000	N/A
L case, in	-	1,230.4	5
L/D case	-	8.43	Note 1
L nozzle, in	-	171.1	3
Nozzle Exit O.D., in	-	140.6	N/A
Total Length, in	-	1,591.3	N/A
W propellant, lbm	-	1,073,951	3,048
W nozzle, lbm	-	13,442.8	567
W insulation, lbm	-	7,003.6	241
W case, lbm	-	26,915.1	909
W igniter, lbm	-	639.2	22
W nose cone, lbm	-	3,742.3	N/A
W ext insul, lbm	-	763.5	N/A
W fwd skirt, lbm	-	2,965.0	N/A
W aft skirt, lbm	-	14,659.7	N/A
W separation, lbm	-	1,257.5	N/A
W misc, lbm	-	1,634.1	N/A
W SRM, lbm	-	1.122E+06	
W stage, lbm	-	2.502E+04	
W SRB, lbm	-	1.147E+06	
V ideal, ft/sec	-	5.975E+03	N/A
Mass Fraction	-	9.363E-01	N/A
(Impulse)sl, lbf-sec	-	2.621E+08	
(Impulse)vac, lbf-sec	-	2.875E+08	

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

Large Motors **Non-Chlorine (PGN/AN/AL) Clean Propellant**

14 January 1993

Independent Terms		Value	Range
Meop, psia	-	1,000	200 To 2000
Initial Area Ratio, Ei	-	7.0	5 To 19
(Favg)vac, lbf	-	2,590,000	320 K To 8.9 M
Burn Time, Tb, seconds	-	111	60 To 178
Dcase, in	-	146	80 To 255
Push Weight, lbm	-	1,000,000	
Nose Cone L/D	-	1.30	

Dependent Terms

Note 1: Cases with L/D greater than 5.6 are difficult to wind w/o joints.

Note 2: MG propellant burn rates (Rbo) are tailorable between 0.33 and 0.818 ips.

Note 3: Data is being extrapolated below range of regression.

Note 4: Data is being extrapolated above range of regression.

Results		Value	RMSE
Rbo, cm/sec	-	1.370	0.00508
(Isp)sl, sec-N/kg	-	2,393.78	N/A
(Isp)vac, sec-N/kg	-	2,625.18	N/A
(A throat)avg, cm^2	-	14,917.7	70.9676
(R throat)avg, cm	-	68.9	N/A
(Favg)sl, N	-	10,504,867	N/A
(Favg)vac, N	-	11,520,320	N/A
L case, cm	-	3,125.3	12.7
L/D case	-	8.43	Note 1
L nozzle, cm	-	434.6	7.62
Nozzle Exit O.D., cm	-	357.2	N/A
Total Length, cm	-	4,042.0	N/A
W propellant, kg	-	487,037	1,382.27
W nozzle, kg	-	6,096.3	257.135
W insulation, kg	-	3,176.1	109.294
W case, kg	-	12,206.0	412.232
W igniter, kg	-	289.9	9.977
W nose cone, kg	-	1,697.1	N/A
W ext insul, kg	-	346.2	N/A
W fwd skirt, kg	-	1,344.6	N/A
W aft skirt, kg	-	6,648.2	N/A
W separation, kg	-	570.3	N/A
W misc, kg	-	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

TA3–0327

Equations for Stage Components

Variable to be Calculated	Equation

Nose Cone Weight, lbm

$$W_{Nose\ Cone} = 3395 - 2098N_{l/d} - 0.4705(D_c/2)^2 + 2.533x10^{-5}\{(D_c/2)\sqrt{(D_c/2)^2 + (N_{l/d}D_c)^2}\ \}^2$$

External Insulation Weight, lbm

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

Fwd Skirt and Attach Weight, lbm

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

Aft Skirt and Attach Weight, lbm

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

Separation System Weight, lbm

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

Misc Weight, lbm

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

TA3–0321

Large Motors Equations For Non-Chlorine Propellant

Variable to be Calculated	Equation	Method & Range
Burning Rate @ 1000 psia, ips	$Rbo = 5.362\left(\frac{D_c}{T_b}\right)^{0.9793} Meop^{-0.3713}$	RMSE = 0.002 (0.33-0.818)
Propellant Weight, lbm	$W_p = 642.4 + 0.004462\bar{F}_v^{+0.9955} T_b^{1.0027} E_i^{-0.07409} Meop^{0.002841}$	RMSE = 3,048 (200k-3M)
Vacuum specific Impulse, lbf-sec/lbm	$Isp_v = \frac{\bar{F}_v T_b}{W_p}$	Analytical Equation
Average Nozzle Throat Area, in²	$\bar{A}_t = -11.5 + 187.8 W_p^{0.9949} Meop^{-0.9708} T_b^{-0.9838} + 1.923E-5\bar{F}_v + 0.3461 T_b$	RMSE = 11 (334-9,760)
Average Nozzle Throat Radius, in	$\bar{R}_t = \sqrt{\frac{\bar{A}_t}{\pi}}$	Analytical Equation
Diameter of Nozzle @ Exit, in	$D_n = 2\sqrt{(\bar{R}_t - 0.005T_b)^2 E_i}$	Analytical Equation
Average Sea Level Thrust, lbf	$\bar{F}_{sl} = \bar{F}_v - 3.675 E_i \pi D_n^2$	Analytical Equation
Sea Level Specific Impulse, lbf-sec/lbm	$Isp_{vsl} = \frac{Isp_v \bar{F}_{sl}}{\bar{F}_v}$	Analytical Equation
Boss-Boss Case Length, in	$L_c = -3.0 + 26.79\left[\frac{W_p}{D_c^2}\right]^{0.9735} + 0.0008531\dot{M} + 0.008615 Meop$	RMSE = 5 (457-1,688)
Nozzle Length (Aft Case Boss to Nozzle Exit), in	$L_n = -16.3 + 1.892 E_i^{0.2937} \bar{A}_t^{+0.5206} - 0.002267 Meop + 0.4660 E_i - 0.02340 T_b$	RMSE = 3 (50-380)
Case length to Diameter Ratio, dim	$L/D_c = \frac{L_c}{D_c}$	Analytical Equation
Booster Total Length, in	$L_{total} = L_c + L_n + N_{l/d} D_c$	Analytical Equation
Igniter Weight, lbm	$W_{ign} = 16.6 + 0.2810 Meop^{0.1167} \bar{A}_t^{+1.287} D_c^{-0.6164}$	RMSE = 22 (77-2,922)
Nozzle Weight, lbm	$W_n = 327.3 + 0.02671\sqrt{\bar{A}_t}\,(1 + E_i) L_n + 0.1664 \bar{A}_t^{0.6079} W_p^{0.4469} E_i^{0.1111}$	RMSE = 567 (2.6k-49.8k)
Internal Case Insulation, lbm	$W_i = -19.4 + 0.2425 W_p^{0.7148} T_b^{0.3103} L_c^{-0.1566} + \bar{A}_t^{0.06609}$	RMSE = 241 (1,700-16,800)
Empty Case Weight, lbm	$W_c = -122.9 + 5.155E-4\bar{F}_v + 6.142E-6 L_c^{0.8250} Meop^{0.7722} \bar{F}_v^{+0.1108} D_c^{1.869}$	RMSE = 909 (2,720-110k)
Total Rocket Motor Weight, lbm	$W_{srm} = W_p + W_n + W_i + W_c + W_{ign}$	Analytical Equation
Total Stage Component Weight, lbm	$W_{stg} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$	Analytical Eq. (4,300-193K)
Total Booster weight, lbm	$W_{srb} = W_{srm} + W_{stg}$	Analytical Equation
Booster Ideal Velocity, ft/sec	$V_{ideal} = Isp_v \ln\left(\frac{W_{push} + W_{srb}}{W_{push} + W_{srb} - W_{prop}}\right) 32.18$	Analytical Equation
Booster Mass Fraction, dim	$Mf_{srb} = \frac{W_p}{W_{srb}}$	Analytical Equation
Total Impulse Sea Level, lbf-sec	$I_{sl} = \bar{F}_{sl} T_b$	Analytical Eq. (45M-720M)
Total Impulse vacuum, lbm-sec	$I_v = \bar{F}_v T_b$	Analytical Eq. (52M-861M)

1/14/93

Figure 56. Script for Non-Chlorine Clean Propellant Model

TA3–0331

```
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
```

```
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
```

```
{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)))^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

{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
```

```
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 I151

{V ideal}
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<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 I155


{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
Fuel Grain	
Escorez	60.0
HTPB	40.0
Oxidizer	
O_2	100.0

Figure 57. Nominal Composition of Hybrid Propellant

Exhaust Product	Mass Fraction @ O/F = 2.8	Mass Fraction @ O/F = 1.8
CO (g)	0.2032	0.5632
CO_2 (g)	0.5236	0.2591
OH (g)	0.0155	0.0000
H (g)	0.0003	0.0000
H_2 (g)	0.0024	0.0224
H_2O (g)	0.2286	0.1536
NO (g)	0.0004	0.0000
N_2 (g)	0.0011	0.0017
O_1 (g)	0.0025	0.0000
O_2 (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 Propellants**

23 March 1993

Independent Terms			Range		
Meop, psia	=	500	500	To	1500
Initial Area Ratio, Ei	=	8	8	To	20
(Favg)vac, lbf	=	1,267,506	280 K	To	21 M
Burn Time, Tb, seconds	=	45	45	To	200
Nose Cone L/D	=	1.3	0.5	To	3.0
Max Ox Flux, lbm/s-in^2	=	0.2	0.2	To	1.0
Avg MR, O/F	=	1.8	1.8	To	2.8
Push Weight, lbm	=	1,000,000			

Dependent Terms

Note 1: Data is being extrapolated below range of regression.

Note 2: Data is being extrapolated above range of regression.

Results			RMSE
D nozzle exit, in	=	132.8	N/A
(Isp)sl, sec-lbf/lbm	=	238.76	N/A
(Isp)vac, sec-lbf/lbm	=	284.48	1.9
(A throat)avg, in^2	=	1,765.4	N/A
(R throat)avg, in	=	23.7	0.9
(Favg)sl, lbf	=	1,063,817	N/A
(Favg)vac, lbf	=	1,267,506	N/A
L tank & case, in	=	803.5	71
L/D case	=	4.91	N/A
L nozzle, in	=	125.7	53
D motor, in	=	163.5	3
Total Length, in	=	1,141.9	N/A
W oxidizer, lbm	=	128,454	N/A
W fuel, lbm	=	71,363	N/A
W propellant, lbm	=	199,818	N/A
W nose cone, lbm	=	6,307.4	N/A
W ext insul, lbm	=	921.5	N/A
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	=	1,666	N/A
W HRM, lbm	=	232,514	
W stage, lbm	=	3.712E+04	
W HRB, lbm	=	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

Figure 59. Printed Output - "Report" English Units

Large Motors **Hybrid Propellants**

23 March 1993

Independent Terms			Range
Meop, psia	=	500	500 To 1500
Initial Area Ratio, Ei	=	8	8 To 20
(Favg)vac, lbf	=	1,267,506	280 K To 21 M
Burn Time, Tb, seconds	=	45	45 To 200
Nose Cone L/D	=	1.3	0.5 To 3.0
Max Ox Flux, lbm/s-in^2	=	0.2	0.2 To 1.0
Avg MR, O/F	=	1.8	1.8 To 2.8
Push Weight, lbm	=	1,000,000	

Dependent Terms

Note 1: Data is being extrapolated below range of regression.

Note 2: Data is being extrapolated above range of regression.

Results			RMSE
D nozzle exit, cm	=	337.4	N/A
(Isp)sl, sec-N/kg	=	2,341.46	N/A
(Isp)vac, sec-N/kg	=	2,789.78	18.6
(A throat)avg, cm^2	=	11,389.7	N/A
(R throat)avg, cm	=	60.2	2.3
(Favg)sl, N	=	4,731,858	N/A
(Favg)vac, N	=	5,637,867	N/A
L tank & case, cm	=	2,041.0	180
L/D case	=	4.91	N/A
L nozzle, cm	=	319.4	135
D motor, cm	=	415.4	8
Total Length, cm	=	2,900.3	N/A
W oxidizer, kg	=	58,254	N/A
W fuel, kg	=	32,363	N/A
W propellant, kg	=	90,617	N/A
W nose cone, kg	=	2,860.4	N/A
W ext insul, kg	=	417.9	N/A
W fwd skirt, kg	=	2,142	N/A
W aft skirt, kg	=	10,539	N/A
W separation, kg	=	118	N/A
W misc, kg	=	756	N/A
W HRM, kg	=	105,445	
W stage, kg	=	1.683E+04	
W HRB, kg	=	1.223E+05	
V ideal, m/sec	=	4.778E+02	N/A
Mass Fraction	=	8.594E-01	0.012
(Impulse)sl, N-sec	=	2.129E+08	N/A
(Impulse)vac, N-sec	=	2.537E+08	N/A

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

Figure 61. Equations for Hybrid Rocket Booster Model

TA3–0422

Equations for Stage Components

Variable to be Calculated	Equation

Nose Cone Weight, lbm

$$W_{Nose\ Cone} = 3395 - 2098N_{l/d} - 0.4705(D_c/2)^2 + 2.533x10^{-5}\{(D_c/2)\sqrt{(D_c/2)^2 + (N_{l/d}D_c)^2}\ \}^2$$

External Insulation Weight, lbm

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

Fwd Skirt and Attach Weight, lbm

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

Aft Skirt and Attach Weight, lbm

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

Separation System Weight, lbm

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

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 Calculated	Equation	Method & Range
Vacuum specific Impulse, lbf-sec/lbm	$Isp_v = 314.4 - 8.242X + 0.4932X^2; where \quad X = Ln\left[\overline{F}_v^{+0.1414} E_i^{3.938} O/F^{3.685} T_b^{-.2526}\right]$	RMSE = 1.9 (280.3-317.8)
Average Nozzle Throat Radius, in	$\overline{R}_t = 1.266 + 0.3718 Meop^{-0.5035} \overline{F}_v^{+0.5123} T_b^{0.007919}$	RMSE = 0.9 (7.5-93.9)
Impulse vacuum, lbm-sec	$I_v = \overline{F}_v T_b$	Analytical Equation
Diameter of Nozzle @ Exit, in	$D_n = 2\sqrt{(\overline{R}_t - 0.005T_b)^2 E_i}$	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, lbf-sec/lbm	$Isp_{vsl} = \frac{Isp_v \overline{F}_{sl}}{\overline{F}_v}$	Analytical Equation
Hybrid Roctet Motor diameter, in	$D_m = 59.8 + 0.005607X - 1.136e-9X^2;\ ;where \quad X = \overline{F}_v^{+0.5991} Fo_{\max}^{-0.4856} T_b^{0.1652}$	RMSE = 3 (84-636)
External Nozzle Length, in	$L_{noz} = 190.1 - 294.4X - 205.3X^2 + 407.9X^3; \quad X = E_i^{0.1327} \overline{R}_t^{+1.568} \overline{F}_v^{-0.6560} Meop^{0.6478}$	RMSE =53 (45-1005)
Total Length of Tank Plus Case, in	$L_{T+C} = 16.7 + 2.860 Fo_{\max}^{0.1767} \overline{F}_v^{+0.4396} T_b^{0.4159} D_m^{-0.3175} Meop^{-0.002468} O/F^{-0.3836}$	RMSE =71 (654-3255)
Hybrid Rocket Motor length, in	$L_{HRM} = L_{noz} + L_{T+C}$	Analytical Eq. (746-3845)
Booster Total Length, in	$L_{HRB} = L_{HRM} + N_{tld} D_m$	Analytical Equation
Fuel Used Weight, lbm	$W_{fuel} = 0.9966 \overline{F}_v T_b / [Isp_v(1 + O/F)]$	Analytical Equation
O_2 Used Weight, lbm	$Wo_2 = W_{fuel} O/F$	Analytical Equation
Total Weight Propellant Used, lbm	$W_p = W_{fuel} + Wo_2$	Analytical Equation
Hybrid Rocket Motor Mass Fraction, dim	$Mf_{HRM} = -5.324 + 6.696X - 0.7267e-6X^2;$ where $X = Meop^{-0.01183} E_i^{-0.001051} Fo_{\max}^{0.002209} O/F^{-0.003599} T_b^{0.004171} I_v^{-0.0007922}$	RMSE = 0.012 (0.73-0.91)
Total Hybrid Rocket Motor Weight, lbm	$W_{HRM} = W_p / Mf_{HRM}$	Analytical Equation
Total Stage Component Weight, lbm	$W_{stg} = W_{NoseCone} + W_{ExtInsulation} + W_{FwdSkirt} + W_{AftSkirt} + W_{Separtion} + W_{Misc.}$	Analytical Eq. (4,300-193K)
Total Hybrid Rocket Booster weight, lbm	$W_{HRB} = W_{HRM} + W_{stg}$	Analytical Equation
Booster Ideal Velocity, ft/sec	$V_{ideal} = Isp_v \ln\left(\frac{W_{push} + W_{HRB}}{W_{push} + W_{HRB} - W_p}\right) 32.18$	Analytical Equation
Total Impulse Sea Level, lbf-sec	$I_{sl} = \overline{F}_{sl} T_b$	Analytical Equation

Figure 62. Script for Hybrid Rocket Booster Model

TA3–0423

```
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}

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


{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>200, 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
```

```
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 "=((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 I414

{(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 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
```

```
{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 I423

{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

{W misc}
Put "=(-1039-0.00204*(G432/L403)+2.854*((G418+G420)/L402)+0.07885*((M426/2)^2))*L403" Into G4
Put "N/A" Into H431
Put "" Into I431

{W HRM}
Put "=G425/G436" Into G432
Put "" Into H432
Put "" Into I432
```

```
{W stage}
Put "=Sum(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

{V ideal}
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

{Mass Fraction}
Put "=(C411^(-0.01183))*(C412^(-0.001051))*(C416^0.002209)*(C417^(-0.003599))
      *(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* Efficiency	0.98450	0.85 to 0.999
Fuel Inlet Enthalpy, kcal/mole	-1.270	-2.154 to 1.856

Performance	Value
Vacuum Thrust, klbf	512.845
Vacuum Isp, sec-lbf/lbm	452.98
SL Thrust, klbf	418.772
SL Isp, sec-lbf/lbm	369.89
ODE C-Star, ft/sec	7,753.62
L-Star, in	30.40
ODE Isp, sec-lbf/lbm	468.92
Energy Release Efficiency	0.98450
Kinetic Efficiency	0.99993
Divergence Efficiency	0.99283
Boundary Layer Efficiency	0.98904
Engine Efficiency	0.96666

Dimensions	Value
Throat Diameter, in	10.3
Throat Area, in^2	83.2
Chamber Length, in	12.3
Nozzle Exit Diameter, in	90.3
Engine Diameter, in	96.0
Nozzle Length, in	119.5
Engine Length, in	168.0

Weights, lbm	Value
Turbomachinery	1,725.0
Preburners	229.0
PB Hot Gas Manifold	558.0
Thrust Chamber	859.0
Nozzle	1,250.0
Gimbal Bearing	105.0
Valves 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	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* Efficiency	0.98450	0.85 to 0.999
Fuel Inlet Enthalpy, kcal/mole	-1.270	-2.154 to 1.856

Performance	**Value**
Vacuum Thrust, kN	2,281.248
Vacuum Isp, sec-N/kg	4,442.25
SL Thrust, kN	1,862.791
SL Isp, sec-N/kg	3,627.39
ODE C-Star, m/sec	2,363.30
L-Star, cm	77.21
ODE Isp, sec-N/kg	2,085.87
Energy Release Efficiency	0.98450
Kinetic Efficiency	0.99993
Divergence Efficiency	0.99283
Boundary Layer Efficiency	0.98904
Engine Efficiency	0.96666

Dimensions	**Value**
Throat Diameter, cm	26.1
Throat Area, cm^2	536.9
Chamber Length, cm	31.2
Nozzle Exit Diameter, cm	229.4
Engine Diameter, cm	243.8
Nozzle Length, cm	303.5
Engine Length, cm	426.6

Weights, kg	**Value**
Turbomachinery	782.3
Preburners	103.9
PB Hot Gas Manifold	253.1
Thrust Chamber	389.6
Nozzle	566.9
Gimbal Bearing	47.6
Valves and Controls	327.4
Controller and Mount	38.5
POGO System	42.6
Propellant Ducts	393.5
Pressurization System	40.4
Other Engine Systems	103.4
Total Dry Weight	3,089.1

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

Liquid Engines	LOX/RP	26 January 1993

Independent Terms	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	
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
Vacuum Thrust, klbf	2,020.700
Vacuum Isp, sec-lbf/lbm	303.10
SL Thrust, klbf	1,799.811
SL Isp, sec-lbf/lbm	269.70
ODE C-Star, ft/sec	5,949.15
L-Star, in	46.71
ODE Isp, sec-lbf/lbm	337.15
Energy Release Efficiency	0.93930
Kinetic Efficiency	0.99796
Divergence Efficiency	0.99186
Boundary Layer Efficiency	0.99210
Engine Efficiency	0.92240

Dimensions	Value
Throat Diameter, in	34.6
Throat Area, in^2	939.4
Chamber Length, in	39.4
Nozzle Exit Diameter, in	138.3
Engine Diameter, in	143.5
Nozzle Length, in	155.5
Engine Length, in	220.4

Weights, lbm	Value
Turbopump and Mount	4,488.5
Thrust Chamber	8,507.0
Engine Mount	467.0
Oxidizer System	652.0
Fuel System	642.4
Purge System	38.4
Controls (Hydraulic)	193.3
Controls (Electrical)	84.6
Gimbal System Supply	179.4
Gas Generator System	341.2
Exhaust System	1,261.6
Flight Instrumentation	145.1
Ignition System	49.0
Interface System	542.3
Pressurization System	1,030.0
Insulation – Permanent	71.5
Thermal Insulation Set	1,182.5
Total Dry Weight	19,875.8

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

Liquid Engines	LOX/RP	26 January 1993
Independent Terms	**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	
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
Vacuum Thrust, kN	8,988.521
Vacuum Isp, sec-N/kg	2,972.40
SL Thrust, kN	8,005.958
SL Isp, sec-N/kg	2,644.85
ODE C-Star, m/sec	1,813.30
L-Star, cm	118.65
ODE Isp, sec-N/kg	1,499.70
Energy Release Efficiency	0.93930
Kinetic Efficiency	0.99796
Divergence Efficiency	0.99186
Boundary Layer Efficiency	0.99210
Engine Efficiency	0.92240

Dimensions	Value
Throat Area, cm^2	87.8
Chamber Length, cm	6,060.7
Nozzle Exit Diameter, cm	100.1
Engine Diameter, cm	351.4
Nozzle Length, cm	364.5
Engine Length, cm	394.9
Engine Length, in	559.8

Weights, kg	Value
Turbopump and Mount	2,035.5
Thrust Chamber	3,857.9
Engine Mount	211.8
Oxidizer System	295.7
Fuel System	291.3
Purge System	17.4
Controls (Hydraulic)	87.7
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
Total Dry Weight	9,013.7

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

3/27/93

Nuclear Engine Weight, Envelope and Performance Function
(NERVA Derived Prismatic Core)

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

OUTPUT WINDOW								
Fvac Klbf	Tc °K	Pc psia	Epsilon -	% L -	Del Isp sec	Total Wt lbm	Envel Dia in	Envel L 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

TA3–0428

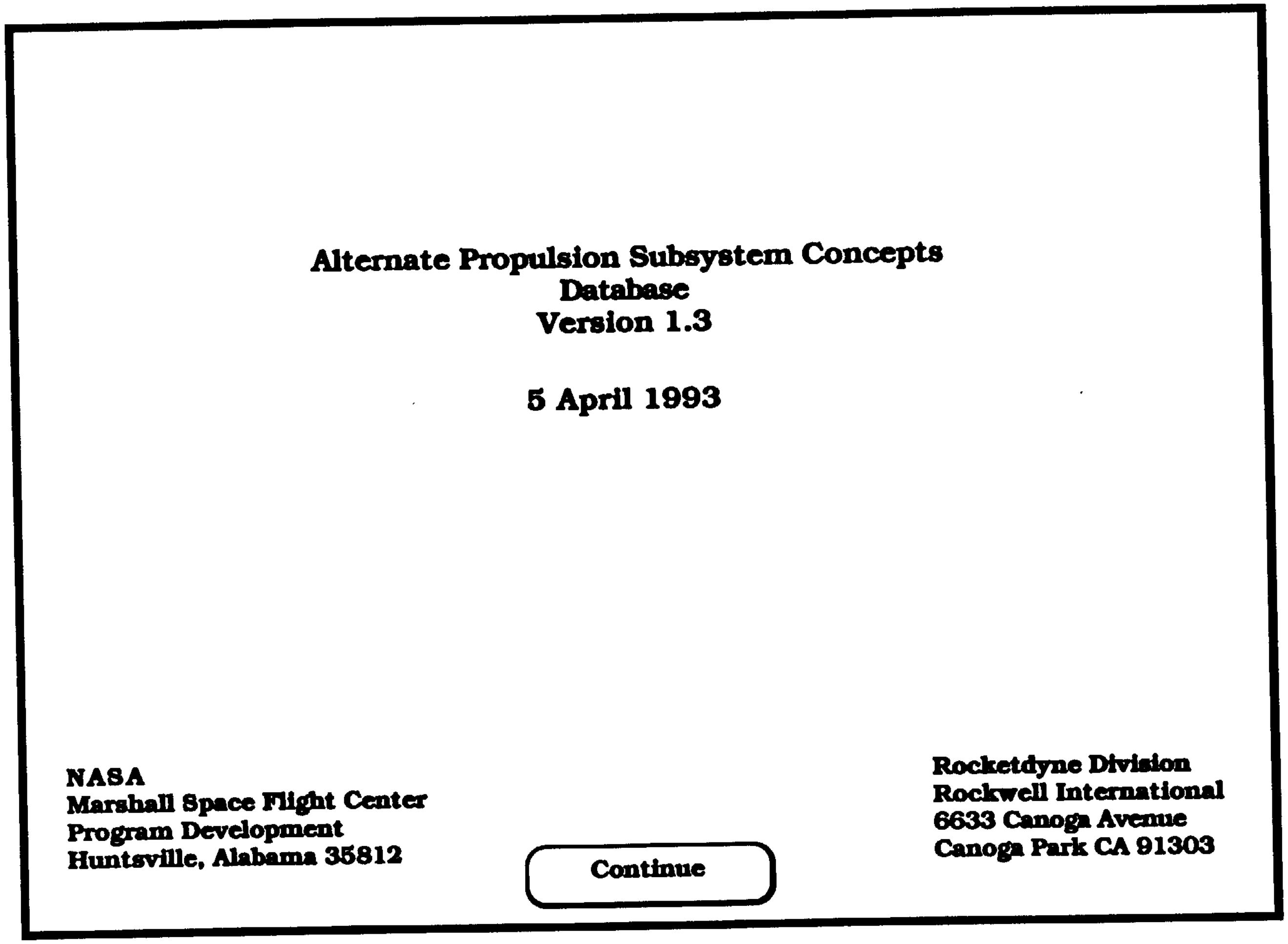


Figure 68. Propulsion System Database Opening Screen

March 27, 1993

Propulsion System Menu

Please click icon for selected propulsion system

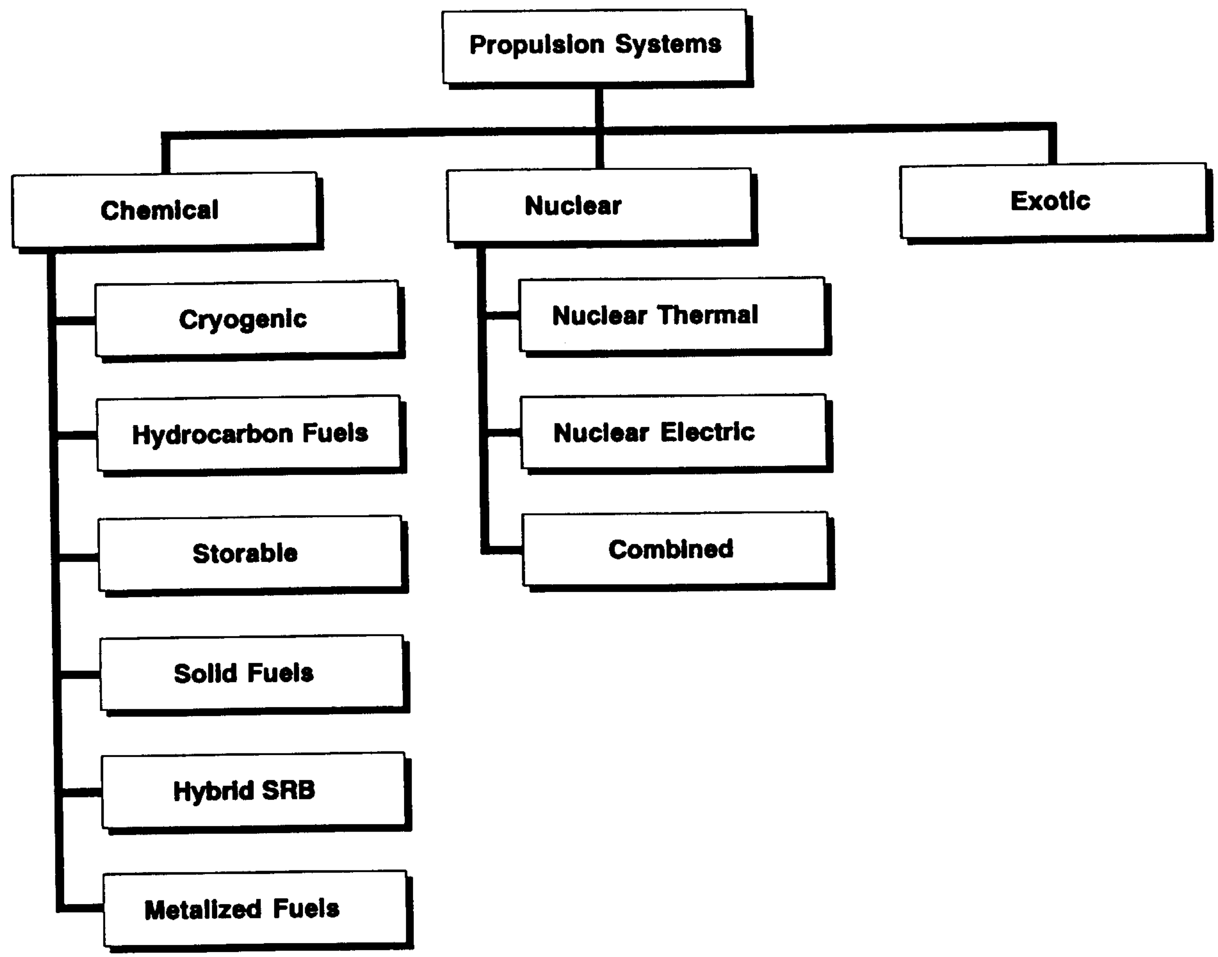


Figure 69. Main Menu of Propulsion Types

Print | More Data | Reports | Data Entry

Summary of Propulsion Systems

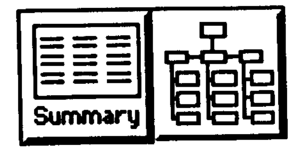
	Engine Name	Acronym	Engine Class
1	Space Transportation Main Engine	STME	Cryogenic Liquid
2	F-1	F-1	Hydrocarbon Liquid
3	F-1A	F-1A	Hydrocarbon Liquid
4	J-2	J-2	Cryogenic Liquid
5	Simplified, High Performance J-2	J-2S	Cryogenic Liquid
6	Space Shuttle Main Engine	SSME	Cryogenic Liquid
7	RD-170	RD-170 (Russian 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

Liquids

March 30, 1993

Reports



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
- Engine Picture/Basic Data
- Engine Drawing
- Engine Balance

Engine Briefing Charts

Propulsion Element Data

- Chart #1
- Chart #2
- Chart #3
- Chart #4
- Chart #5
- Chart #6

- 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 Performance 1

Print | Reports

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid   Chemical

Propellants

Oxidizer	Liquid Oxygen	
Fuel	Liquid Hydrogen	
Mixture Ratio – Engine/Thrust Chamber	6.000	6.993

Nominal Chamber Pressure	2,250
Expansion Ratio	45.02
Engine Design Life (Flights)	1

Engine Restarts

Design	0
Demonstrated	

Engine Thrust Data

	Sea Level	Vacuum
Nominal	552,980	650,000
Maximum		
Minimum	357,980	455,000

Thrust data in units of lbf

Engine Starts

Design	11
Demonstrated	

Engine Reliability, sec

Design	5,500
Demonstrated	

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum		
Minimum	64.70	70.00

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	365.15	429.22
@Maximum Thrust		
@Minimum Thrust	337.95	429.54

Specific Impulse data in units of seconds

Nozzle Data

Type	Bell
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

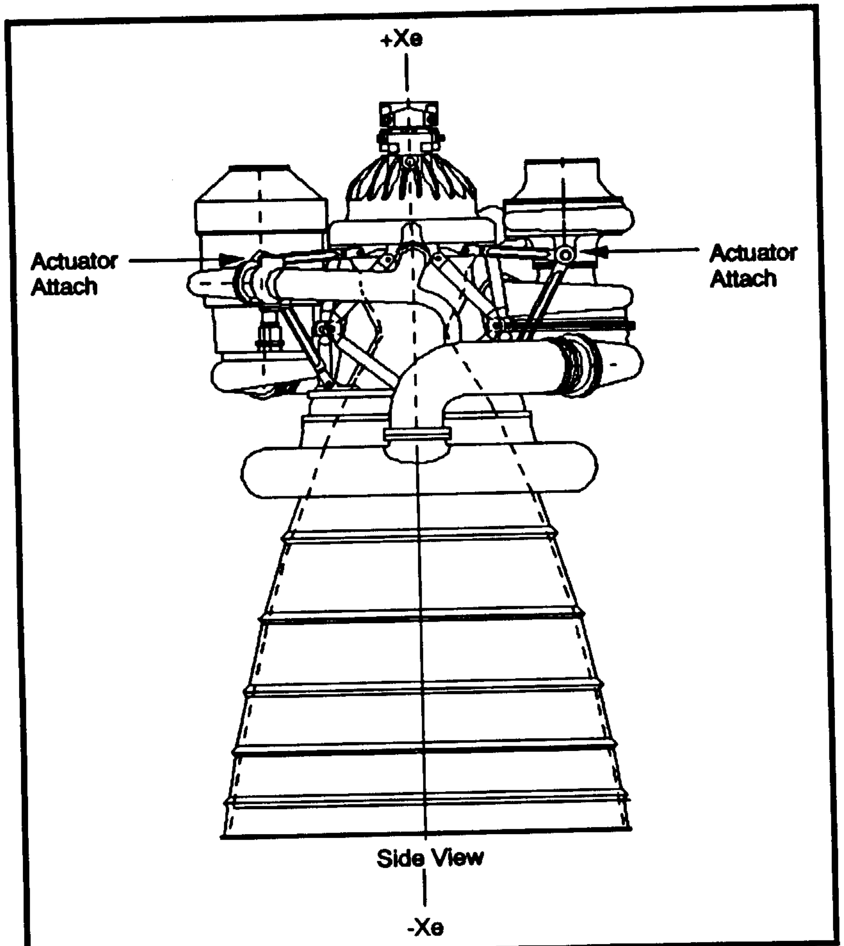
Figure 72. Typical Report Page Layout

Figure 73.

Output for Space Transportation Main Engine (STME) Propulsion System

TA3–0424

STME Propulsion System

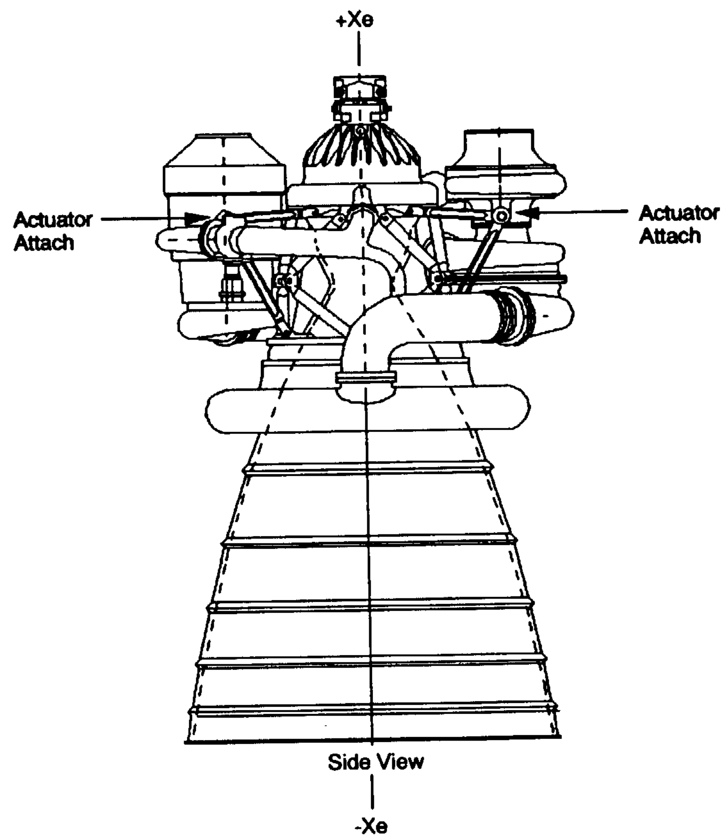


• Nominal Thrust (lbf)	
• Sea Level	552,980
• Vacuum	650,000
• Specific Impulse (sec)	
• Sea Level	364.5
• Vacuum	428.5
• Chamber Pressure (psia) (Nozzle Stagnation)	2,250
• Engine Mixture Ratio	6.000
• Expansion Ratio	45.00
• Length (in)	161.00
• Weight (lbm)	9,100

3/31/93

Advanced Propulsion Subsystem Concepts Database

Engine Name:	**Space Transportation Main Engine**	
Class of Engine:	**Cryogenic Liquid**	**Chemical**

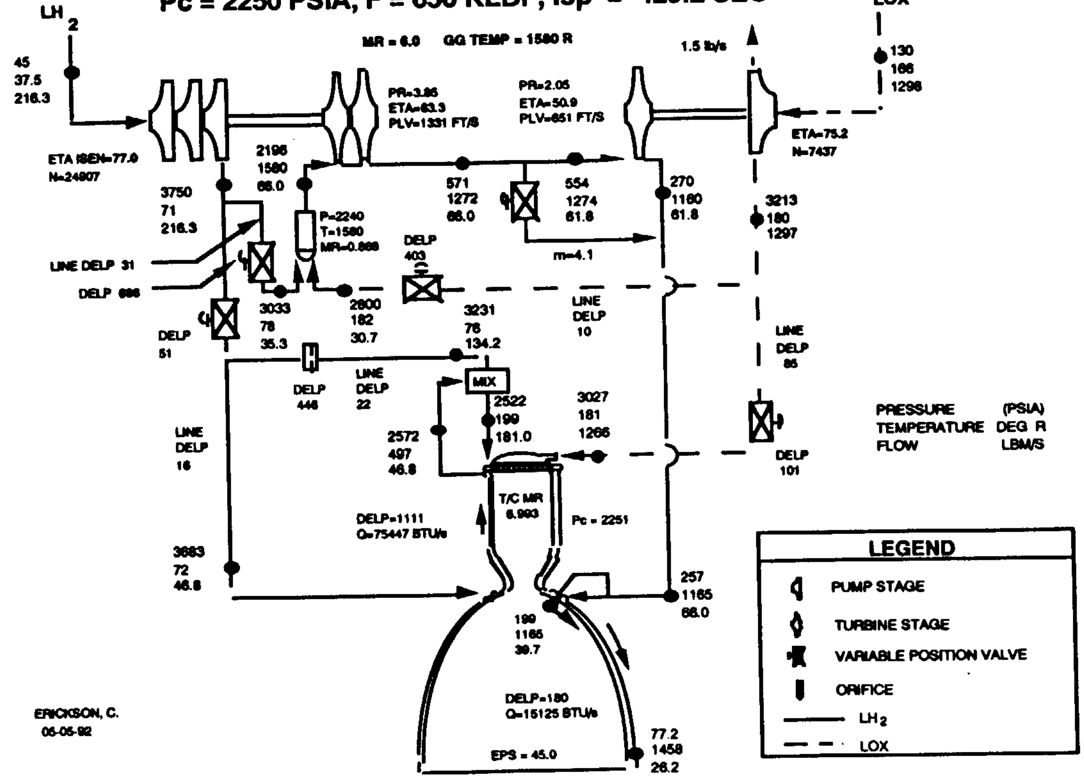


Advanced Propulsion Subsystem Concepts Database

Engine Name: Space Transportation Main Engine
Class of Engine: Cryogenic Liquid Chemical

STEP - REV. 26b @ RPL INLET

Pc = 2250 PSIA, F = 650 KLBF, Isp = 429.2 SEC



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

Propulsion System General Data

Creation Date	Modification Date	Record Number
3/18/93	3/31/93	1

Engine Name	Space Transportation Main Engine	
Class of Engine	Cryogenic Liquid	Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	STME	
Application	Booster Engine	
Manufacturer	Consortium (Aerojet, Pratt & Whitney, Rocketdyne)	
Program Status	Detailed Study	
Manrated		
IOC/Date Studied (Month/Year)	12/1992	
Mixture Ratio – Engine/ Thrust Chamber	6.000	6.993

Propellants

Oxidizer	Liquid Oxygen
Fuel	Liquid Hydrogen

Engine Design Life (Flights)	1
Restart Capability	No
Engine Cycle	Gas Generator
Nominal Chamber Pressure	2,250
Expansion Ratio	45.00
TVC Method	Gimbal

Dimensions

Maximum Length (Inches)	161.00
Maximum Width (Inches)	101.22
Engine Mass (lbm)	9,100.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	552,980	650,000
Maximum		
Minimum	357,980	455,000

March 31, 1993

Engine Performance 1

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid Chemical

Propellants

Oxidizer	Liquid Oxygen	
Fuel	Liquid Hydrogen	
Mixture Ratio – Engine/Thrust Chamber	6.000	6.993

Nominal Chamber Pressure	2,250
Expansion Ratio	45.00
Engine Design Life (Flights)	1

Engine Restarts

Design	0
Demonstrated	

Engine Thrust Data

	Sea Level	Vacuum
Nominal	552,980	650,000
Maximum		
Minimum	357,980	455,000

Thrust data in units of lbf

Engine Starts

Design	11
Demonstrated	

Engine Reliability, sec

Design	5,500
Demonstrated	

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum		
Minimum	64.70	70.00

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	364.54	428.50
@Maximum Thrust		
@Minimum Thrust	336.74	428.00

Specific Impulse data in units of seconds

Nozzle Data

Type	Bell
Length (in)	116.00
Diameter (in)	91.67
Throat Area (sq. in)	146.61
Exit Area (sq. in)	6,597.45
Expansion Ratio	45.00

March 31, 1993

Engine Performance 2

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid — Chemical

Engine Mass (lbm)

Total Mass w/TVC	9,100.0
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	11.3
Max Gimbal Rate (deg/s)	4.7

Engine Cycle

Type: Gas Generator

Pressures

	Oxidizer Turbopump	Fuel Turbopump
Min Pump Inlet	47	32
Turbine Inlet	554.0	2,196.0

Pressures in psia

Envelope

Length	
Nominal	161
Stowed	
Extended	
Maximum Gimbal	

Diameter	
Nozzle Exit	97.0
Maximum	101.2
Maximum Gimbal	

Envelope Dimensions in inches

Engine Component Masses

Component	Allocations
Turbomachinery	
Oxygen Turbopump	1570
Fuel Turbopump	1718
Combustion Devices	
Main Injector	1226
Combustion Chamber	1601
Nozzle	1729
Gas Generator	92
Igniter - CC	7
- GG	7
Controls	
Controller	35
Sensors	35
Valves/Actuators	214
Interconnects	17
Pneumatic System	18
Propellant Feed	
Ducts	323
Miscellaneous (System Hardware)	353
Support Devices	
Gimbal System	138
Heat Exchanger	19
Engine Total	9100

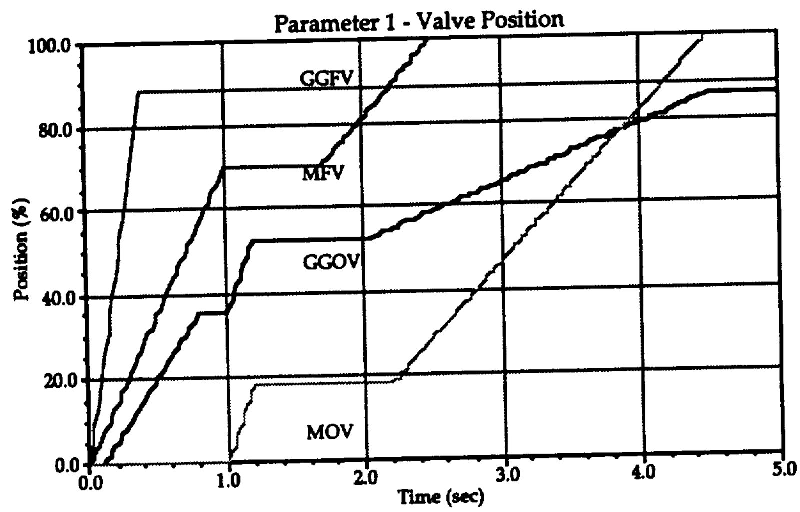
March 18, 1993

Start-Up/Shutdown Sequences

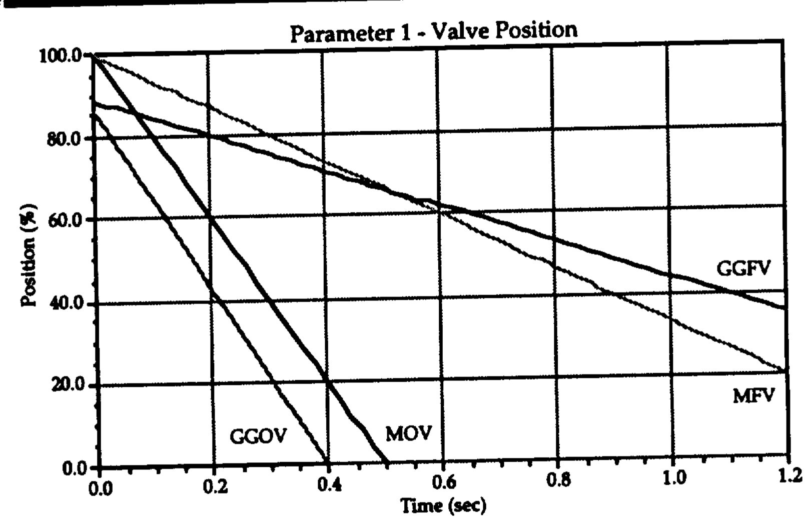
Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid Chemical

StartUp Sequence



Shutdown Sequence



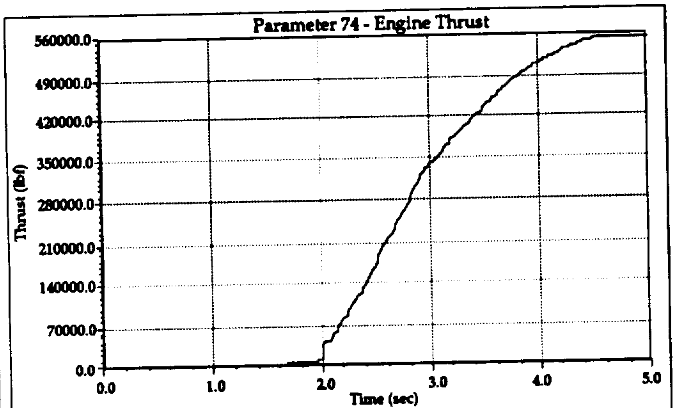
March 18, 1993

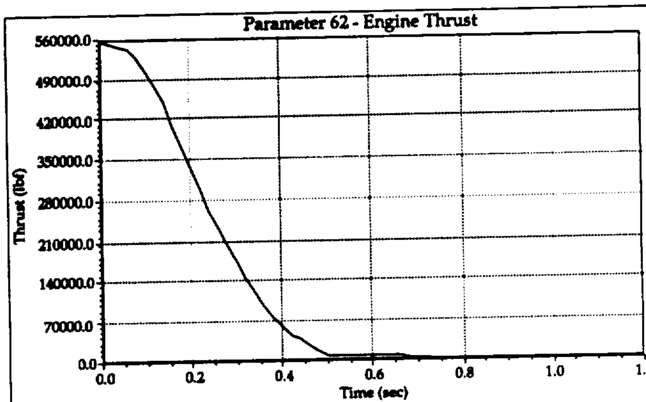
Start-Up/Shutdown Profiles

Engine Name: Space Transportation Main Engine

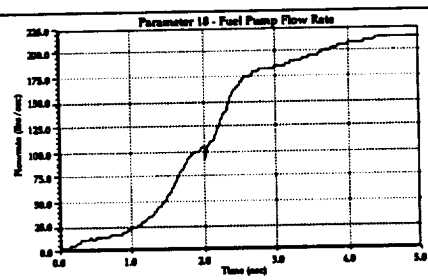
Class of Engine: Cryogenic Liquid   Chemical

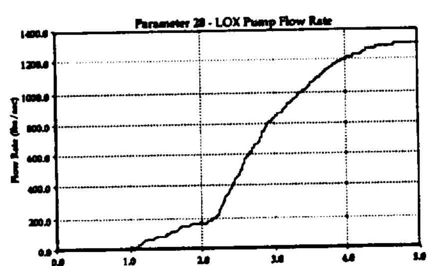
Thrust Profile

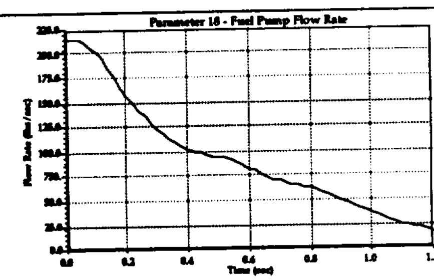


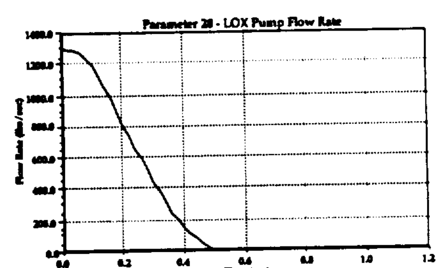


Flowrate Profile









March 18, 1993

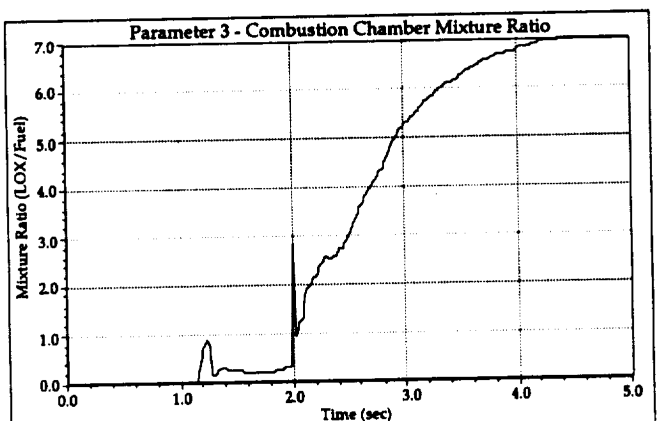
Start-Up/Shutdown Profiles

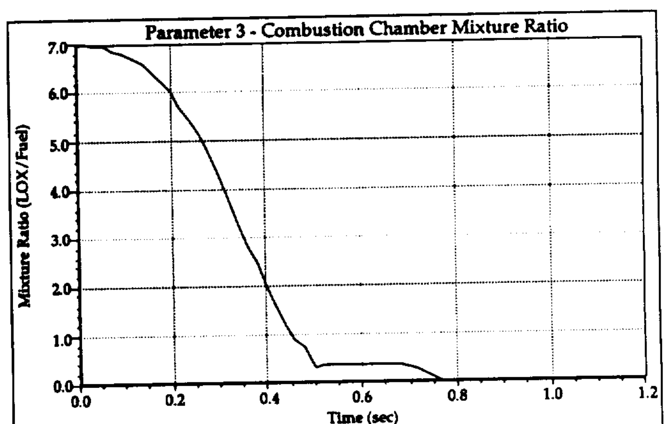
Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid — Chemical

Isp Profile

Mixture Ratio Profile





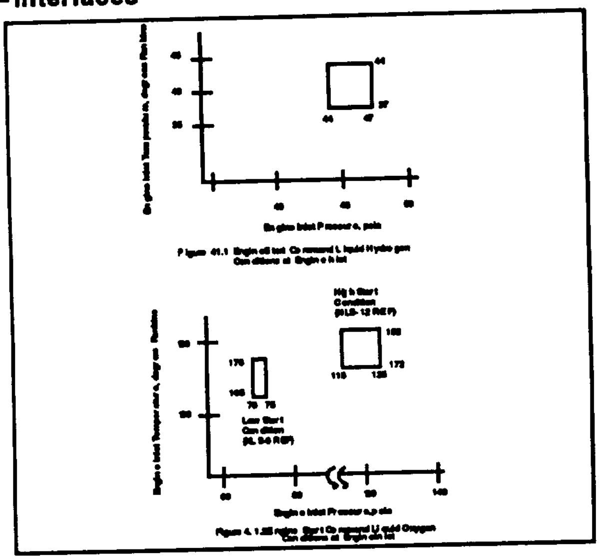
March 18, 1993

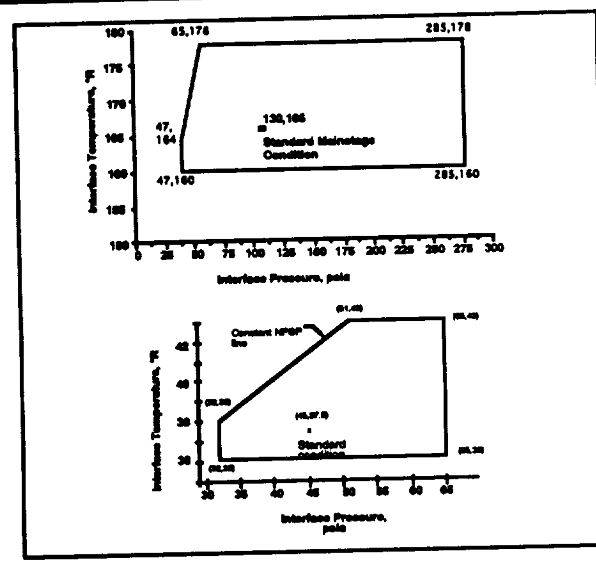
Interfaces

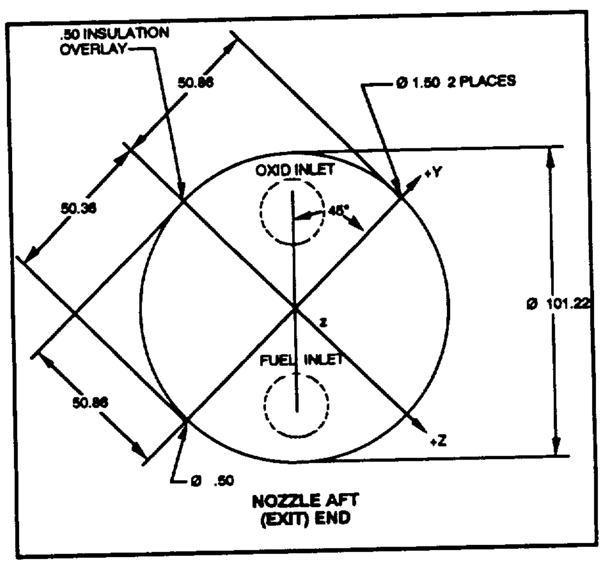
Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid Chemical

Interfaces







March 18, 1993

Technology Development

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid Chemical

Technology Development

March 31, 1993

Advanced Development Plan

Engine Name: Space Transportation Main Engine

Class of Engine: Cryogenic Liquid

Chemical

Advanced Development Plan

ENGINE DEVELOPMENT PROGRAM SCHEDULE - 20K VEHICLE

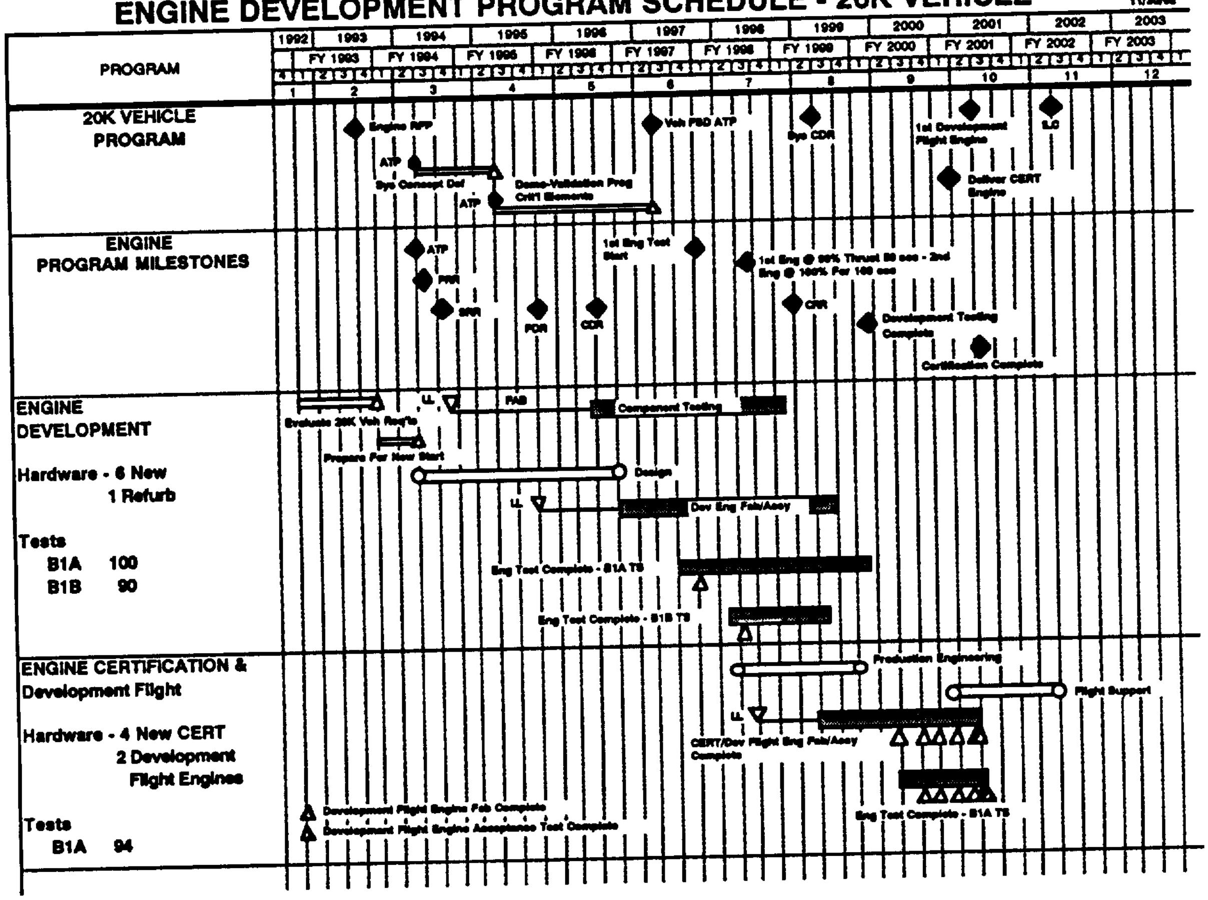
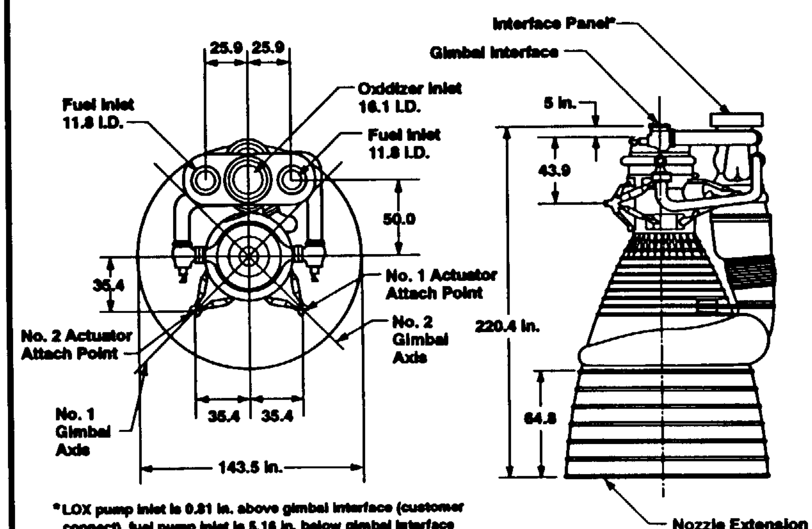


Figure 74.

Output for F-1 Propulsion System

TA3–0310

F-1 Propulsion System

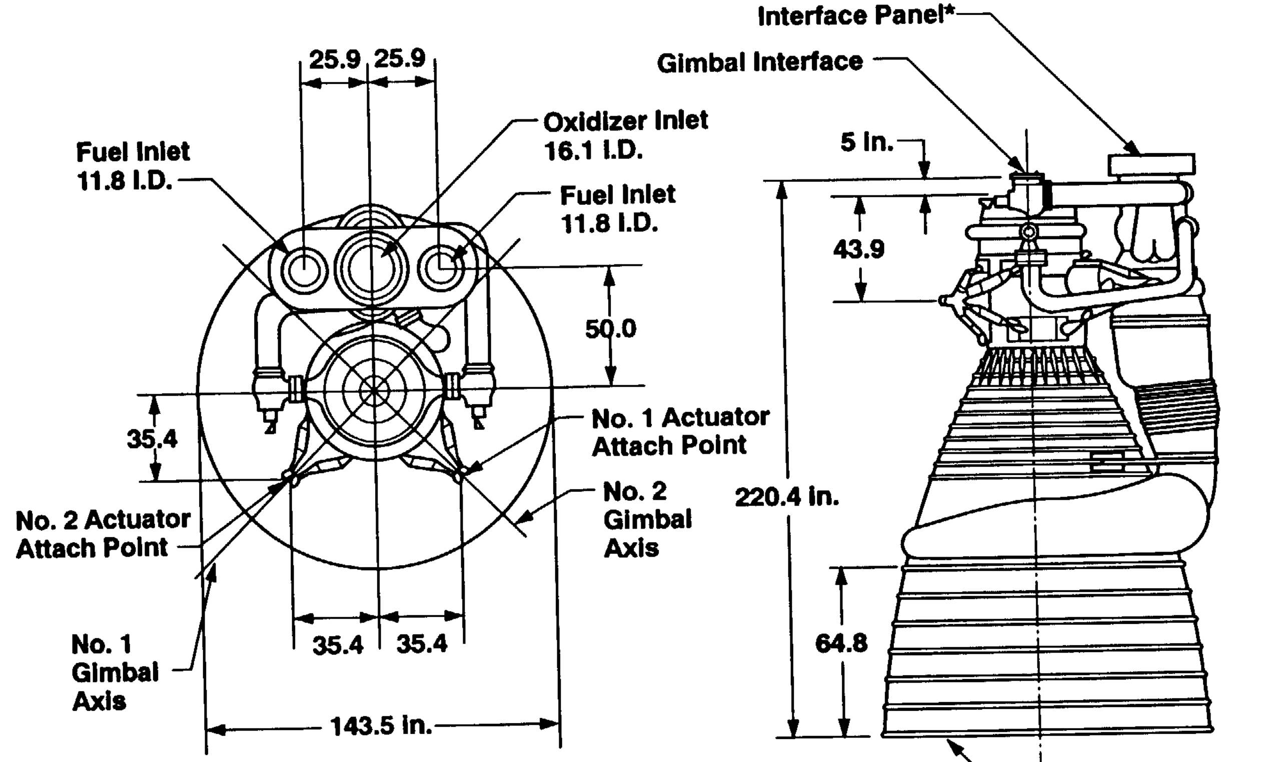


• Nominal Thrust (lbf)	
• Sea Level	1,522,008
• Vacuum	1,748,200
• Specific Impulse (sec)	
• Sea Level	265.4
• Vacuum	304.8
• Chamber Pressure (psia) (Nozzle Stagnation)	982
• Engine Mixture Ratio	2.270
• Expansion Ratio	16.00
• Length (in)	220.40
• Weight (lbm)	18,616

Advanced Propulsion Subsystem Concepts Database

Engine Name: F-1

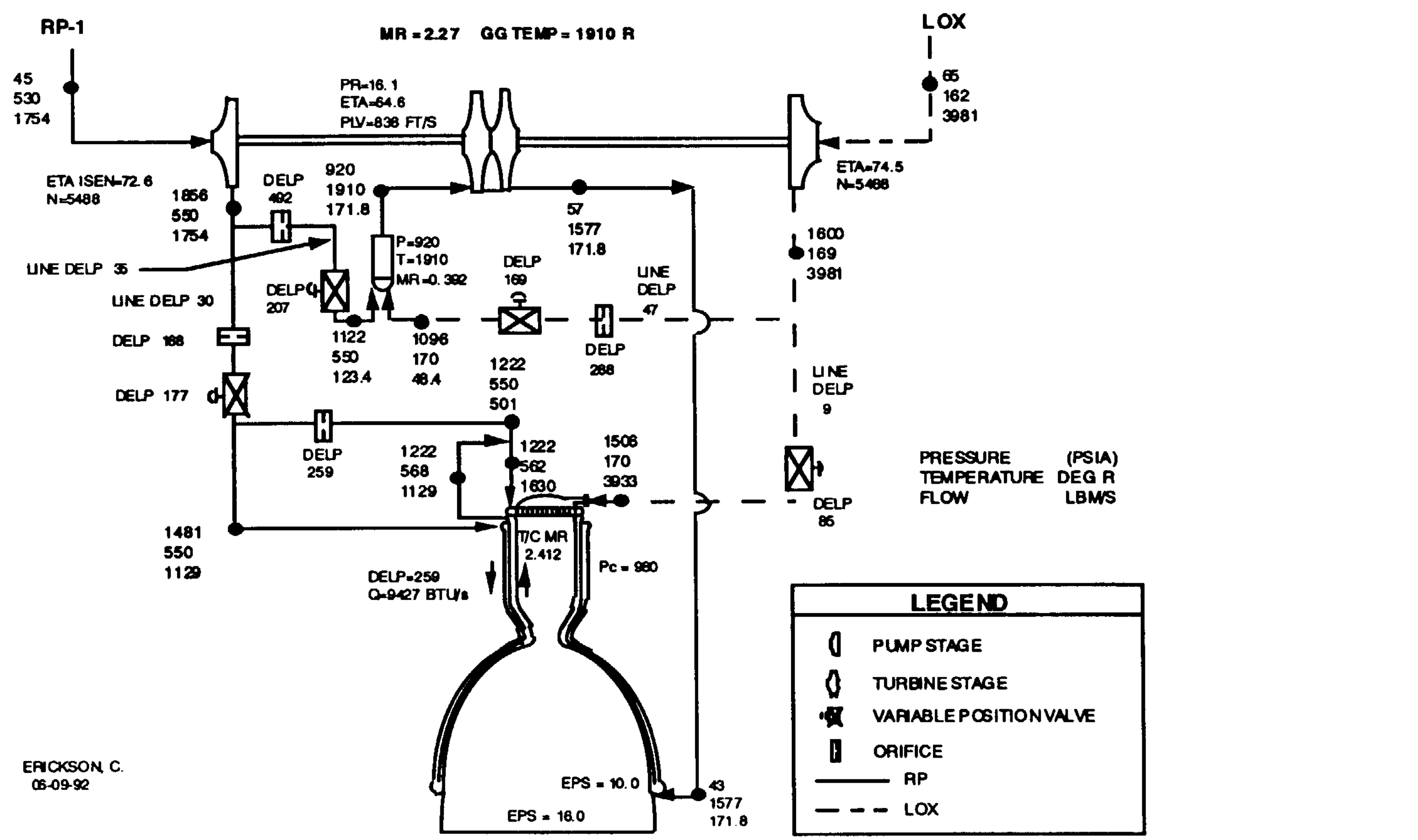
Class of Engine: Hydrocarbon Liquid — Chemical



*LOX pump inlet is 0.81 in. above gimbal interface (customer connect), fuel pump inlet is 5.16 in. below gimbal interface

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid Chemical



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

Source: F-1/F-1A Engine Data Package (BC91-74), Unpublished Rocketdyne Data; Technical Manual F-1 Rocket Engine, R-3896-1, 31 March 1967 (Change 12 – 12 May 1972); The Saturn V F-1 Engine Revisited, AIAA 92-1547, 24 March 1992.

Date: 1991

Entered by: Dan Levack

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date	Record Number
8/31/92	3/30/93	2

Engine Name	F-1
Class of Engine	Hydrocarbon Liquid / Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas
Acronym	F-1
Application	Saturn V Booster Engine
Manufacturer	Rockwell International Corporation
Program Status	11 Successful Apollo / Saturn Flights
Manrated	Yes
IOC/Date Studied (Month/Year)	Sept 1966
Mixture Ratio – Engine/ Thrust Chamber	2.270 / 2.410

Propellants

Oxidizer	Liquid Oxygen (MIL-P-255086)
Fuel	RP-1 (MIL-P-25576B)

Engine Design Life (Flights)	1
Restart Capability	No
Engine Cycle	Gas Generator
Nominal Chamber Pressure	982
Expansion Ratio	16.00
TVC Method	Gimbal

Dimensions

Maximum Length (inches)	220.40
Maximum Width (inches)	143.50
Engine Mass (lbm)	18,616.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	1,522,008	1,748,200
Maximum		
Minimum		

March 13, 1993

Engine Performance 1

Engine Name: F-1

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	2.410

Nominal Chamber Pressure (psia)	982
Expansion Ratio	16.00
Engine Design Life (Flights)	1

Engine Restarts

Design	0
Demonstrated	0

Engine Thrust Data

	Sea Level	Vacuum
Nominal	1,522,008	1,748,200
Maximum		
Minimum		

Thrust data in units of lbf

Engine Starts

Design	20
Demonstrated	60

Engine Reliability, sec

Design	2,250
Demonstrated	5,924

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum		
Minimum		

Nozzle Data

Type	Bell, Tubular Wall
Length (in)	158.00
Diameter (in)	139.97
Throat Area (sq. in)	961.70
Exit Area (sq. in)	15,387.2
Expansion Ratio	16.00

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	265.40	304.84
@Maximum Thrust		
@Minimum Thrust		

Specific Impulse data in units of seconds

March 7, 1993

Engine Performance 2

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid — Chemical

Engine Mass (lbm)

Total Mass w/TVC	18,616.0
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	8.5
Max Gimbal Rate (deg/s)	

Engine Cycle

Type: Gas Generator

Pressures

Oxidizer Turbopump

Min Pump Inlet	48.4
Turbine Inlet	945.0

Fuel Turbopump

Min Pump Inlet	24.3
Turbine Inlet	945.0

Pressures in psia

Envelope

Length

Nominal	220.4
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	140.0
Maximum	143.5
Maximum Gimbal	

Envelope Dimensions in inches

Engine Component Masses

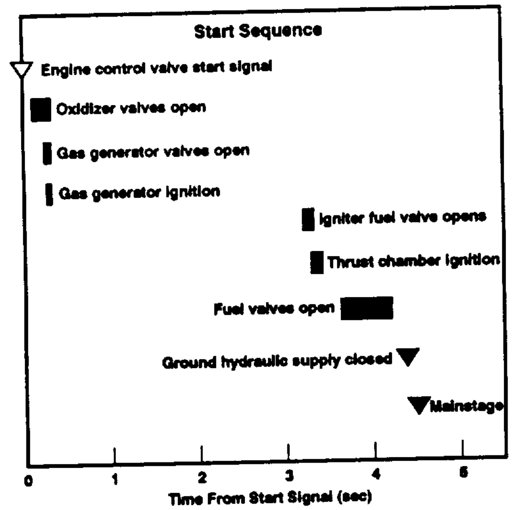
Turbopump and Mount	3,493.2
Thrust Chamber	8,506.8
Engine Mount	467.0
Oxidizer System	652.0
Fuel System	642.4
Purge System	38.3
Controls (Hydraulic)	193.2
Controls (Electrical)	84.6
Gimbal System Supply	179.5
Gas Generator System	341.0
Exhaust System	993.7
Flight Instrumentation	145.2
Ignition System	49.0
Interface System	642.3
Pressurization System	1,090.0
Insulation - Permanent	71.8
Thermal Insulation Set	1,182.4
Total Dry Weight	18,612.2

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

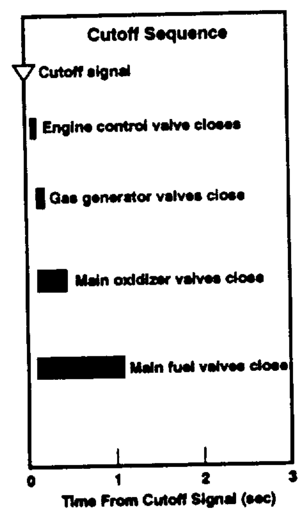
Engine Name: F-1

Class of Engine: Hydrocarbon Liquid Chemical

StartUp Sequence



Shutdown Sequence



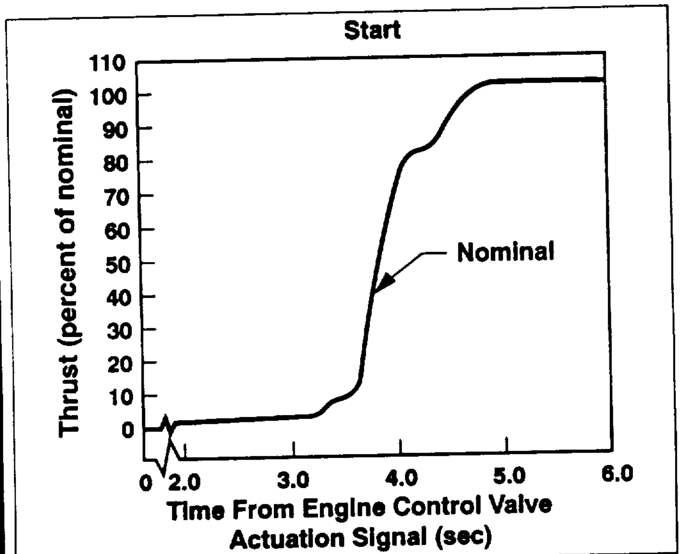
February 20, 1993

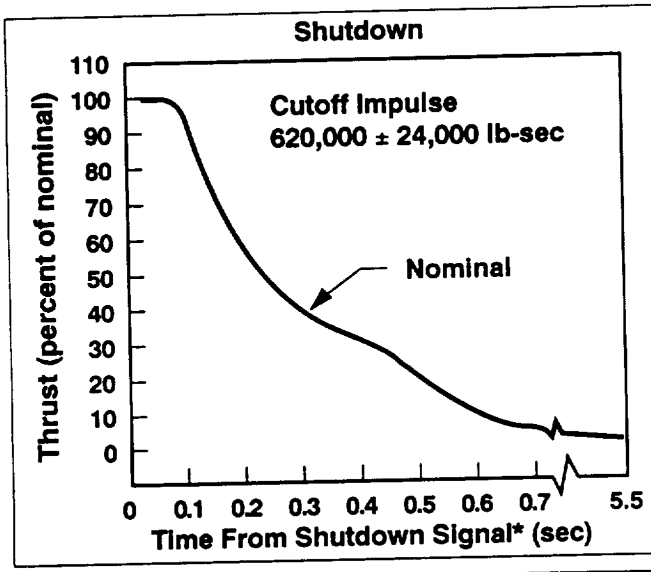
Start-Up/Shutdown Profiles

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid — Chemical

Thrust Profile





Flowrate Profile

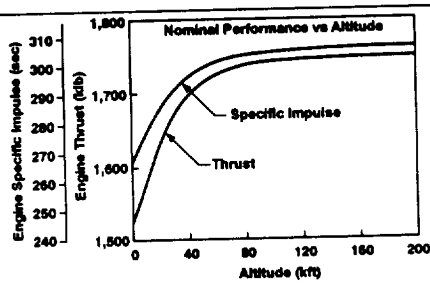
February 20, 1993

Start-Up/Shutdown Profiles

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid Chemical

Isp Profile



Performance Specifications			
Parameter	Operating Limits*	Nominal Performance*	Altitude
Thrust (lb)	1,500,000 to 1,548,000	1,522,000	1,748,200
Engine mixture ratio (O/F)	2.225 to 2.315	2.27	2.27
Specific impulse (sec)	263.7 minimum	265.4	304.1

*Sea level

Mixture Ratio Profile

February 20, 1993

Interfaces

Engine Name: F-1

Class of Engine: Hydrocarbon Liquid — Chemical

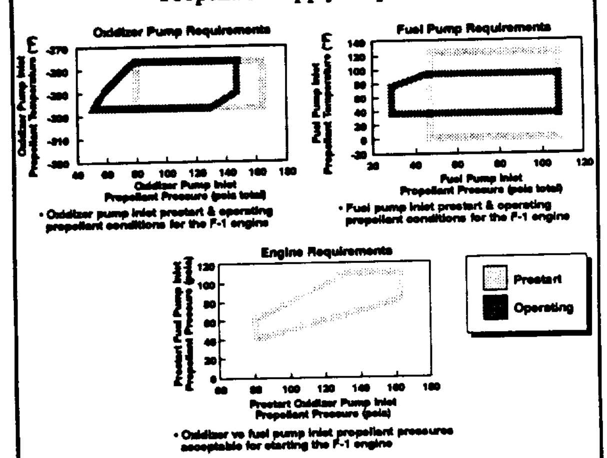
Interfaces

Interface Requirements

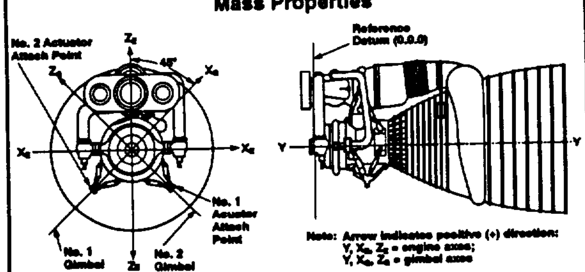
Propellant	
Liquid oxygen	
Total min pr (psia)	46.4
Min NPSH (ft)	65
Inlet diam (in.)	16.1
RP-1	
Total min pr (psia)	34.3
Min NPSH (ft)	70
Inlet diam (in.) (2)	11.6
Electrical	
Engine	
Voltage (Vdc)	28
Power (watts)	180 (start) 100 (mainstage)
Turbopump heater (2)*	
Voltage (Vac)	190-220
Power (watts)	1,800
High voltage igniters (4)*	
Voltage (Vac)	500-750
Power (watts)	16,000 total
Hydraulic**	
Fluid	RP-1
Temp (°F)	60 to 130
Flow rate (gpm)	11.6
Pressure (psig)	1,500 to 1,800
Pneumatic	
Flight	
Helium***	
Flow rate (lb/sec)	0.4 to 1.6
Temp (°F)	-400 to 130
Pressure (psia)	280 to 415
Nitrogen (T/P LOX seal purge)	
Flow rate (lb/sec)	0.004
Temp (°F)	0 to 130
Pressure (psia)	75 to 115
Preflight*	
Nitrogen	
T/P LOX seal purge	
Flow rate (lb/sec)	0.005
Temp (°F)	0 to 130
Pressure (psig)	60 to 160
LOX dome/GG LOX purges	
Flow rate (lb/sec)	0.25 to 3.0
Temp (°F)	0 to 130
Pressure (psig)	105 to 185
Insulation cocoon purge	
Temp (°F)	210 to 300
Pressure (psig)	180 to 208

*Ground requirements only
**Flight hydraulic control requirements are supplied by the engine
***Required only when heat exchanger is used for pressurization

Propellant Supply Requirements



Mass Properties



Description	Weight Pounds	Center of Gravity, (in.)			Axis System Orientation	Origin of Axes (in.)			Moment of Inertia,** Slug ft2		
		$\bar{Y}$	$\bar{X}$	$\bar{Z}$		Y	X	Z	I_Y	I_X	I_Z
Wet gimbal* mass	20,029	58.1	0.1	17.2	Engine	0.0	0.0	0.0	8,896	34,542	31,421

* Wet weight less stationary part of gimbal bearing
** Moment of inertia about the center of gimbal

February 20, 1993

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

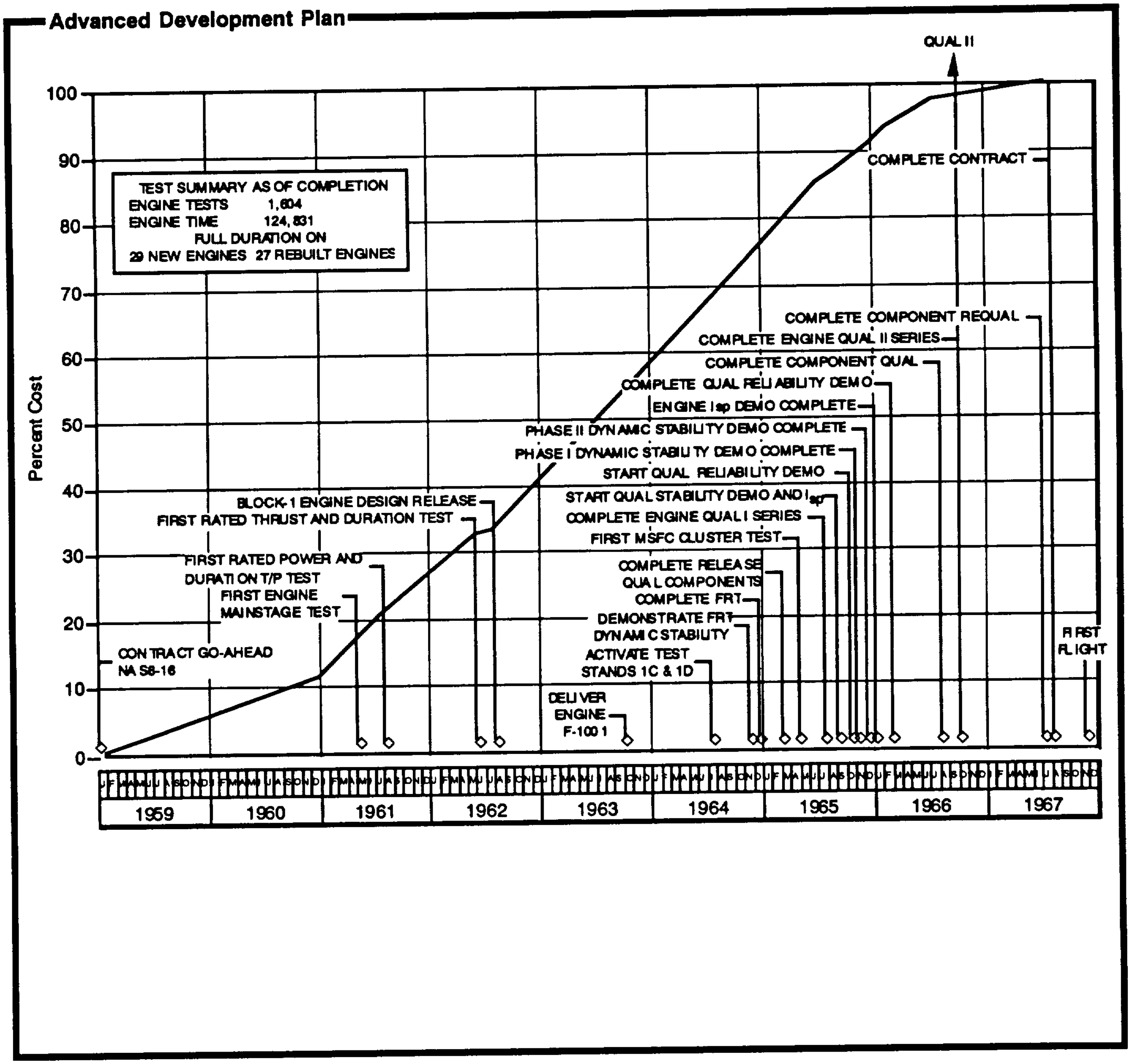
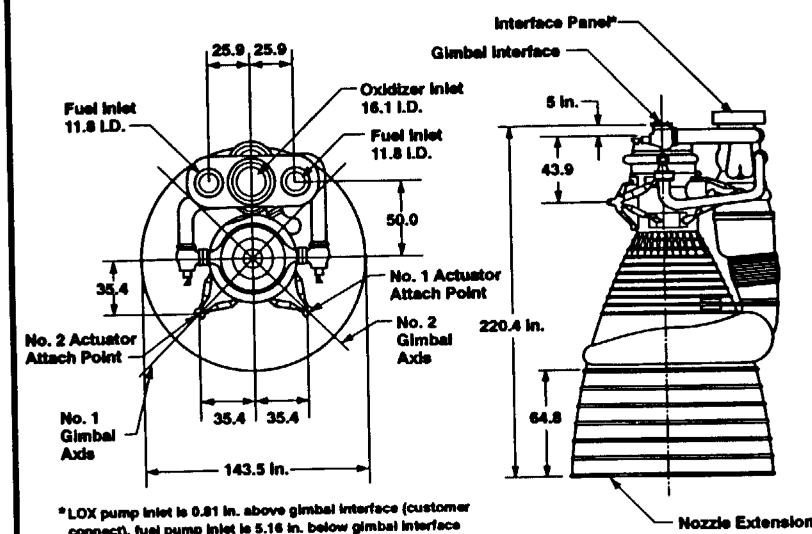


Figure 75.

Output for F-1A Propulsion System

TA3–0311

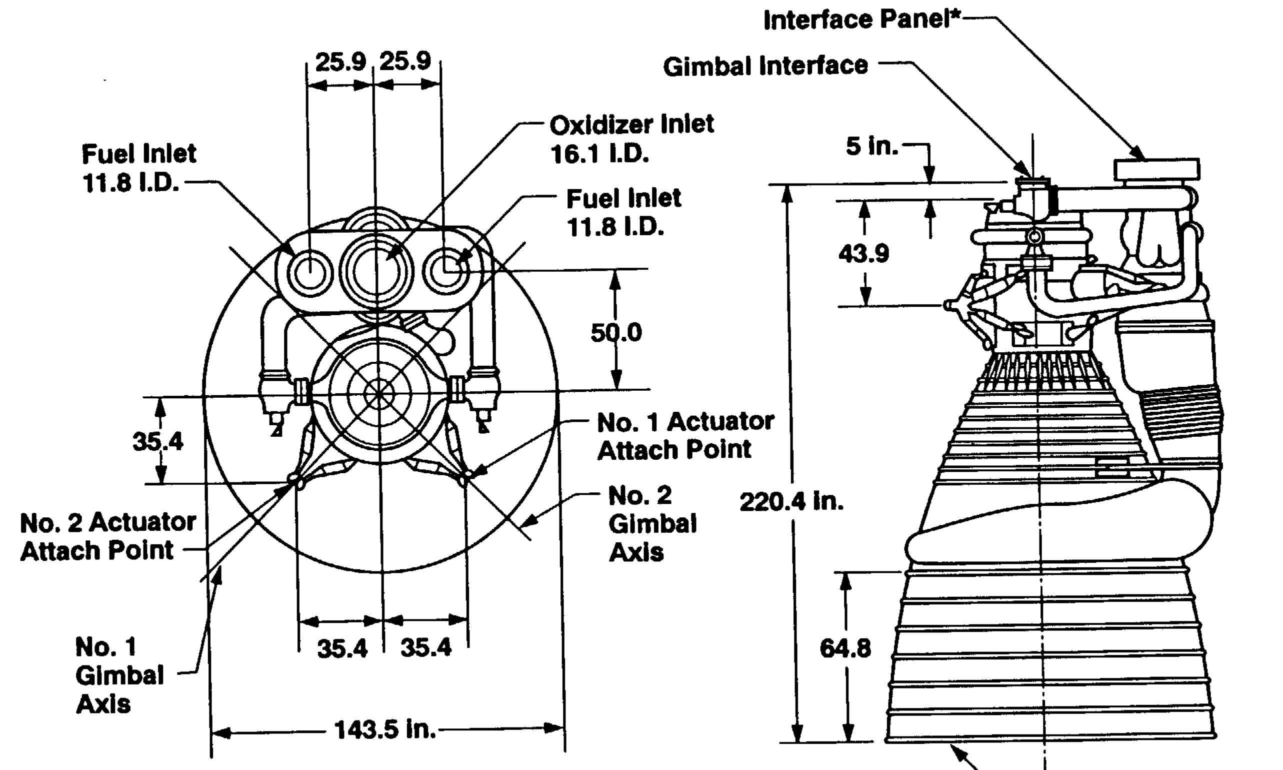
F-1A Propulsion System



• Nominal Thrust (lbf)	
• Sea Level	1,800,001
• Vacuum	2,020,700
• Specific Impulse (sec)	
• Sea Level	269.7
• Vacuum	302.8
• Chamber Pressure (psia) (Nozzle Stagnation)	1,161
• Engine Mixture Ratio	2.270
• Expansion Ratio	16.00
• Length (in)	220.40
• Weight (lbm)	19,875

Engine Name: F-1A

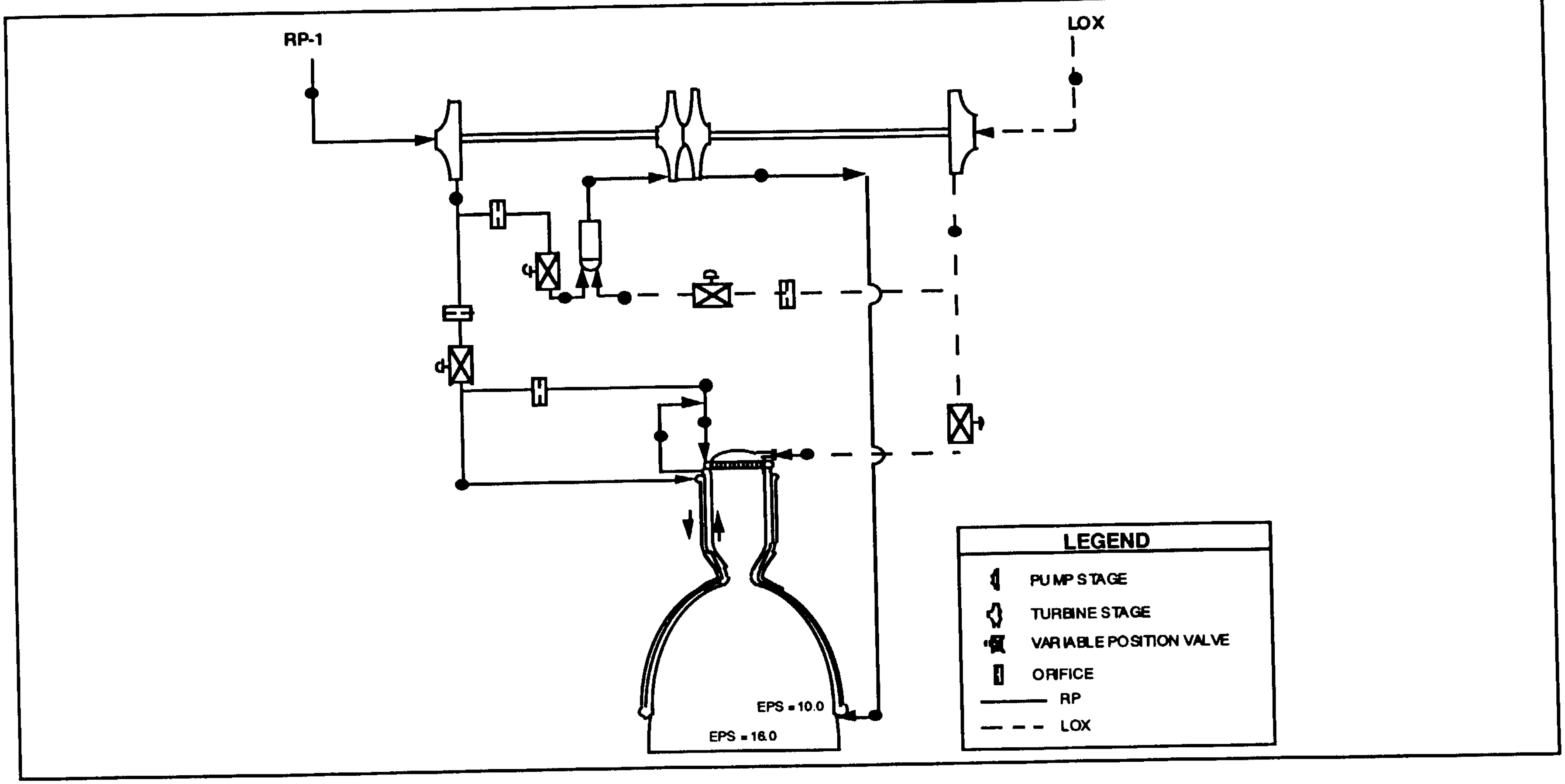
Class of Engine: Hydrocarbon Liquid — Chemical



*LOX pump inlet is 0.81 in. above gimbal interface (customer connect), fuel pump inlet is 5.16 in. below gimbal interface

Advanced Propulsion Subsystem Concepts Database

Engine Name:	**F-1A**	
Class of Engine:	**Hydrocarbon Liquid**	**Chemical**



March 13, 1993

Background Information

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid   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

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

Date: 1991

Entered by: Dan Levack

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date	Record Number
8/31/92	3/30/93	3

Engine Name	F-1A	
Class of Engine	Hydrocarbon Liquid	Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	F-1A	
Application	Booster Engine	
Manufacturer	Rockwell International Corporation	
Program Status	16 Tests	
Manrated	Yes	
IOC/Date Studied (Month/Year)	March 1969 (Testing Completed)	
Mixture Ratio – Engine/ Thrust Chamber	2.270	

Propellants

Oxidizer	Liquid Oxygen (MIL-P-255086)
Fuel	RP-1 (MIL-P-25576B)

Engine Design Life (Flights)	1
Restart Capability	No
Engine Cycle	Gas Generator
Nominal Chamber Pressure	1,161
Expansion Ratio	16.00
TVC Method	Gimbal

Dimensions

Maximum Length (inches)	220.40
Maximum Width (inches)	143.50
Engine Mass (lbm)	19,875.40

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	1,800,001	2,020,700
Maximum		
Minimum	1,350,001	1,570,700

March 13, 1993

Engine Performance 1

Engine 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)	1,161
Expansion Ratio	16.00
Engine Design Life (Flights)	1

Engine Restarts

Design	0
Demonstrated	

Engine Thrust Data

	Sea Level	Vacuum
Nominal	1,800,001	2,020,700
Maximum		
Minimum	1,350,001	1,570,700

Thrust data in units of lbf

Engine Starts

Design	1
Demonstrated	16

Engine Reliability, sec

Design	2,250
Demonstrated	1,753

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum	100.00	100.00
Minimum	75.00	77.73

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	269.70	302.77
@Maximum Thrust		
@Minimum Thrust		

Specific Impulse data in units of seconds

Nozzle Data

Type	Bell, Tubular Wall
Length (in)	158.00
Diameter (in)	138.26
Throat Area (sq. in)	961.00
Exit Area (sq. in)	15,376
Expansion Ratio	16.00

March 7, 1993

Engine Performance 2

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid Chemical

Engine Mass (lbm)

Total Mass w/TVC	19,875.4
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	8.5
Max Gimbal Rate (deg/s)	

Engine Cycle

Type Gas Generator

Pressures

Oxidizer Turbopump

Min Pump Inlet	
Turbine Inlet	

Fuel Turbopump

Min Pump Inlet	
Turbine Inlet	

Pressures in psia

Envelope

Length

Nominal	220.4
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	140.0
Maximum	143.5
Maximum Gimbal	

Envelope Dimensions in inches

Engine Component Masses

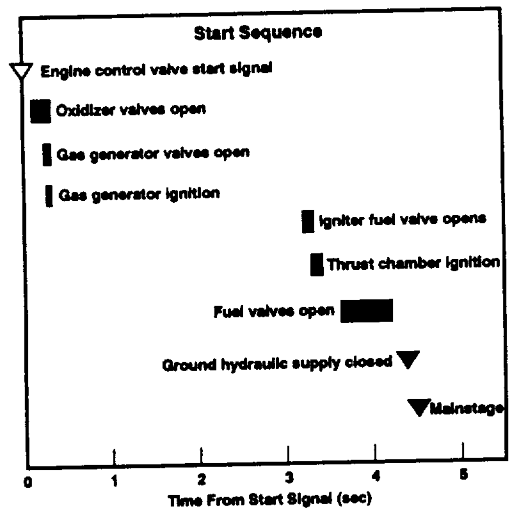
Turbopump and Mount	4,488.5
Thrust Chamber	8,506.8
Engine Mount	467.0
Oxidizer System	652.0
Fuel System	642.4
Purge System	38.3
Controls (Hydraulic)	193.2
Controls (Electrical)	84.6
Gimbal System Supply	179.5
Gas Generator System	341.0
Exhaust System	1,261.6
Flight Instrumentation	145.2
Ignition System	49.0
Interface System	542.3
Pressurization System	1,030.0
Insulation - Permanent	71.8
Thermal Insulation Set	1,182.4
Total Dry Weight	19,875.4

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

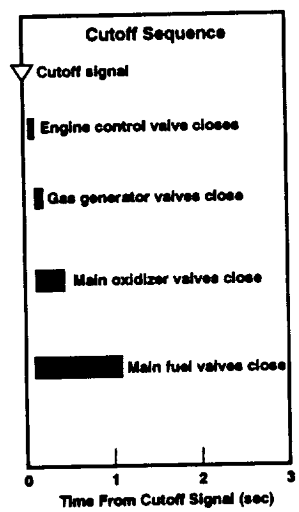
Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid Chemical

StartUp Sequence



Shutdown Sequence



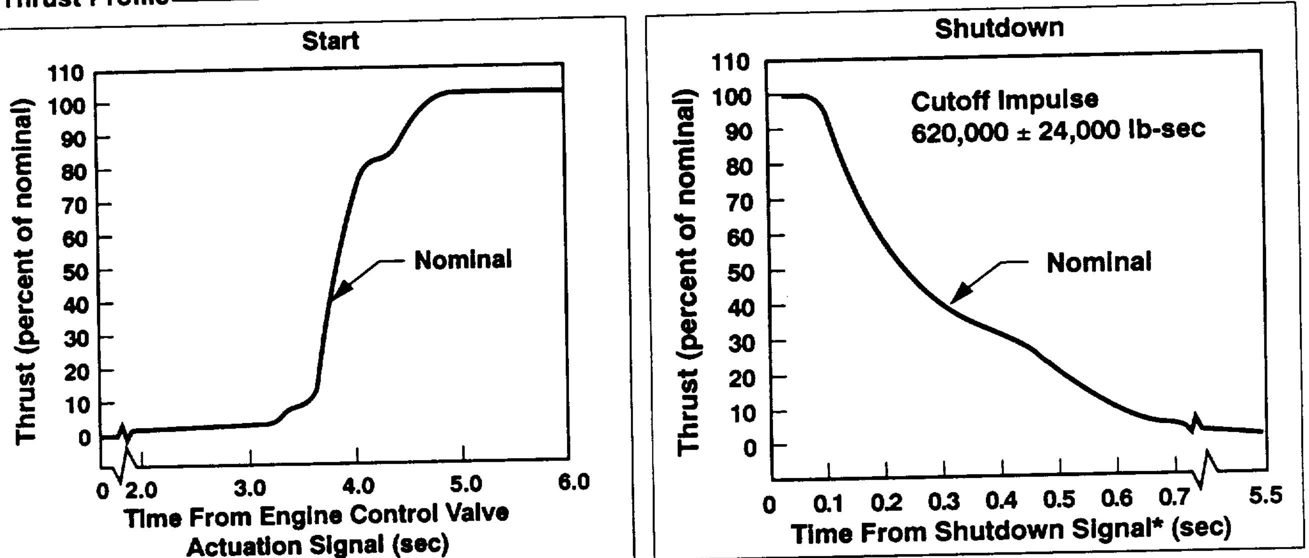
February 20, 1993

Start-Up/Shutdown Profiles

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid — Chemical

Thrust Profile



Flowrate Profile

February 20, 1993

Start-Up/Shutdown Profiles

Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid Chemical

Isp Profile

Mixture Ratio Profile

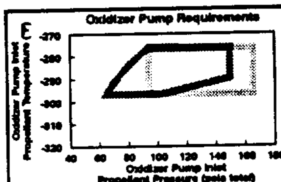
March 27, 1993

Interfaces

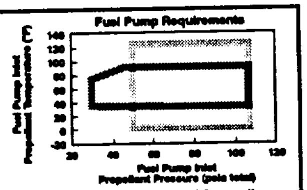
Engine Name: F-1A

Class of Engine: Hydrocarbon Liquid Chemical

Interfaces



• Oxidizer pump inlet prestart & operating propellant conditions for the F-1A engine



• Fuel pump inlet prestart & operating propellant conditions for the F-1A engine

February 20, 1993

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

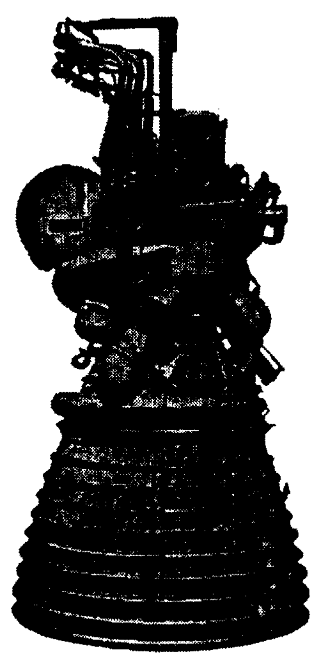
Advanced Development Plan

Figure 76.

Output for J-2 Propulsion System

TA3–0312

J-2 Propulsion System



• Nominal Thrust (lbf)	
• Sea Level	161,548
• Vacuum	230,000
• Specific Impulse (sec)	
• Sea Level	298.4
• Vacuum	424.9
• Chamber Pressure (psia) (Nozzle Stagnation)	780
• Engine Mixture Ratio	5.500
• Expansion Ratio	27.16
• Length (in)	133.00
• Weight (lbm)	4,050

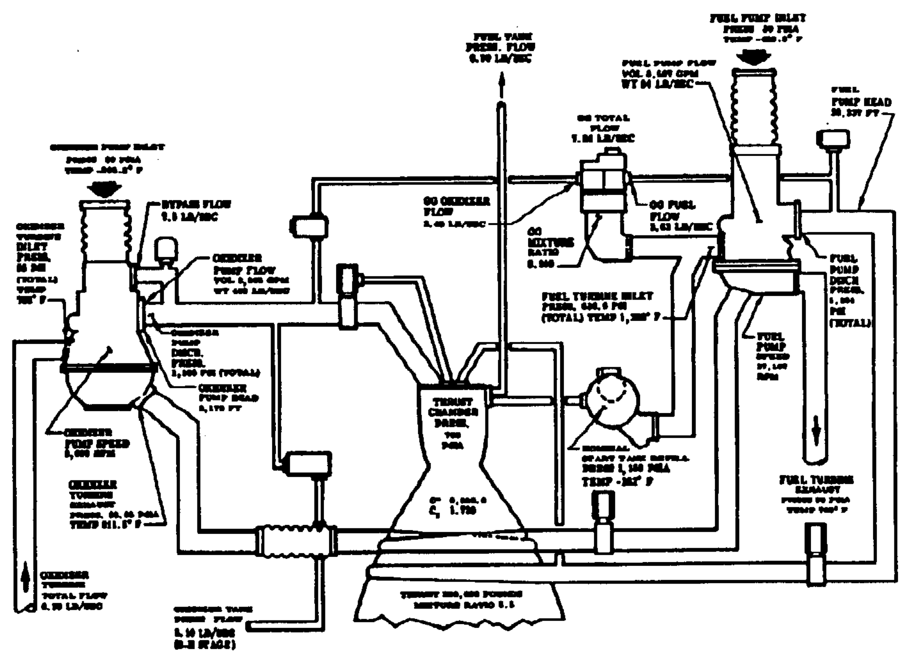
Advanced Propulsion Subsystem Concepts Database

Engine Name: J-2
Class of Engine: Cryogenic Liquid — Chemical

Advanced Propulsion Subsystem Concepts Database

Engine Name: J-2

Class of Engine: Cryogenic Liquid — Chemical



March 7, 1993

Background Information

Engine Name: J-2

Class of Engine: Cryogenic Liquid Chemical

Background

The J-2 engine was developed to provide the power for the SIVB stage of the Saturn IB vehicle and for the SII and SIVB stages of the Saturn V vehicle.

The J-2 rocket engine is a high-performance, multiple-restart engine that uses liquid oxygen for oxidizer and liquid hydrogen for fuel. Each propellant is pumped into the thrust chamber by separate gas-turbine-driven, direct-drive turbopumps. The two turbopumps are powered in series by a single gas generator that uses the same propellants as the thrust chamber. The thrust chamber is tubular-walled and is regeneratively cooled by circulating fuel through the tubes before the fuel is injected into the combustion area. The engine has a refillable start tank from which pressurized gaseous hydrogen is routed to the turbopump turbines for starting the engine. This feature, combined with the augmented spark ignition system, makes the J 2 a multi-start engine.

The J-2 engine envelope is 80.75 inches in diameter and 133 inches long and the engine weighs approximately 3,492 pounds dry. Thrust vector control is achieved by gimbaling the entire engine. The gimbal is installed at the center of the thrust chamber injector dome, and gimbal actuator attach points are located on the thrust chamber body. The rocket engine comprises the propellant feed system, gas generating system, start system, ignition n system, control system, purge system, and the flight instrumentation system.

Comments

No Comments.

References

Source: Technical Data J-2 Rocket Engine, Change No. 12 (R-3825-1), Technical Data J-2 Rocket Engine (R-3825-1A)

Date: 18 October 1972, 4 December 1973

Entered by: Dan Levack

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date	Record Number
8/31/92	3/30/93	4

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 SIVB
Manrated	Yes
IOC/Date Studied (Month/Year)	
Mixture Ratio – Engine/ Thrust Chamber	5.500

Propellants

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

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	230,000
Minimum	113,548	182,000

March 13, 1993

Engine Performance 1

Engine Name: J-2

Class of Engine: Cryogenic Liquid — Chemical

Propellants

Oxidizer	Liquid Oxygen	
Fuel	Liquid Hydrogen	
Mixture Ratio – Engine/Thrust Chamber	5.500	

Nominal Chamber Pressure (psia)	780
Expansion Ratio	27.16
Engine Design Life (Flights)	30

Engine Restarts

Design	
Demonstrated	

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

Engine Starts

Design	30
Demonstrated	

Engine Reliability, sec

Design	3,750
Demonstrated	

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum	100.00	100.00
Minimum	79.00	79.00

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	298.44	424.90
@Maximum Thrust	298.44	424.90
@Minimum Thrust	268.27	430.00

Specific Impulse data in units of seconds

Nozzle Data

Type	Bell, Tubular Wall
Length (in)	
Diameter (in)	77.00
Throat Area (sq. in)	169.70
Exit Area (sq. in)	4,609.052
Expansion Ratio	27.16

March 7, 1993

Engine Performance 2

Engine Name: J-2

Class of Engine: Cryogenic Liquid — Chemical

Engine Mass (lbm)

Total Mass w/TVC	3,492.0
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	
Max Gimbal Rate (deg/s)	

Engine Cycle

Type: Gas Generator

Pressures

	Oxidizer Turbopump	Fuel Turbopump
Min Pump Inlet	33	27
Turbine Inlet	89.3	652.6

Pressures in psia

Envelope

Length		Diameter	
Nominal	133	Nozzle Exit	80.8
Stowed		Maximum	
Extended		Maximum Gimbal	
Maximum Gimbal			

Envelope Dimensions in inches

Engine Component Masses

Component Weights, lbm

Gimbal Bearing (Without Seal and Attached Hardware)	77	Start Tank Discharge Valve	29
Thrust Chamber Injector Dome	313	Oxidizer Turbine Bypass Valve	10
Thrust Chamber Body	601	Mixture Ratio Control Valve	25
Fuel Turbopump	416	Start Tank Discharge Valve Hose	17
Oxidizer Turbopump	304	High-Pressure Oxidizer Duct (With Flowmeter)	64
Fuel Turbine Exhaust Duct	73	High-Pressure Fuel Duct (With Flowmeter and Insulated)	74
Heat Exchanger Exhaust Duct	104	Primary Instrumentation Package	33
Fuel Turbopump Inlet Duct	247	Auxiliary Instrumentation Package	29
Oxidizer Turbopump Inlet Duct	215	Electrical Control Assembly	59
Integral Hydrogen-Helium Start Tank	89	Helium Regulator Assembly (Pneumatic Control Package)	20
Main Oxidizer Valve	33	Other Engine Systems	303
Main Fuel Valve	24		
Gas Generator Control Valve	21		
Fuel Bleed Valve	12		
Oxidizer Bleed Valve	13		
		Total Dry Weight	3,492

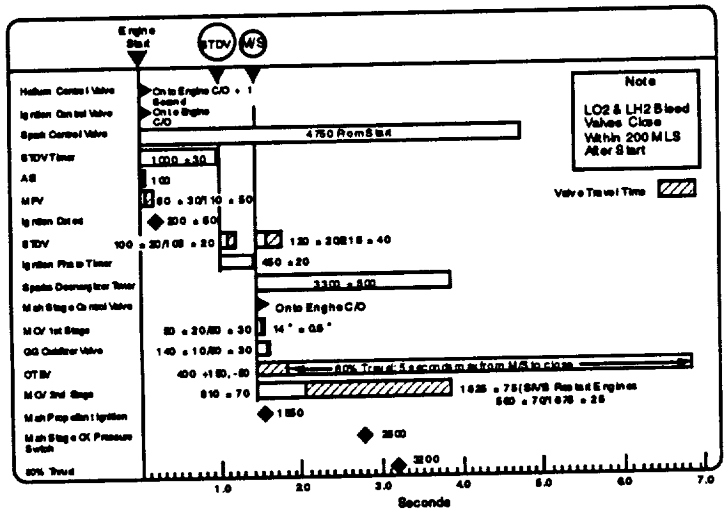
March 7, 1993

Start-Up/Shutdown Sequences

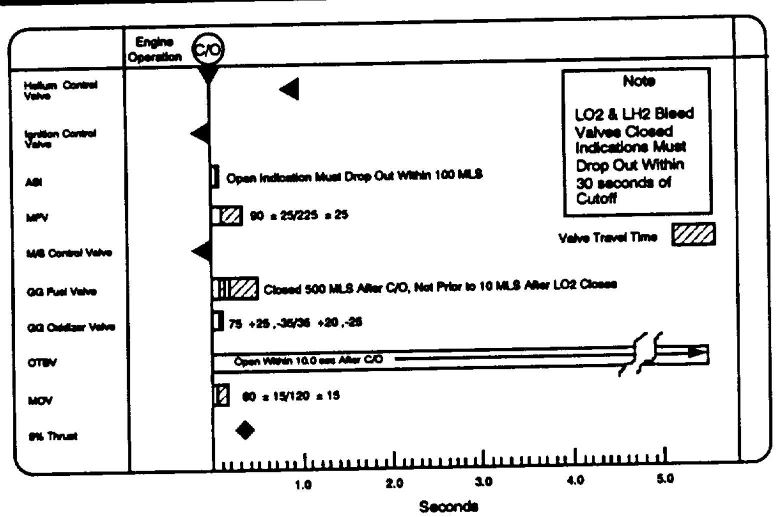
Engine Name: J-2

Class of Engine: Cryogenic Liquid — Chemical

StartUp Sequence



Shutdown Sequence



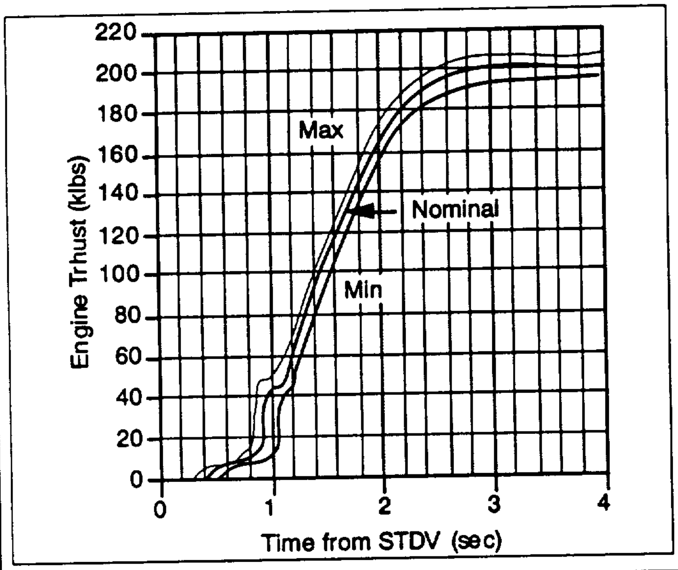
March 7, 1993

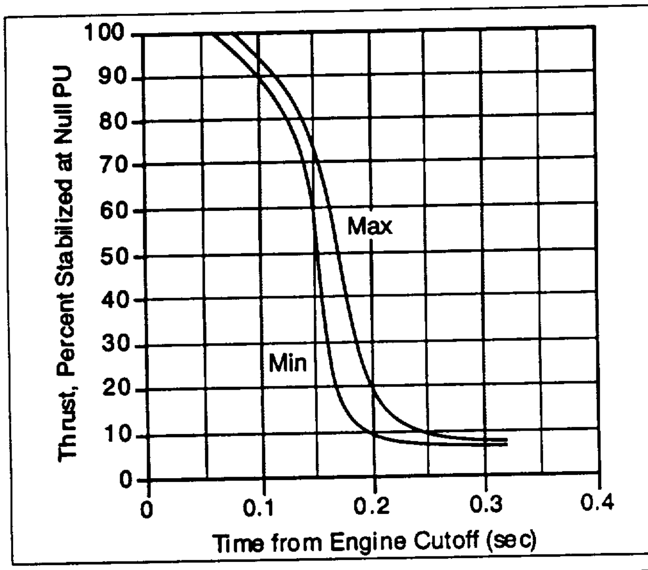
Start-Up/Shutdown Profiles

Engine Name: J-2

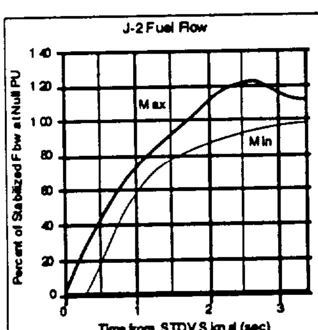
Class of Engine: Cryogenic Liquid Chemical

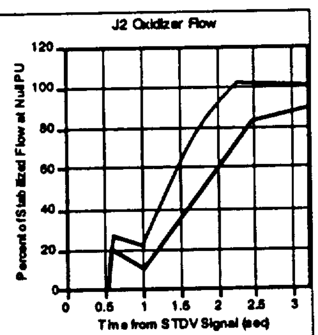
Thrust Profile





Flowrate Profile





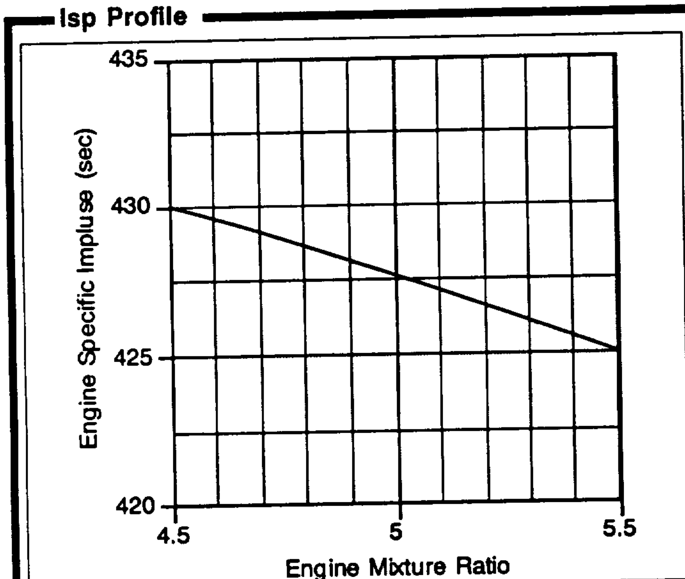
March 7, 1993

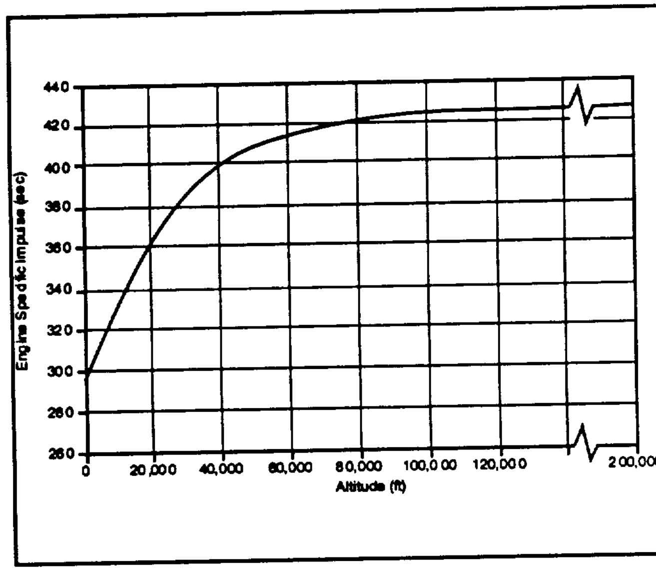
Start-Up/Shutdown Profiles

Engine Name: J-2

Class of Engine: Cryogenic Liquid Chemical

Isp Profile





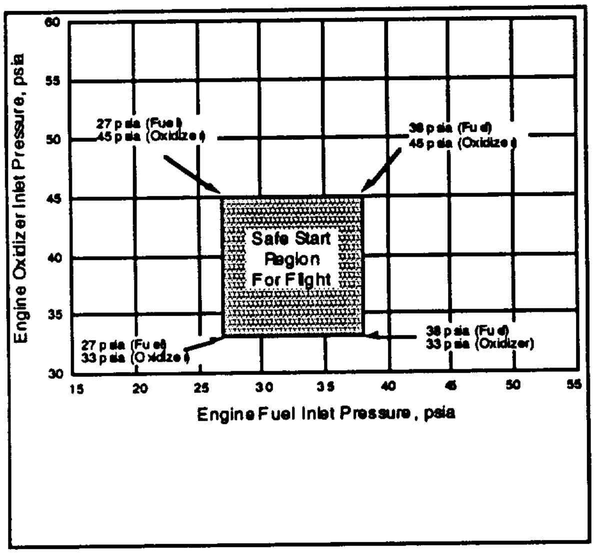
Mixture Ratio Profile

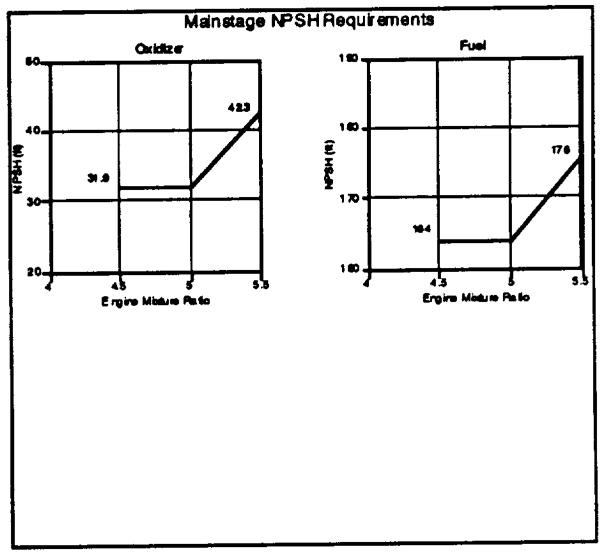
Interfaces

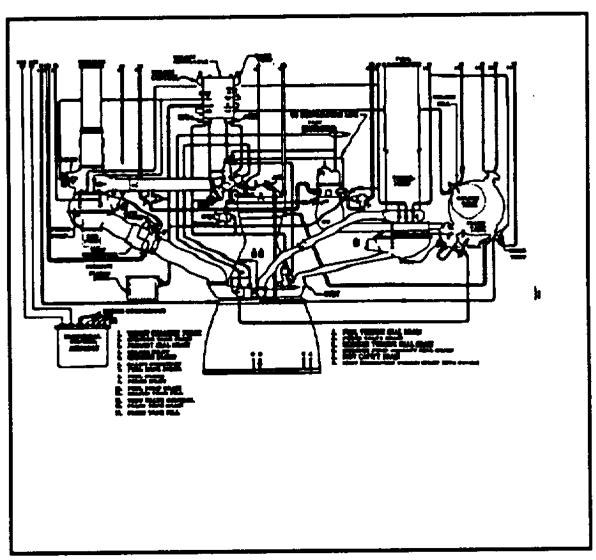
Engine Name: J-2

Class of Engine: Cryogenic Liquid   Chemical

Interfaces







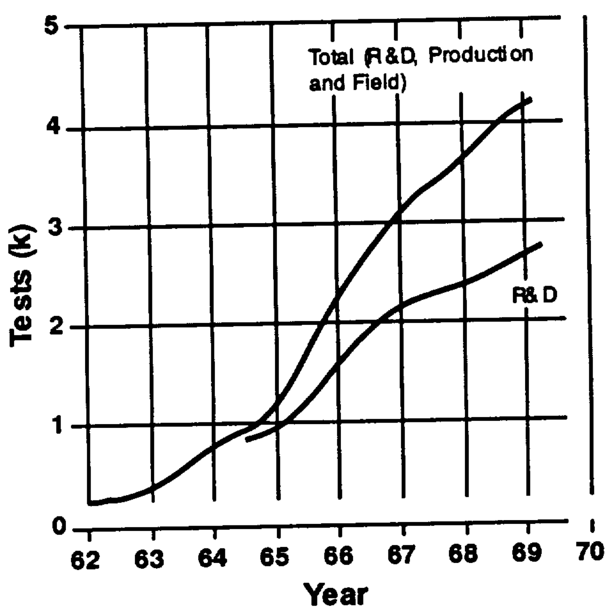
March 13, 1993

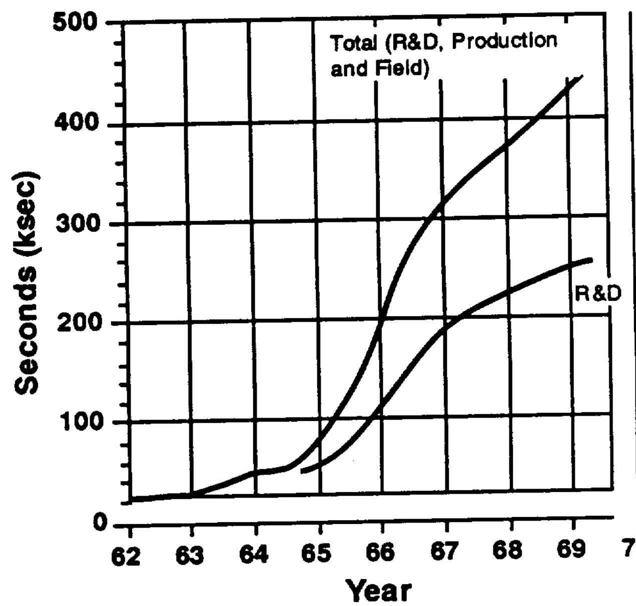
Technology Development

Engine Name:	J-2	
Class of Engine:	Cryogenic Liquid	Chemical

Technology Development

J-2 Test Experience





March 24, 1993

Advanced Development Plan

Engine Name: J-2

Class of Engine: Cryogenic Liquid — Chemical

Advanced Development Plan

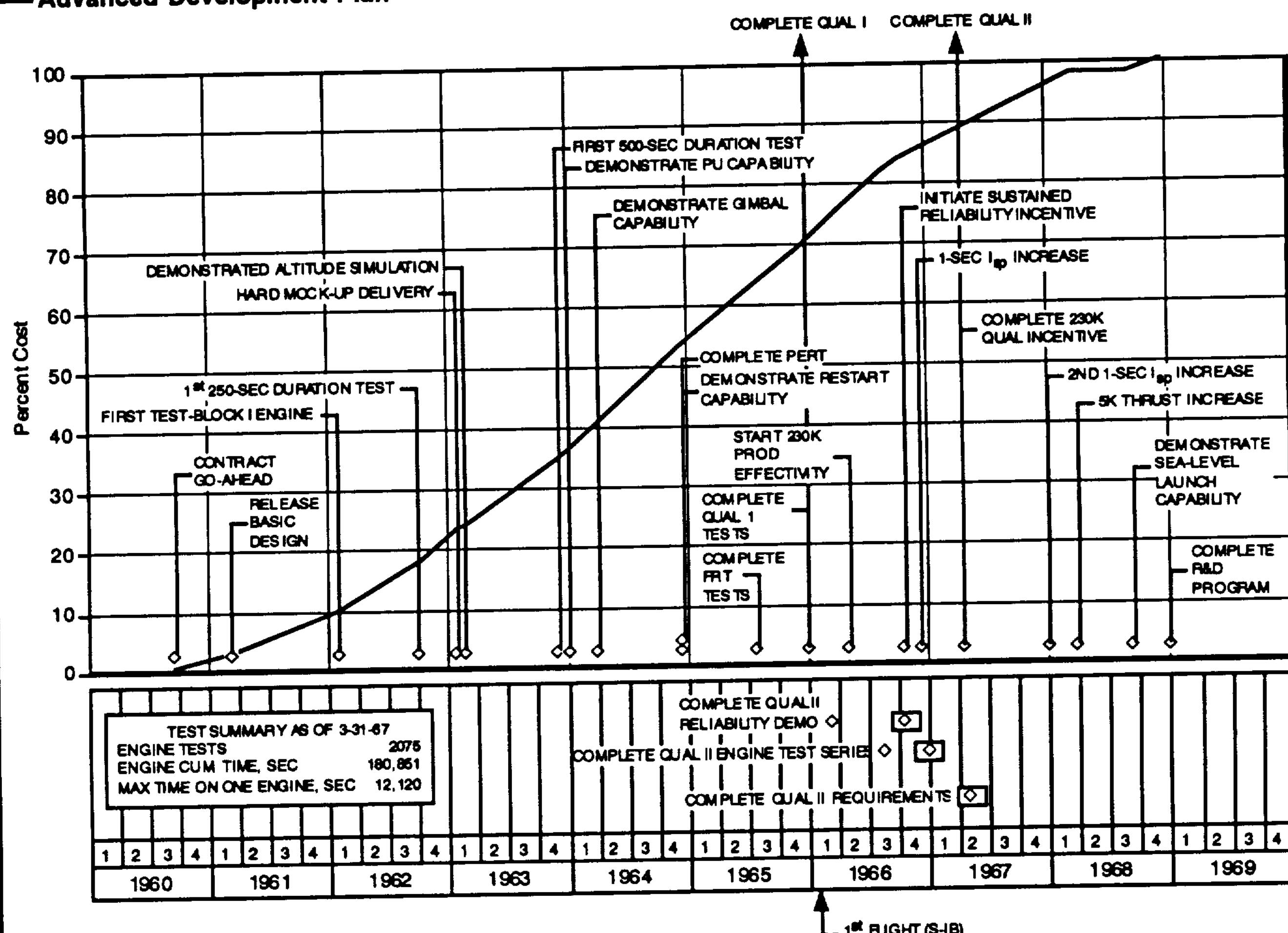
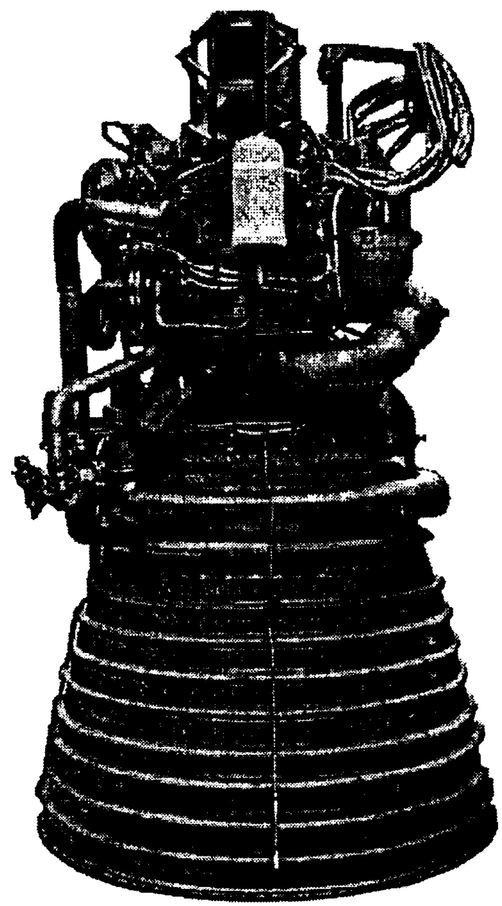


Figure 77.

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

TA3–0313

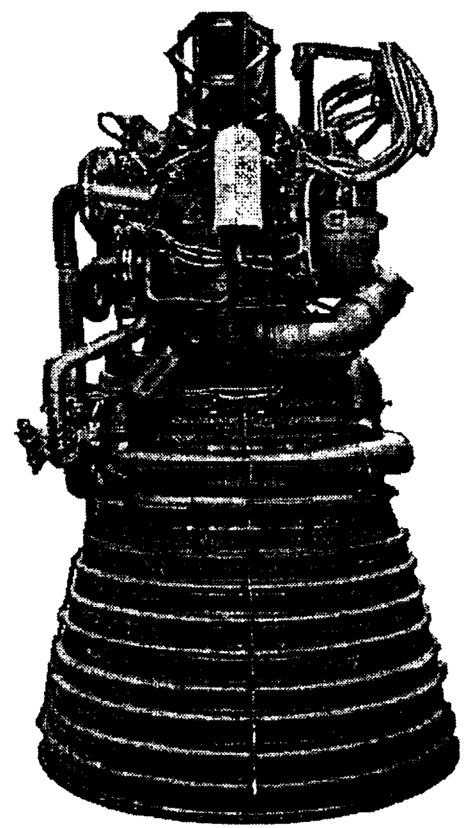
J-2S Propulsion System



- Nominal Thrust (lbf)
  - Sea Level — 196,903
  - Vacuum — 265,000
- Specific Impulse (sec)
  - Sea Level — 321.8
  - Vacuum — 433.1
- Chamber Pressure (psia) (Nozzle Stagnation) — 1,200
- Engine Mixture Ratio — 5.500
- Expansion Ratio — 40.00
- Length (in) — 133.00
- Weight (lbm) — 4,050

Advanced Propulsion Subsystem Concepts Database

Engine Name:	**Simplified, High Performance J-2**	
Class of Engine:	**Cryogenic Liquid**	**Chemical**

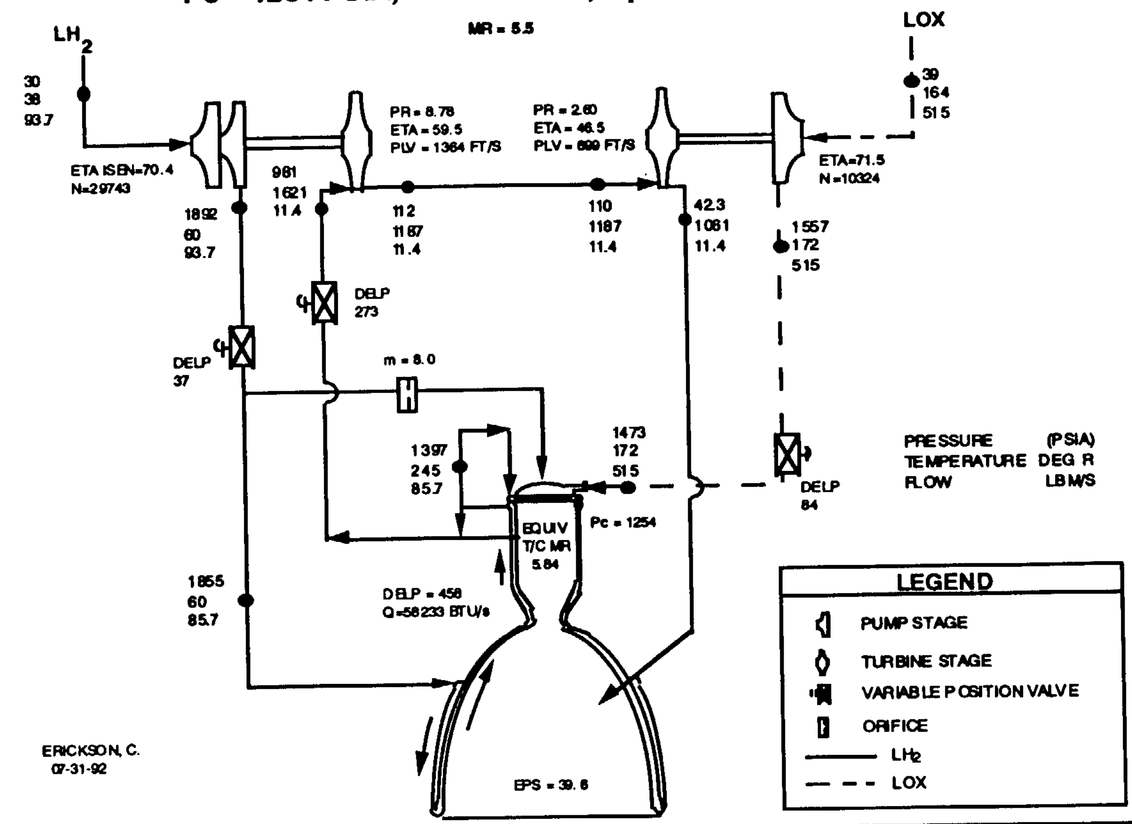


Advanced Propulsion Subsystem Concepts Database

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid Chemical

Pc = 1254 PSIA, F = 265 KLBF, Isp = 435.0 SEC



March 7, 1993

Background Information

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: ?,1971

Entered by: J. A. McClanahan, Dan Levack

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date	Record Number
5/18/92	3/30/93	5

Engine Name	Simplified, High Performance J-2	
Class of Engine	Cryogenic Liquid	Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	J-2S	
Application	ETO / Space Transfer	
Manufacturer	Rockwell International Corporation	
Program Status	6 Flight-Design Engines Built and Tested	
Manrated	Yes	
IOC/Date Studied (Month/Year)	6-1-72	
Mixture Ratio – Engine/ Thrust Chamber	5.500	5.830

Propellants

Oxidizer	Liquid Oxygen
Fuel	Liquid Hydrogen

Engine Design Life (Flights)	30
Restart Capability	2
Engine Cycle	Tap-Off Turbine Drive
Nominal Chamber Pressure	1,200
Expansion Ratio	40.00
TVC Method	Gimbal

Dimensions

Maximum Length (inches)	133.00
Maximum Width (inches)	80.00
Engine Mass (lbm)	4,050.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	196,903	265,000
Maximum		
Minimum		

March 13, 1993

Engine Performance 1

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid Chemical

Propellants

Oxidizer	Liquid Oxygen	
Fuel	Liquid Hydrogen	
Mixture Ratio – Engine/Thrust Chamber	5.500	5.830

Nominal Chamber Pressure (psia)	1,200
Expansion Ratio	40.00
Engine Design Life (Flights)	30

Engine Thrust Data

	Sea Level	Vacuum
Nominal	196,903	265,000
Maximum		
Minimum		

Thrust data in units of lbf

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum		
Minimum		

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	321.79	433.08
@Maximum Thrust		
@Minimum Thrust		

Specific impulse data in units of seconds

Engine Restarts

Design	2
Demonstrated	

Engine Starts

Design	120
Demonstrated	99

Engine Reliability, sec

Design	3,750
Demonstrated	11,509

Nozzle Data

Type	Bell, Tubular Wall
Length (in)	87.70
Diameter (in)	76.80
Throat Area (sq. in)	116.90
Exit Area (sq. in)	4,676
Expansion Ratio	40.00

March 7, 1993

Engine Performance 2

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid   Chemical

Engine Mass (lbm)

Total Mass w/TVC	4,050.0
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	7.5
Max Gimbal Rate (deg/s)	30.0

Engine Cycle

Type: Tap-Off Turbine Drive

Pressures

Oxidizer Turbopump

Min Pump Inlet	19.5
Turbine Inlet	115.0

Fuel Turbopump

Min Pump Inlet	4.4
Turbine Inlet	1,021.0

Pressures in psia

Envelope

Length

Nominal	133
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	80.0
Maximum	80.0
Maximum Gimbal	116.0

Envelope Dimensions in inches

Engine Component Masses

March 7, 1993

Start-Up/Shutdown Sequences

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid Chemical

StartUp Sequence

Shutdown Sequence

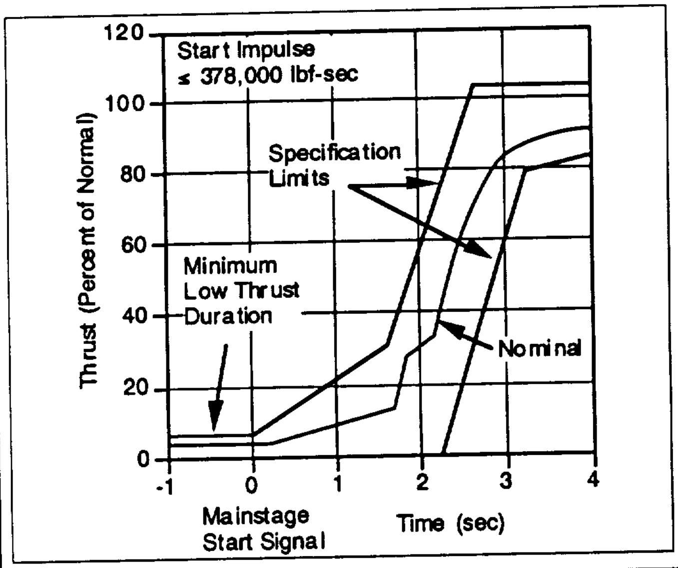
March 7, 1993

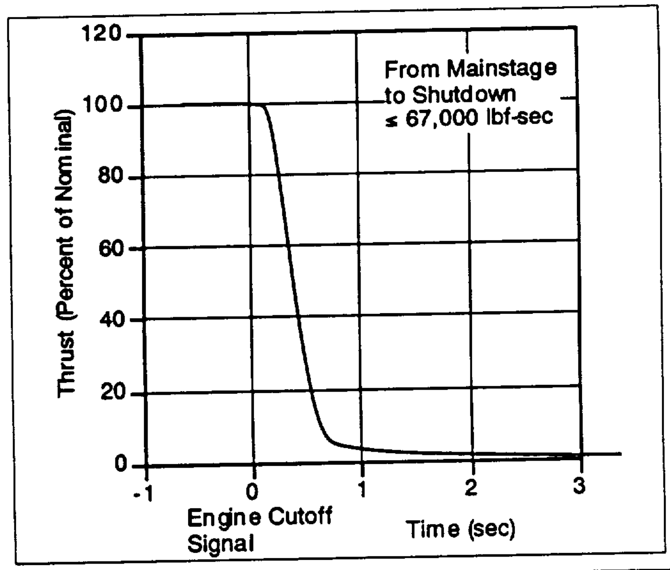
Start-Up/Shutdown Profiles

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid Chemical

Thrust Profile





Flowrate Profile

March 7, 1993

Start-Up/Shutdown Profiles

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid Chemical

Isp Profile

Mixture Ratio Profile

March 7, 1993

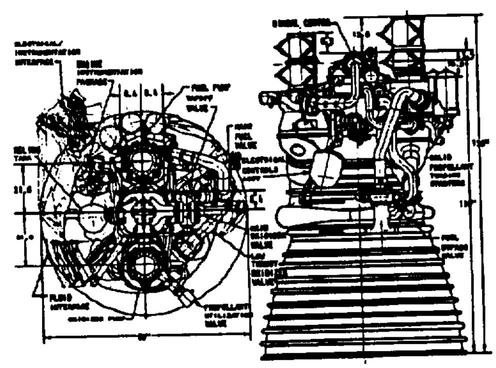
Interfaces

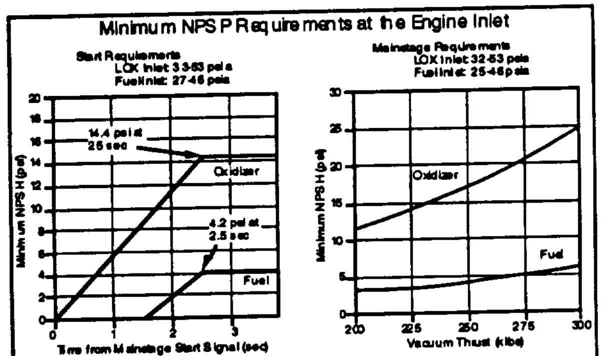
Engine Name: Simplified, High Performance J-2

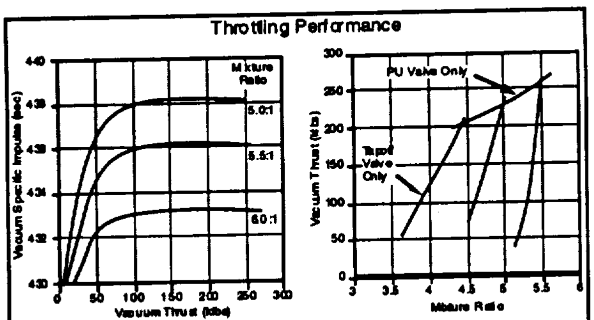
Class of Engine: Cryogenic Liquid

Chemical

Interfaces







March 7, 1993

Technology Development

Engine Name:	Simplified, High Performance J-2	
Class of Engine:	Cryogenic Liquid	Chemical

Technology Development

March 7, 1993

Advanced Development Plan

Engine Name: Simplified, High Performance J-2

Class of Engine: Cryogenic Liquid Chemical

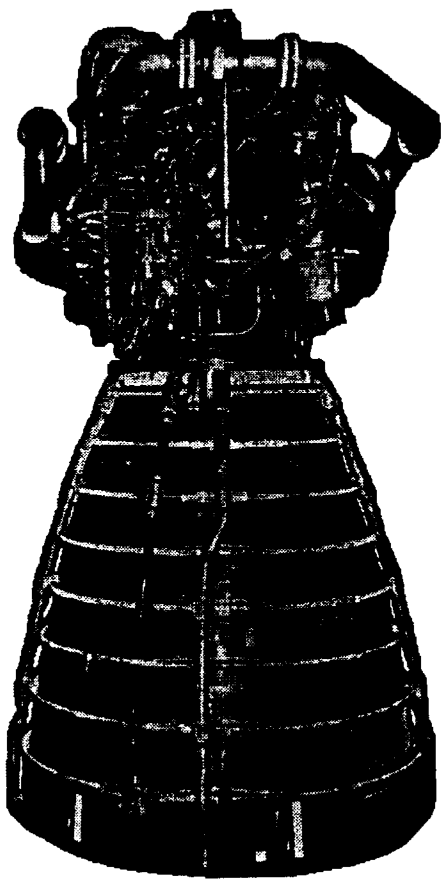
Advanced Development Plan

Figure 78.

Output for Space Shuttle Main Engine (SSME) Propulsion System

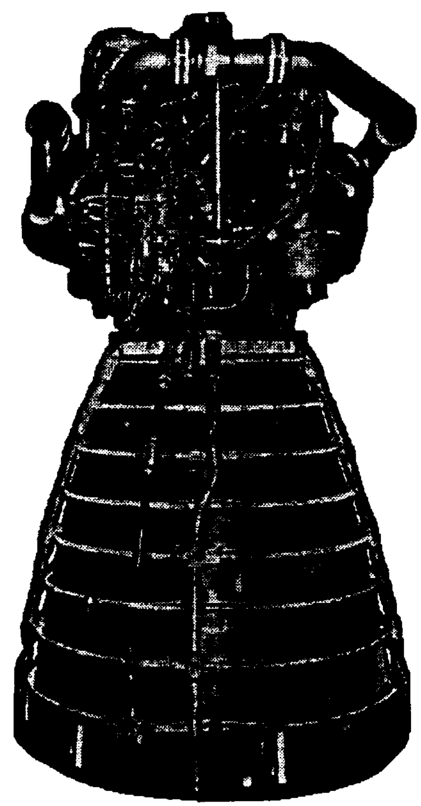
TA3–0315

SSME Propulsion System



- Nominal Thrust (lbf)
  - Sea Level 375,004
  - Vacuum 469,000
- Specific Impulse (sec)
  - Sea Level 362.5
  - Vacuum 453.3
- Chamber Pressure (psia) (Nozzle Stagnation) 3,028
- Engine Mixture Ratio 6.011
- Expansion Ratio 77.50
- Length (in) 168.00
- Weight (lbm) 6,979

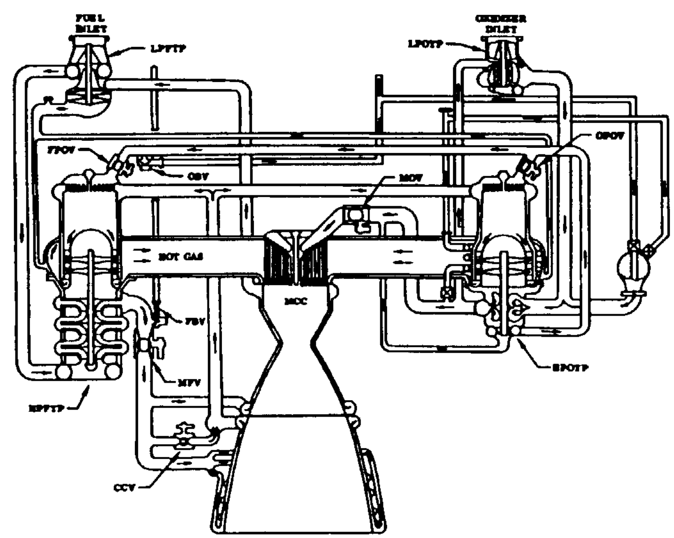
Engine Name:	**Space Shuttle Main Engine**	
Class of Engine:	**Cryogenic Liquid**	**Chemical**



Advanced Propulsion Subsystem Concepts Database

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical



C-3

February 22, 1993

Background Information

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical

Background

The Space Shuttle Main Engines (SSME's) are reusable, high performance, liquid-propellant rocket engines with variable thrust. They are ignited on the ground at launch and operate in parallel with the solid rocket boosters during the initial ascent phase of the Space Transportation System, and continue to operate for a nominal 500 seconds total firing time. Each of the engines has an expansion ratio of 77.5:1 and operates at a mixture ratio of 6:1. The engines are continuously throttleable over a thrust range of 65 to 109 percent of the design thrust level (rated power level, RPL – 469,000 lbf vacuum thrust). This provides a higher thrust level during lift-off and the initial ascent phase and allows orbiter accelerations and dynamic pressures to be kept within design limits. The engines are gimbaled to provide pitch, yaw and roll control during the orbiter boost phases. Gaseous hydrogen and oxygen are tapped off the engine for pressurizing the external tank.

A staged combustion power cycle coupled with high combustion chamber pressures is employed. In the SSME staged combustion cycle, propellants are partially burned at high pressure and relatively low temperature in the preburners, then completely burned at high temperature and pressure in the main chamber before expanding through the high area ratio nozzle. Hydrogen fuel is used to cool all combustion devices components which are directly exposed to high temperature combustion products. An electronic engine controller automatically performs checkout, start, mainstage, and engine shutdown functions.

Input Notes:
The performance characteristics given here are for the Flight-Phase II Configuration.

Demonstrated life – The number of seconds shown represent all the components except the high pressure fuel turbopump (HPFTP) and the high pressure oxidizer turbopump (HPOTP). The number is for the least demonstrated time among those components. For the HPFTP, 95% of the components have been demonstrated for 15,000 seconds and the rest for 10,000 seconds. For the HPOTP, 83% of the components have been demonstrated for 15,000 seconds and the rest for 10,000 seconds.

LPFTP – low pressure fuel turbopump
HPFTP – high pressure fuel turbopump
LPOTP – low pressure oxidizer turbopump
HPOTP – high pressure oxidizer turbopump
MFV – main fuel valve
MOV – main oxidizer valve
FPOV – fuel preburner oxidizer supply valve
OPOV – oxidizer preburner oxidizer supply valve
CCV – coolant control valve
FBV – fuel bypass valve
OBV – oxidizer bypass valve
MCC – main combustion chamber

Comments

No Comments.

References

Source: RI / RD87-142, CPIA/M5 (Oct 1985), Space Shuttle Orbiter Vehicle/Main Engine Interface Control Document (ICD-13M15000, Rev. "V"), Space Shuttle Main Engine Pocket Data (RSS-8559-10.

Date: 6-1-1991,10/85,13 July 1989, 22 August 1984

Entered by: J. A. McClanahan, Dan Levack

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date
4/20/92	3/29/93

Record Number: 6

Engine Name	Space Shuttle Main Engine	
Class of Engine	Cryogenic Liquid	Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	SSME	
Application	ETO	
Manufacturer	Rockwell International Corporation	
Program Status	Space Transportation System, 4 Orbiter Fleet	
Manrated	Yes	
IOC/Date Studied (Month/Year)	4-12-81	
Mixture Ratio – Engine/ Thrust Chamber	6.011	6.034

Propellants

Oxidizer	Liquid Oxygen
Fuel	Liquid Hydrogen

Engine Design Life (Flights)	55
Restart Capability	0
Engine Cycle	Staged Combustion
Nominal Chamber Pressure	3,028
Expansion Ratio	77.50
TVC Method	Gimbal

Dimensions

Maximum Length (Inches)	168.00
Maximum Width (Inches)	90.00
Engine Mass (lbm)	6,979.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	375,004	469,000
Maximum	418,304	512,300
Minimum	209,204	303,200

March 13, 1993

Engine Performance 1

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical

Propellants

Oxidizer	Liquid Oxygen	
Fuel	Liquid Hydrogen	
Mixture Ratio – Engine/Thrust Chamber	6.011	6.034

Nominal Chamber Pressure (psia)	3,028
Expansion Ratio	77.50
Engine Design Life (Flights)	55

Engine Restarts

Design	0
Demonstrated	0

Engine Thrust Data

	Sea Level	Vacuum
Nominal	375,004	469,000
Maximum	418,304	512,300
Minimum	209,204	303,200

Thrust data in units of lbf

Engine Starts

Design	55
Demonstrated	27,000

Engine Reliability, sec

Design	27,000
Demonstrated	37,000

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum	111.30	109.00
Minimum	56.10	65.00

Nozzle Data

Type	Bell, Tubular Wall
Length (in)	121.00
Diameter (in)	90.23
Throat Area (sq. in)	83.40
Exit Area (sq. in)	6,463.5
Expansion Ratio	77.50

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	362.45	453.30
@Maximum Thrust	370.37	453.60
@Minimum Thrust	311.94	452.10

Specific Impulse data in units of seconds

February 22, 1993

Engine Performance 2

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid — Chemical

Engine Mass (lbm)

Total Mass w/TVC	6,979.0
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	10.5
Max Gimbal Rate (deg/s)	10.0

Engine Cycle

Type: Staged Combustion

Pressures

Oxidizer Turbopump

Min Pump Inlet	
Turbine Inlet	4,924.0

Fuel Turbopump

Min Pump Inlet	
Turbine Inlet	4,932.0

Pressures in psia

Envelope

Length

Nominal	168
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	90.7
Maximum	94.0
Maximum Gimbal	153.0

Envelope Dimensions in inches

Engine Component Masses

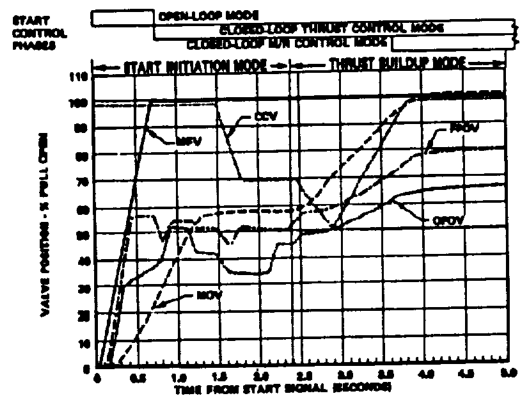
Turbomachinery	1,725
Preburners	229
PB Hot Gas Manifold	556
Thrust Chamber	859
Nozzle	1,250
Gimbal Bearing	105
Valves and Controls	722
Controller and Mount	85
POGO System	94
Propellant Ducts	868
Pressurization System	69
Other Engine Systems	395
Total Dry Weight	6,979

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

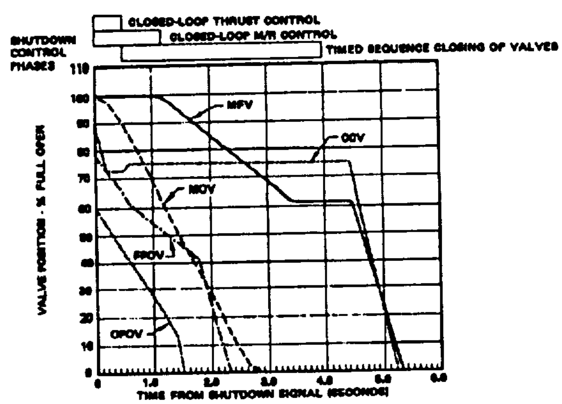
Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical

StartUp Sequence



Shutdown Sequence



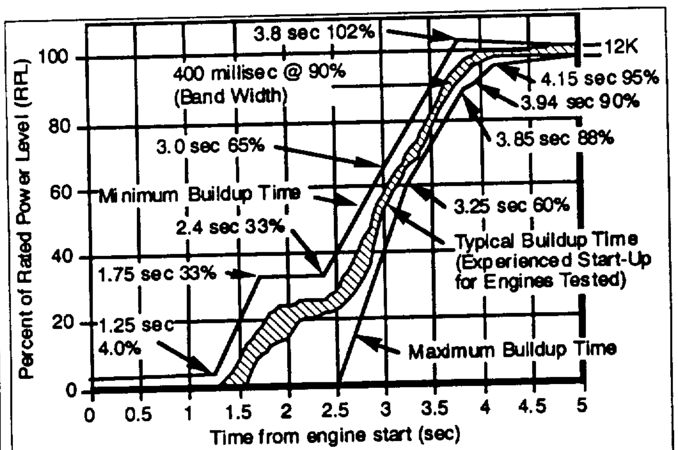
February 22, 1993

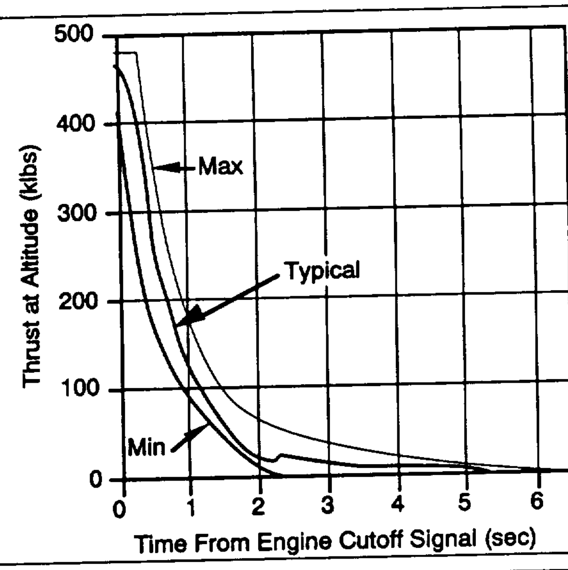
Start-Up/Shutdown Profiles

Engine Name: Space Shuttle Main Engine

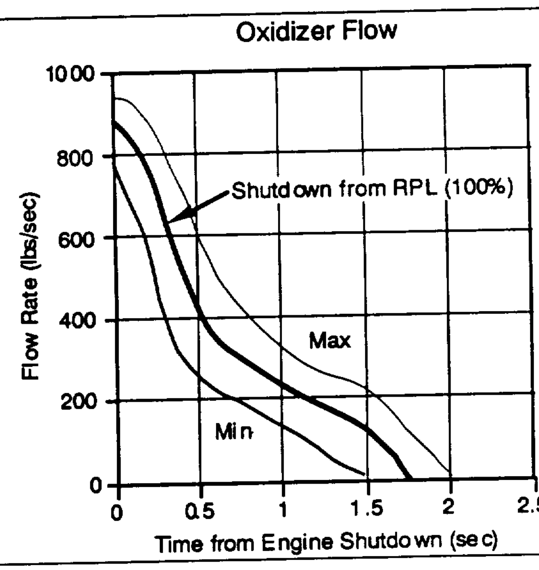
Class of Engine: Cryogenic Liquid — Chemical

Thrust Profile





Flowrate Profile



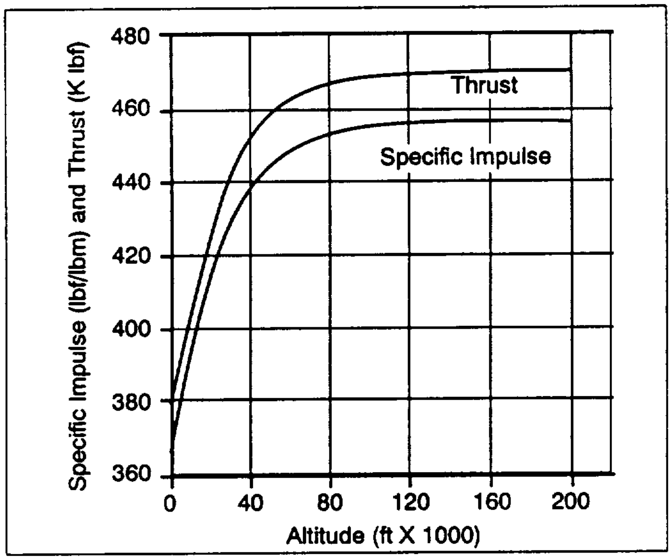
February 22, 1993

Start-Up/Shutdown Profiles

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical

Isp Profile



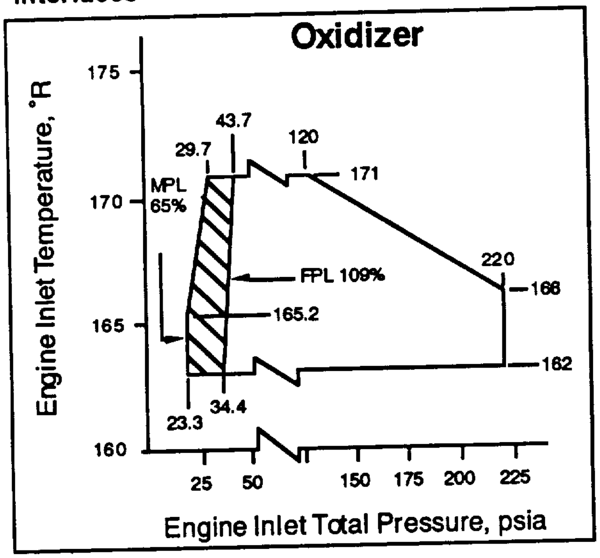
Mixture Ratio Profile

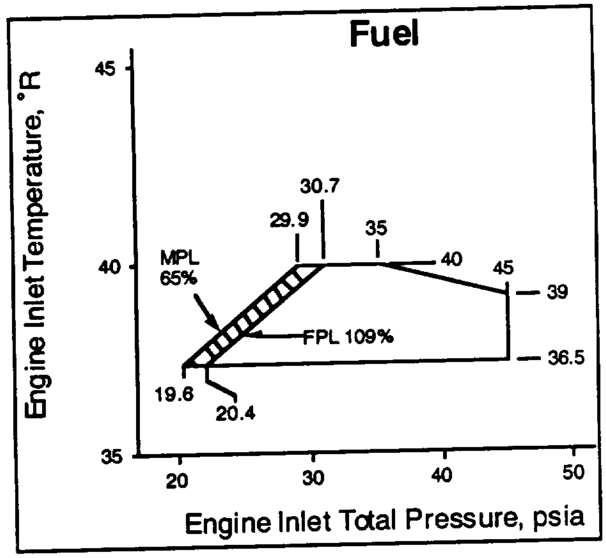
February 22, 1993

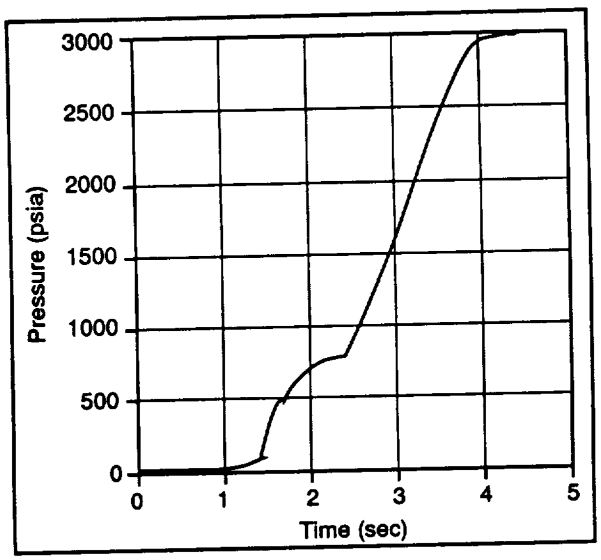
Interfaces

Engine Name:	Space Shuttle Main Engine
Class of Engine:	Cryogenic Liquid — Chemical

Interfaces







February 22, 1993

Technology Development

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical

Technology Development

March 27, 1993

Advanced Development Plan

Engine Name: Space Shuttle Main Engine

Class of Engine: Cryogenic Liquid Chemical

Advanced Development Plan

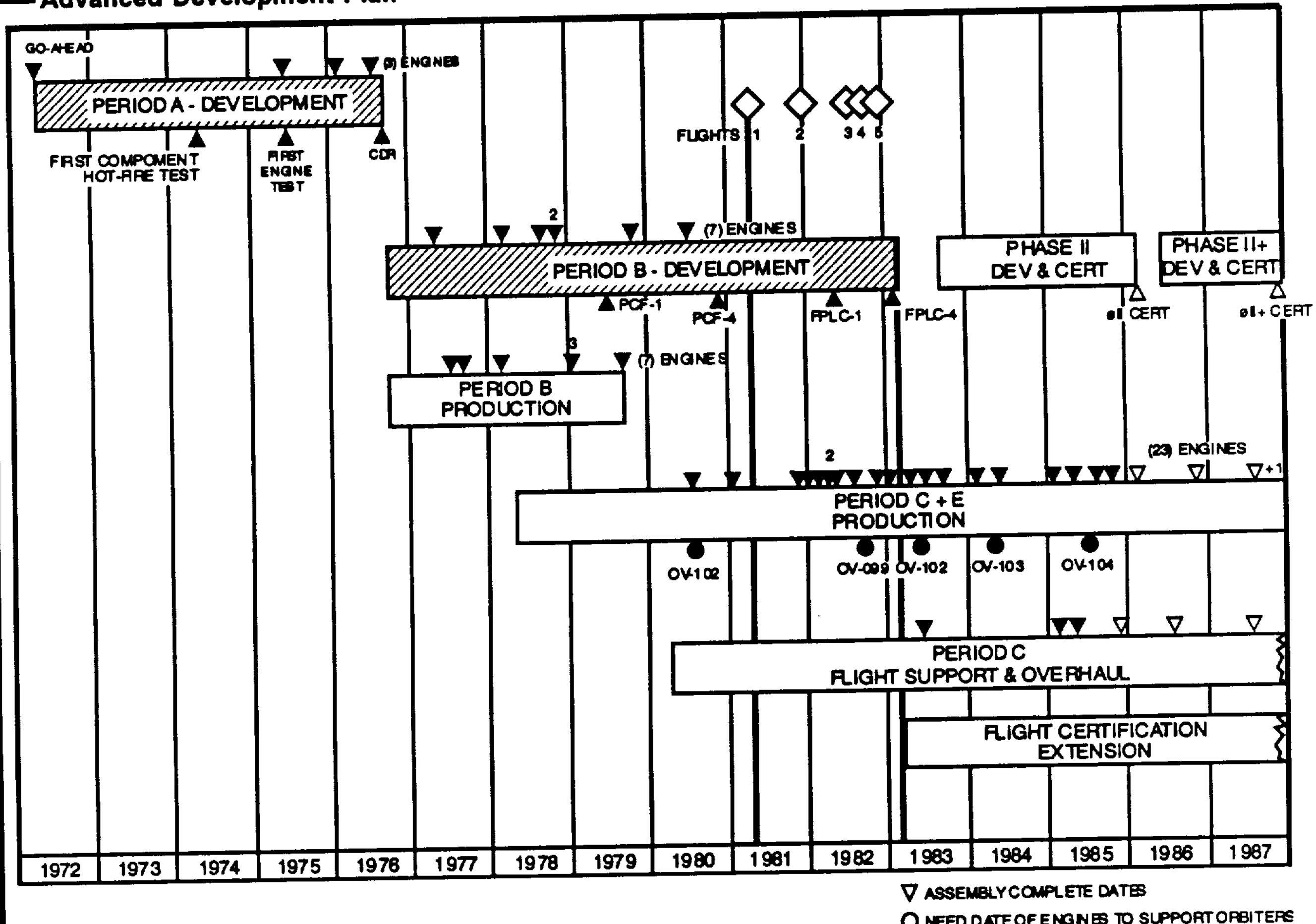
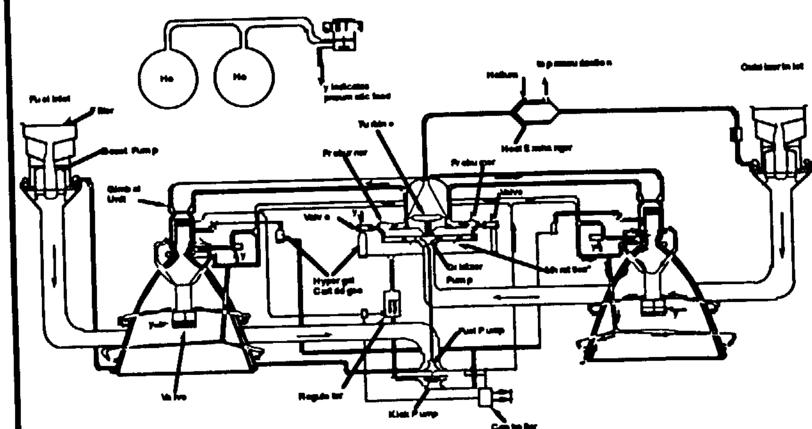


Figure 79.

Output for RD-170 Propulsion System

TA3–0316

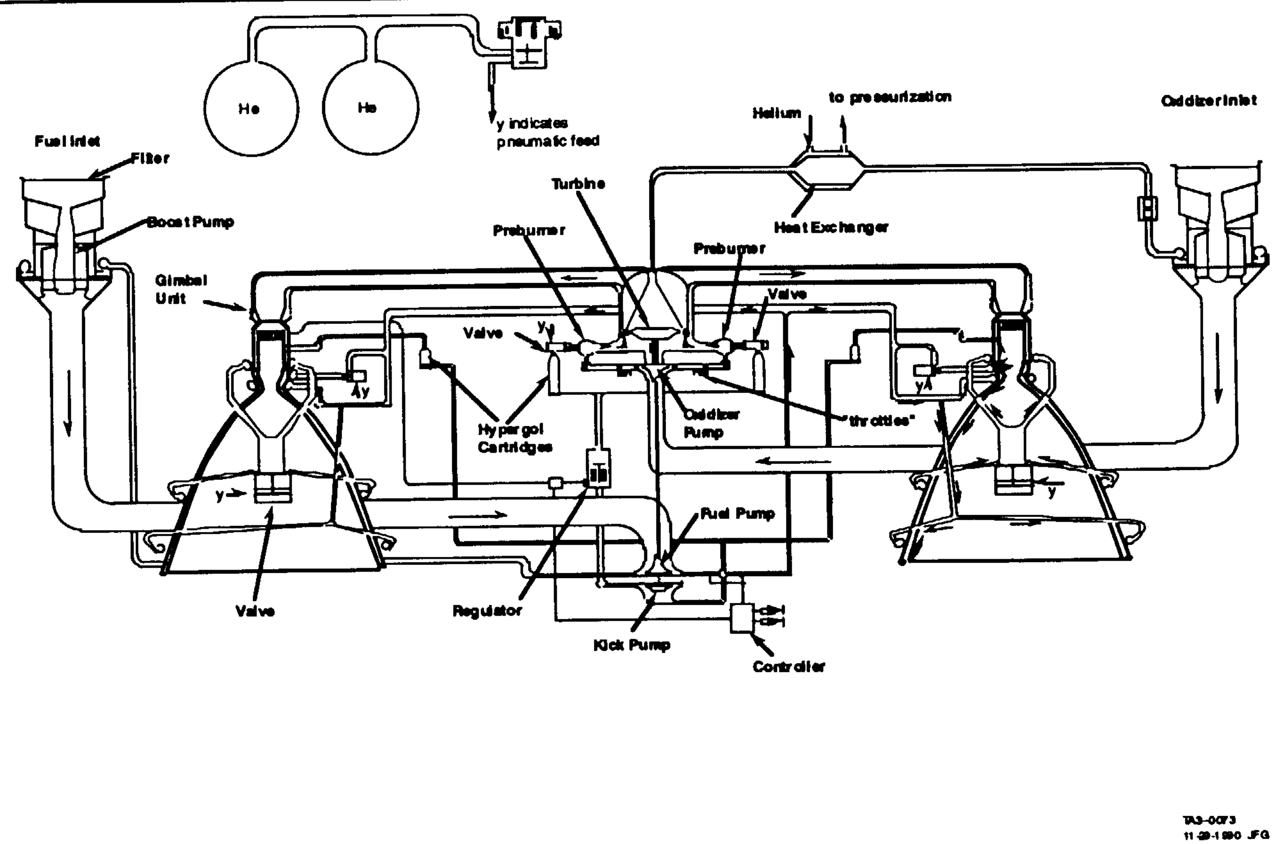
RD-170 Propulsion System



• Nominal Thrust (lbf)	
• Sea Level	1,630,545
• Vacuum	1,776,926
• Specific Impulse (sec)	
• Sea Level	309.2
• Vacuum	337.0
• Chamber Pressure (psia) (Nozzle Stagnation)	3,556
• Engine Mixture Ratio	2.630
• Expansion Ratio	36.80
• Length (in)	158.00
• Weight (lbm)	23,507

2/20/93

Engine Name:	**RD-170**	
Class of Engine:	**Hydrocarbon Liquid**	**Chemical**

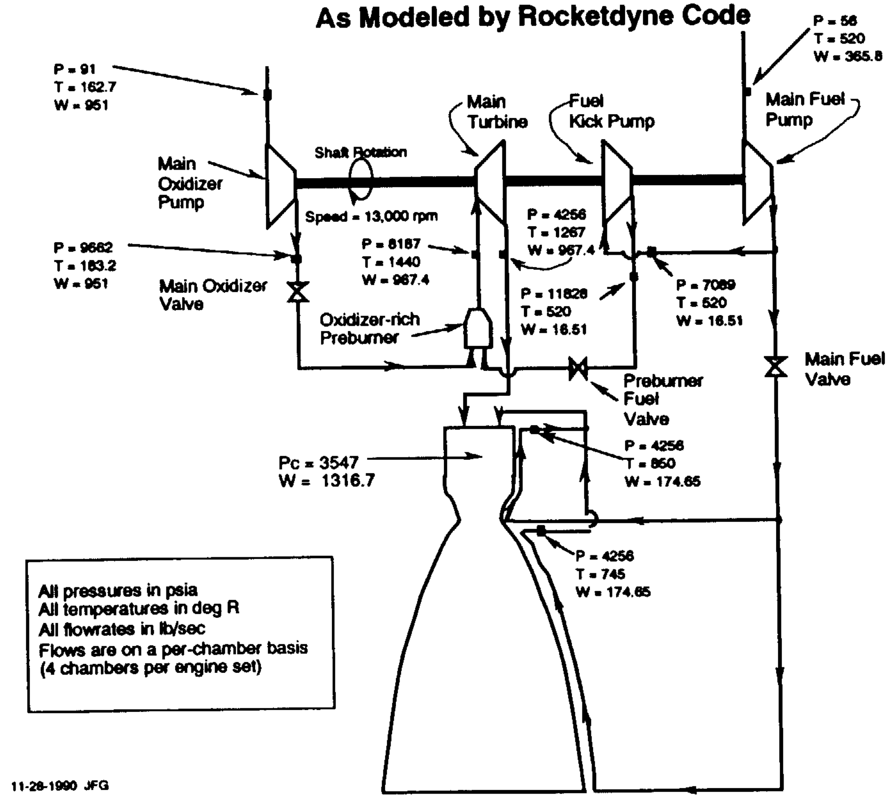


Advanced Propulsion Subsystem Concepts Database

Engine Name:	**RD-170**	
Class of Engine:	**Hydrocarbon Liquid**	**Chemical**

Russian RD-170 Engine Schematic

As Modeled by Rocketdyne Code



February 22, 1993

Background Information

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid — Chemical

Background

The RD-170 is the most powerful rocket engine currently in production anywhere in the world, and it is used as the strap-on booster on the Energyia heavy-lift launcher and (in the RD-171 variant) on the first stage of the Zenit launcher. It is a 4-combustion chamber engine driven by a single turbopump assembly.

Engine development was started in 1976 and the first flight of the RD-171 occurred during the first launch of a Zenit booster in 1985. The first flight of the RD-170 occurred in May 1985 as the booster engine on Energiya.

The West is aware of two successful unmanned Energiya launches, and one flight failure of a Zenit launcher is known to have occurred in the fall of 1990, which is believed to be related to a failure of the RD-171 engine.

Reference Sources:

1. "RD-170--Super Powered Liquid Propellant Rocket Engine 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 Special Report 2, "USSR Rocket Engines, second edition", January 1992, by Technology Detail, 99 Kingsway North, Clifton, York YO3 6JH, United Kingdom.

Comments

References

Source: See "Engine Background"

Date:

Entered by: Jim Glass

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date	Record Number
12/11/92	3/29/93	7

Engine Name	RD-170
Class of Engine	Hydrocarbon Liquid / Chemical
Propulsion 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

Oxidizer	Liquid Oxygen
Fuel	Kerosene

Engine Design Life (Flights)	10
Restart Capability	
Engine Cycle	Staged Combustion
Nominal Chamber Pressure	3,556
Expansion Ratio	36.80
TVC Method	Gimbal

Dimensions

Maximum Length (Inches)	158.00
Maximum Width (Inches)	56.30
Engine Mass (lbm)	23,507.00

Engine Thrust Data, lbf

	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
Expansion Ratio	36.80
Engine Design Life (Flights)	10

Engine Restarts

Design	
Demonstrated	0

Engine Thrust Data

	Sea Level	Vacuum
Nominal	1,630,545	1,776,926
Maximum	1,719,391	1,865,772
Minimum	742,082	888,463

Thrust data in units of lbf

Engine Starts

Design	10
Demonstrated	19

Engine Reliability, sec

Design	1,650
Demonstrated	2,567

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum		105.00
Minimum		49.00

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	309.24	337.00
@Maximum Thrust		
@Minimum Thrust		

Specific Impulse data in units of seconds

Nozzle Data

Type	Bell with helical slotted liner
Length (in)	70.00
Diameter (in)	112.60
Throat Area (sq. in)	270.60
Exit Area (sq. in)	9,958.08
Expansion Ratio	36.80

February 20, 1993

Engine Performance 2

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid — Chemical

Engine Mass (lbm)

Total Mass w/TVC	23,507.0
Total Mass wo/TVC	140.4

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	8.0
Max Gimbal Rate (deg/s)	

Engine Cycle

Type: Staged Combustion

Pressures

Oxidizer Turbopump

Min Pump Inlet	92.45
Turbine Inlet	

Fuel Turbopump

Min Pump Inlet	34.1
Turbine Inlet	

Pressures in psia

Envelope

Length

Nominal	158
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	56.3
Maximum	
Maximum Gimbal	

Envelope Dimensions in inches

Engine Component Masses

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

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid Chemical

StartUp Sequence

Shutdown Sequence

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

Isp Profile

Mixture Ratio Profile

February 22, 1993

Interfaces

Engine Name: RD-170

Class of Engine: Hydrocarbon Liquid — Chemical

Interfaces

Summary of Quoted Russian Values for RD-170 Engine

Parameter	Value Metric	Value English
Vacuum thrust	201.6 tonnes force	444,447.4 lbf *
Chamber pressure	250 kgf/sq cm	3,555.84 psia
Coolant inlet pressure	420 kgf/sq cm	5,973.80 psia
Oxidizer (GG) consumption	432.5 kg/s per chamber	[illegible] lb/s *
Fuel (kerosene) consumption	164.75 kg/s per chamber	363.21 lb/s *
"Consumption ratio"		
Absolute	527.5 g/s sq. cm	7.50 lbm/s sq. in
Relative	2.11 g/s sq. cm	0.03 lbm/s sq. in
Vacuum specific impulse	3,304.94 N-s/kg	337.0 seconds *
Nozzle area ratio	36.8440 (diam ratio 6.07)	
Chamber height	2,466 mm	97.08 inch
Nozzle exit diameter	1,430 mm	56.30 inch
Chamber mass	490 kg	1080.21 lb
Oxidizer pump discharge pressure	580 kgf/sq. cm	8,246.17 psia
Fuel pump discharge pressure	500 kgf/sq. cm	7,111.67 psia
Kick pump discharge pressure	800 kgf/sq. cm	11,378.7 psia
Oxidizer pump flowrate	1,734 kg/s (4 chambers)	3,822.75 lb/s *
Fuel pump flowrate	[illegible] kg/s (4 chambers)	1 482.83 lb/s *
Kick pump flowrate	30 kg/s (4 chambers)	66.14 lb/s
Turbine inlet temperature	520 C	1427.7 R
Turbine pressure ratio	1.83	
Turbine efficiency	0.82	
Oxidizer pump efficiency	0.74	
Fuel pump efficiency	0.76	
Turbine power	190,000 kW	254,794 HP

Reference: "RD-170 - Super-Powered Liquid Propellant Rocket Engine of New Generation", F. Yu. Chelkis, Chief Designer
Revised data indicated by *. Revisions follow data provided in letter of 20 August 1991 from Felix Chelkis to W.F. East

Revised 09-20-1991 JFG

Summary of Quoted Russian Values for RD-170 Engine

Parameter	Value Metric	Value English
Nominal sea-level thrust	740 tonnes force (4 chambers)	1,631,404 lbf
Nominal vacuum thrust	806.4 tonnes force (4 chambers)	1,777,788.4 lbf *
Nominal cut-off thrust	[illegible] tonnes force (4 chambers)	873,021.6 lbf
Nominal sea-level specific impulse	3,033.2 N-s/kg	309.3 seconds *
Nominal mixture ratio	2.63 (previously quoted @ 2.60)	2.63 *
Nominal cut-off chamber pressure	123.3 kgf/sq. cm	1,753.74 psia
Nominal nozzle exit pressure	0.73 kgf/sq. cm	10.383 psia
Operation flight time	151 seconds	
Dry engine mass (various versions)	10,700 to 12,175 kgf	23,589 to 26,841 lb
Total engine length	4,015 mm	158.07 inch
Engine exit diameter (4 chambers)	3,565 mm	140.35 inch
Nominal oxidizer inlet static pressure	5.7 to 7.1 kgf/sq. cm (nominal 6.5)	81.07 to 100.98 psia (nominal 92.45) *
Nominal fuel inlet static pressure	3.3 to 4.6 kgf/sq. cm (nominal 2.4)	46.94 to 65.43 psia (nominal 34.14) *
Nominal oxidizer inlet temperature	-182 C (91.15 K)	164.07 R *
Nominal fuel inlet temperature	-15 C (258.15 K)	464.67 R *
Maximum gimbal angle	plus or minus 8 degrees	
Helium bottle volume (pneumatic controls)	160 litre	5.65 cubic feet
Helium bottle pressure (pneumatic controls)	220 kgf/sq. cm	3,129.1 psia
Engine service life	10 flights	
Engine reliability	0.999	

Revised data indicated by shading. Revisions follow data provided in letter of 20 August 1991 from Felix Chelkis to W.F. East

Revised 09-20-1991 JFG

February 20, 1993

Technology Development

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

Technology Development

February 20, 1993

Advanced Development Plan

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

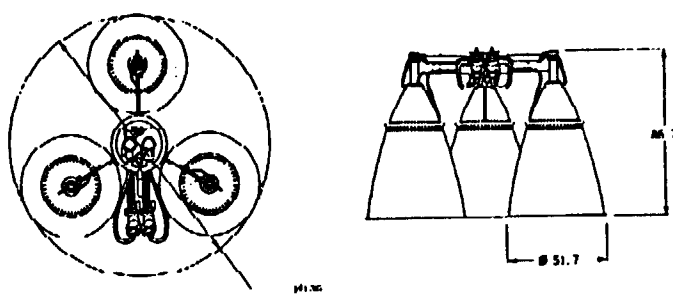
Advanced Development Plan

Figure 80.

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

TA3–0317

IME Propulsion System

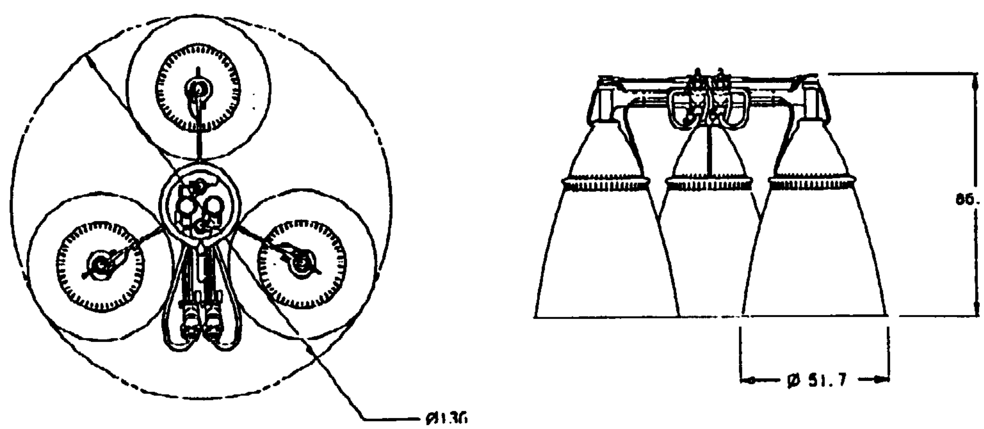


• Nominal Thrust (lbf)	
• Sea Level	15,393
• Vacuum	30,000
• Specific Impulse (sec)	
• Sea Level	246.3
• Vacuum	480.0
• Chamber Pressure (psia) (Nozzle Stagnation)	1,746
• Engine Mixture Ratio	6.000
• Expansion Ratio	700.00
• Length (in)	87.70
• Weight (lbm)	1,048

Advanced Propulsion Subsystem Concepts Database

Engine Name: Integrated Modular Engine

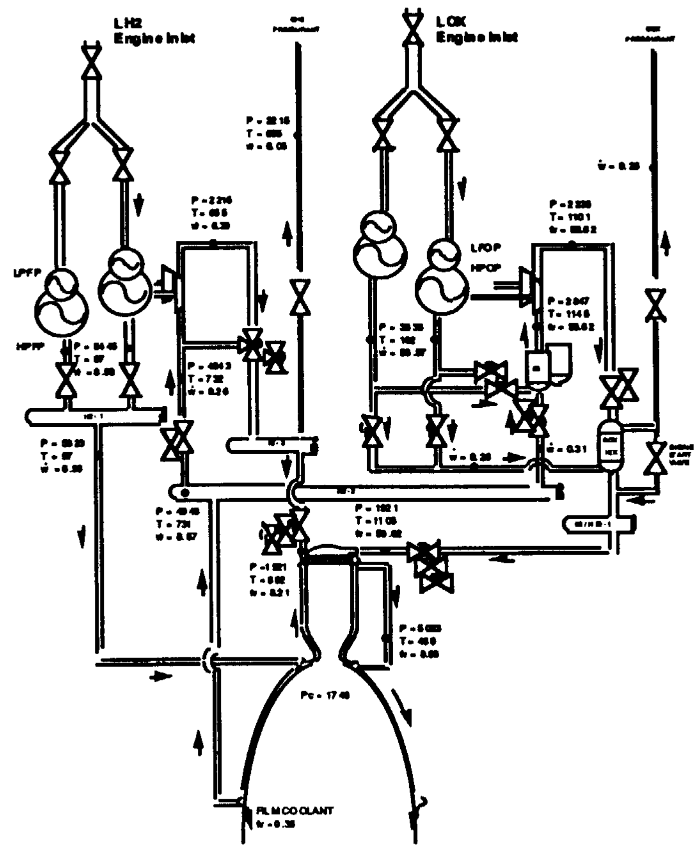
Class of Engine: Cryogenic Liquid   Chemical



Advanced Propulsion Subsystem Concepts Database

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid — Chemical



March 7, 1993

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: 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 Date	Record Number
12/11/92	3/29/93	8

Engine Name	Integrated Modular Engine	
Class of Engine	Cryogenic Liquid	Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	IME	
Application	Air Force Upper Stage	
Manufacturer	Conceptual Engine (Rocketdyne Study)	
Program Status	Study: RI/RD90-134	
Manrated		
IOC/Date Studied (Month/Year)	1 May 1992	
Mixture Ratio – Engine/ Thrust Chamber	6.000	

Propellants

Oxidizer	Liquid Oxygen
Fuel	Liquid Hydrogen

Engine Design Life (Flights)	1
Restart Capability	3
Engine Cycle	Hybrid: Fuel Side Expander, Oxid Side Preburner
Nominal Chamber Pressure	1,746
Expansion Ratio	700.00
TVC Method	Differential Throttling

Dimensions

Maximum Length (inches)	87.70
Maximum Width (inches)	136.00
Engine Mass (lbm)	1,048.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	15,393	30,000
Maximum		
Minimum		

March 13, 1993

Engine Performance 1

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid — Chemical

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

	Sea Level	Vacuum
Nominal	15,393	30,000
Maximum		
Minimum		

Thrust data in units of lbf

Throttle Ratio, Percent

	Sea Level	Vacuum
Maximum		
Minimum		

Specific Impulse Data

	Sea Level	Vacuum
@Nominal Thrust	246.28	480.00
@Maximum Thrust		
@Minimum Thrust		

Specific Impulse data in units of seconds

Engine Restarts

Design	3
Demonstrated	

Engine Starts

Design	3
Demonstrated	

Engine Reliability, sec

Design	2,200
Demonstrated	

Nozzle Data

Type	3 Bell Modules, Tubular Wall
Length (in)	87.70
Diameter (in)	35.57
Throat Area (sq. in)	2.84
Exit Area (sq. in)	1,988
Expansion Ratio	700.00

March 7, 1993

Engine Performance 2

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid   Chemical

Engine Mass (lbm)

Total Mass w/TVC	1,048.0
Total Mass wo/TVC	

TVC

Method	Differential Throttling
Mass (lbm)	
Max Gimbal Angle (deg)	3.0
Max Gimbal Rate (deg/s)	3.0

Engine Cycle

Type Hybrid: Fuel Side Expander, Oxid Side Preburner

Pressures

Oxidizer Turbopump

Min Pump Inlet	19.8
Turbine Inlet	4,843.0

Fuel Turbopump

Min Pump Inlet	17.2
Turbine Inlet	2,847.0

Pressures in psia

Envelope

Length

Nominal	87.7
Stowed	87.7
Extended	87.7
Maximum Gimbal	87.7

Diameter

Nozzle Exit	136.0
Maximum	136.0
Maximum Gimbal	136.0

Envelope Dimensions in inches

Engine Component Masses

Component Mass, lbm

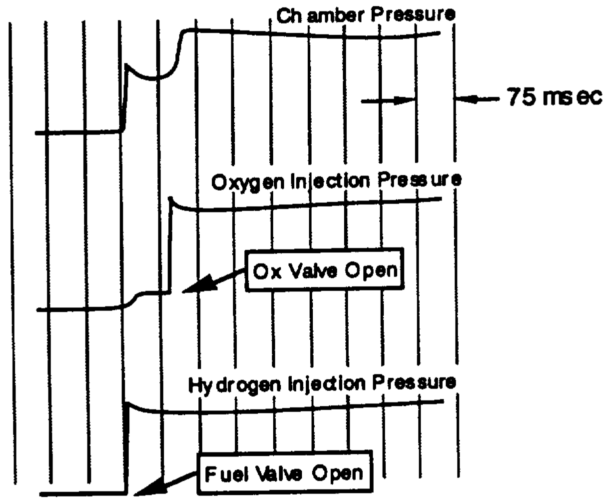
Thrust Chambers (3)	502	Preburner (2)	29
Turbomachinery – High Pressure (4)	102	GOX Heat Exchanger (2)	5
Turbomachinery – Low Pressure (4)	28	Controller	24
Propellant Valves, Ducts, Flanges	211	Harness and Sensors	13
External LH2 Feed Line	20	Ignition System	14
Thrust Mount Cap	3	Misc Components and Contingency	97

March 13, 1993

Start-Up/Shutdown Sequences

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

StartUp Sequence



Shutdown Sequence

March 7, 1993

Start-Up/Shutdown Profiles

Engine Name: Integrated Modular Engine

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

March 7, 1993

Interfaces

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid Chemical

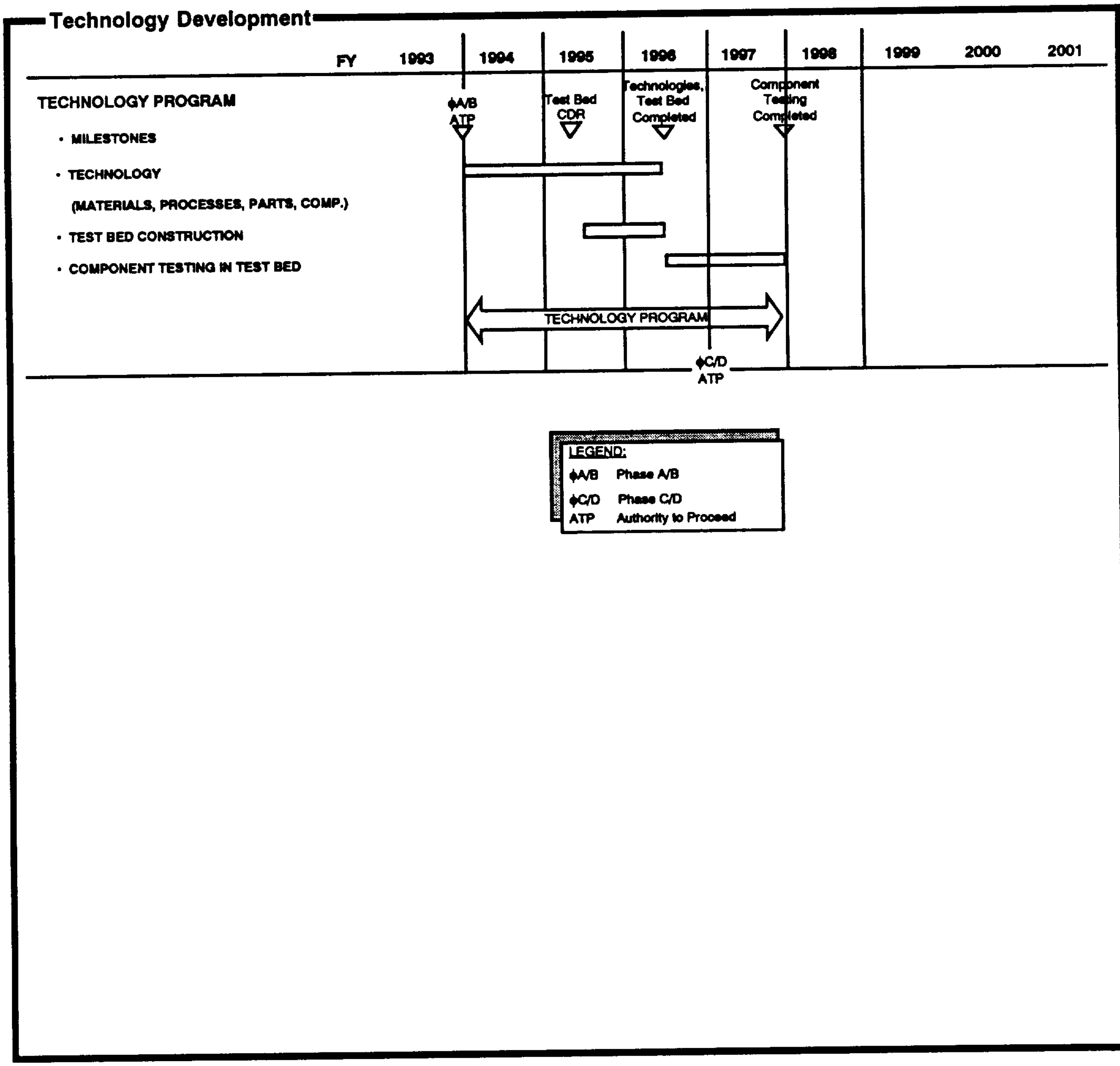
Interfaces

March 13, 1993

Technology Development

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid Chemical



March 7, 1993

Advanced Development Plan

Engine Name: Integrated Modular Engine

Class of Engine: Cryogenic Liquid Chemical

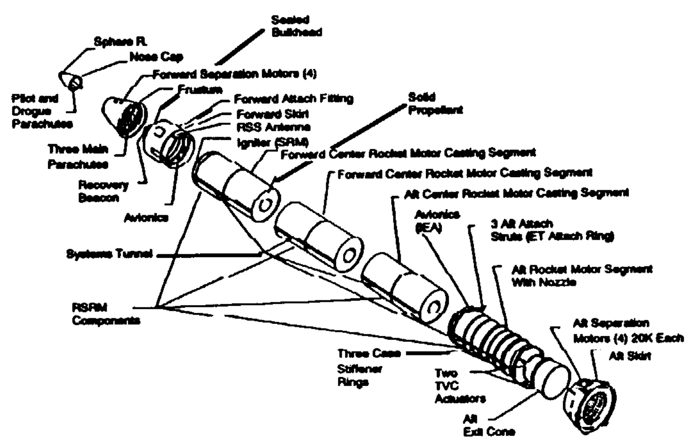
Advanced Development Plan

Figure 81.

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

TA3–0318

RSRM Propulsion System



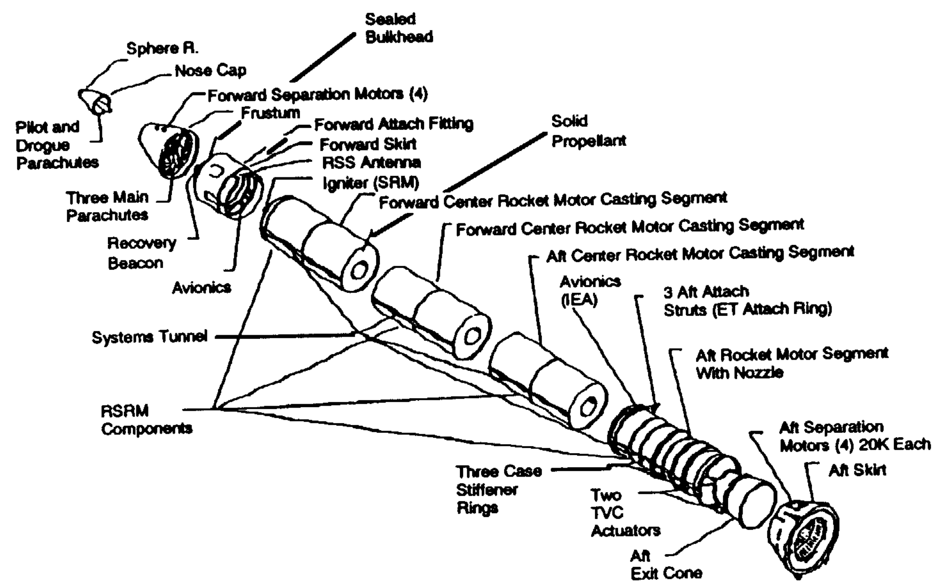
• Nominal Thrust (lbf)	
• Sea Level	2,146,371
• Vacuum	2,405,000
• Specific Impulse (sec)	
• Sea Level	238.7
• Vacuum	267.5
• Chamber Pressure (psia)	612.1
• Action Time	123.4
• Expansion Ratio	7.72
• Length (in)	1,513.4
• Weight (lbm)	1,255,979

3/7/93

Advanced Propulsion Subsystem Concepts Database

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel — Chemical



February 14, 1993

Background Information

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel | Chemical

Background

The original design and development of the SRM occurred during the mid-1970s and the first shuttle flight was in April 1981. Modifications were made to increase the performance in the early 1980s with the design referred to as the high performance motor (HPM). The final configuration of the HPM was first launched on the shuttle in August of 1983 (STS-8). The design presented here commenced in mid-1986 and is referred to as the RSRM. It first flew in 1988.

Marshall Space Flight Center (MSFC) has the overall management responsibility for the design and procurement of the solid rocket boosters (SRB). Thiokol Space Operations is the contractor responsible for the development and production of the SRMs, the major component of the SRB. United Space Boosters, Inc. (USBI), Sunnyvale, California, has responsibility for the SRB aft and forward skirt refurbishment and assembly, USBI also supplies systems tunnel floor plates, tunnel covers, and external tank (ET) attach ring, while the joint venture of Lockheed Space Operations Company (composed of Lockheed, Thiokol, and Grumman) has the contract for the SRM and SRB assembly, checkout, launch, recovery, and disassembly.

The two SRMs on the Space Shuttle provide the main thrust to lift the vehicle off the pad and up to an altitude of about 150,000 ft, 24 nmi (28 mi). On the pad, the two SRBs support the entire weight of the ET and orbiter and transmit the weight load through their structure to the mobile launch platform. Each RSRM booster has a thrust (sea level) of 2.9 Mlb at launch. They are ignited after the three shuttle main engines total thrust level is verified. The two SRMs provide 71.4 percent of the thrust at liftoff and accelerate the shuttle to approximately 3,100 mph before separating from the remainder of the shuttle launch vehicle. SRB apogee occurs 75 sec after SRB separation, at an altitude of 220,000 ft, 35 nmi (41 mi) down range. SRB impact occurs in the ocean approximately 122 nmi (141 mi) down range.

The SRMs are the largest solid propellant motors ever flown and the first designed for reuse. Each is 126.11 ft (1,513.38 in.) long and 12.16 ft (146.08 in.) in diameter. At launch, each weighs 1,255,978 lb of which 88 percent, 1,107.168 lb, is propellant. The boosters are designed to be used 20 times.

Primary elements of each booster are the motor (including case, propellant, igniter, and nozzle), structure, separation systems, operational flight instrumentation, recovery avionics, pyrotechnics, deceleration system, thrust vector control system, and range safety destruct system.

Each booster is attached to the ET at the SRB's aft frame by two lateral struts and a diagonal strut. The forward end of each SRB is attached to the ET at the forward end of the SRB forward skirt. On the launch pad, each booster also is attached to the mobile launch platform at the aft skirt by four bolts which are severed by small explosives at liftoff.

The propellant mixture in each SRB motor consists of ammonium perchlorate (oxidizer, approximately 69.7 percent by weight), aluminum (fuel, 16 percent), iron oxide (a burn rate catalyst, approximately 0.3 percent), a polymer (a binder that holds the mixture together, 12.04 percent), and an epoxy curing agent (1.96 percent). The propellant is molded into an 11-point star-shaped perforation in the forward portion of the forward segment that transitions into a cylindrical perforation (CP) grain in the aft portion of the forward segment. Each of the three aft segments have aft tapered CP grains. This configuration provides high thrust at ignition, then reduces the thrust by approximately one-third, 20 sec after liftoff to prevent overstressing of the vehicle during maximum dynamic pressure (Max Q).

Each RSRM is made up of four solid rocket motor casting segments. The segmented design provides maximum flexibility in RSRM fabrication, transportation, and handling. Each segment is shipped to the launch site on a heavy duty railcar with a specially built cover.

The nozzle expansion ratio of each booster is 7.72:1. The moveable nozzle is gimbaled for thrust vector control (TVC) direction. Each SRB has its own redundant auxiliary power units and hydraulic pumps. The omnidirectional gimbaling capability is 8 deg. Each nozzle has a carbon cloth phenolic liner which erodes and chars during firing. The nozzle is a convergent-divergent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism.

The cone-shaped aft skirt reacts the aft loads between the SRB and the mobile launch platform. Eight separation motors, four mounted on the aft skirt and four mounted on the forward skirt provide the thrust and directional control to clear the SRBs from the orbiter and external tank after booster separation. The aft skirt contained avionics and TVC system which consists of two auxiliary power units, hydraulic pumps, and hydraulic system.

Comments

References

Source: Design Data Book (DDB) for Space Shuttle Redesigned Solid Rocket Motor (RSRM) – (TWR-16881)

Date: 11/01/89

Entered by: Daniel Levack

March 30, 1993

Propulsion System General Data

Creation Date	Modification Date	Record Number
8/31/92	3/29/93	9

Engine Name	Space Shuttle Redesigned Solid Rocket Motor	
Class of Engine	Solid Fuel	Chemical
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	RSRM	
Application	ETO	
Manufacturer	Thiokol	
Program Status	Operational	
Manrated	Yes	
IOC/Date Studied (Month/Year)	1988	
Mixture Ratio – Engine/ Thrust Chamber		

Propellants

Oxidizer	AP
Fuel	Aluminum Powder

Engine Design Life (Flights)	20
Restart Capability	No
Engine Cycle	
Nominal Chamber Pressure	612
Expansion Ratio	7.72
TVC Method	Gimbal

Dimensions

Maximum Length (inches)	1,513.38
Maximum Width (inches)	152.60
Engine Mass (lbm)	1,255,979.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	2,146,371	2,405,000
Maximum		
Minimum		

February 14, 1993

Motor Performance 1

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel Chemical

Propellant Composition

Material	Weight. Percent	Function
AP	69.7	Oxidizer
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, lbf

	Sea Level	Vacuum
Maximum Expected Operating	3,348,371	3,607,000
Maximum Operating	3,055,371	3,314,000
Burn Time Average	2,337,371	2,596,000
Action Time Average	2,146,371	2,405,000

Impulse, lbf-sec

	Sea Level	Vacuum
Burn Time	260,850,636	289,713,600
Action Time	264,862,217	296,777,000

Throttle Ratio

	Sea Level	Vacuum
Maximum		
Minimum		

Specific Impulse, sec-lbf/lbm

	Sea Level	Vacuum
Burn Time Avg		
Action Time Avg	238.73	267.50

Nozzle Data

Type	Bell – carbon phenolic ablative
Length (in)	178.75
Diameter (in)	149.67
Throat Area (sq. in)	2,278
Expansion Ratio	7.72
Submergence Ratio, percent	19

February 22, 1993

Motor Performance 2

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel — Chemical

Engine Mass (lbm)

Total Mass w/TVC	1,255,979
Total Mass wo/TVC	

TVC

Method	Gimbal
Mass (lbm)	
Max Gimbal Angle (deg)	8.0
Max Gimbal Rate (deg/s)	

Envelope

Length

Nominal	1513.38
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	
Maximum	152.6
Maximum Gimbal	

Envelope Dimensions in inches

Engine Component Masses

Weights, lbm	
Case	98,010
Insulation	20,191
Liner	1,347
Inhibitor	1,800
Igniter Inerts	485
Systems Tunnel	533
Instrumentation	80
Joint Heater Cable	24
Nozzle-to-Forward Section	17,524

Propellant	
Motor	1,107,035
Igniter	134
External Insulation	637
Shipping Segment	1,247,802
Items Shipped Separate	
Exit Cone*	6,193
Separation System	231
Stiffener Rings*	908
Joint Heater System	348
Exit Cone Installation	22
S&A Installation	15
RSRM Installation	439
System Tunnel Joints	21
Total	1,255,979

* With external insulation installed

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

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel Chemical

StartUp Sequence

Expected Nominal Operational RSRM Sequence

Time (sec)	Activity
-6.0	SSME Ignition
0.0	Fire signal to ignition system initiators
0.23	RSRM liftoff at 563.5 psia chamber pressure
21.5	Burnout of star section web in forward segment
78.5	Burnout of aft tapered section in aft segment commences
111.6	Burnout of aft tapered section in aft segment complete and tailoff commences
122.2	Separation sequence initiated; chamber pressure is 50 psia
125.9	RSRM physically separated (approximately)
127.1	Propellant burnout
396.2	Nozzle extension is severed and jettisoned
405.5	Splashdown

Shutdown Sequence

February 20, 1993

Start-Up/Shutdown Profiles

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel

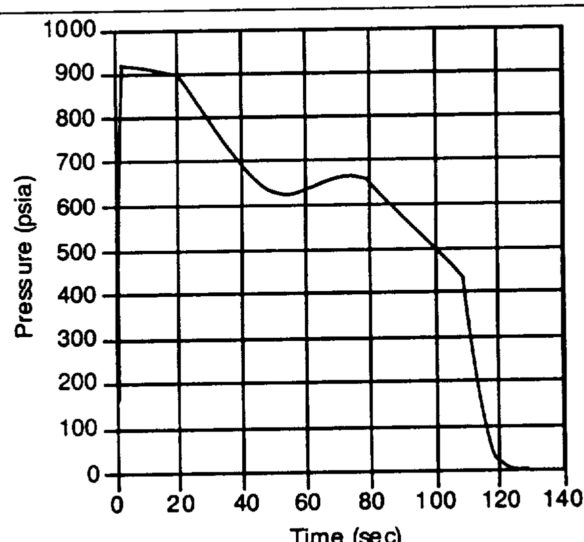
Chemical

Isp Profile

(Nominal 60 °F and 0.368 ips Burn Rate)

Time seconds	Headend Pressure psia	Nozzle Stagnation Pressure psia	Vacuum Thrust lbf	Total Mass Flow Rate lbm/sec	Specific Impluse sec-lbf/lbm
1.0	910.93	817.85	3,177,675	11,848.3	268.20
2.0	896.99	812.63	3,162,380	11,783.2	268.38
4.0	890.58	818.74	3,196,184	11,891.1	268.79
8.0	896.58	840.37	3,298,001	12,243.4	269.37
12.0	887.95	840.91	3,314,362	12,291.9	269.64
16.0	879.63	839.04	3,321,176	12,306.2	269.90
20.0	873.86	837.88	3,330,801	12,328.8	270.16
24.0	832.69	802.25	3,198,860	11,844.9	270.06
28.0	778.24	753.37	3,009,303	11,160.2	269.65
32.0	735.86	715.26	2,862,180	10,630.1	269.25
36.0	699.16	681.96	2,733,822	10,167.9	268.87
40.0	664.90	650.61	2,612,666	9,731.1	268.49
44.0	638.28	626.28	2,519,380	9,396.4	268.12
48.0	615.63	606.40	2,439,656	9,111.0	267.77
52.0	594.16	585.27	2,362,641	8,835.1	267.42
56.0	600.75	592.61	2,396,414	8,967.5	267.23
60.0	610.67	603.19	2,443,418	9,149.3	267.06
64.0	622.55	615.64	2,498,140	9,360.1	266.89
68.0	629.32	622.96	2,532,199	9,494.3	266.71
72.0	635.40	629.56	2,563,350	9,617.9	266.52
76.0	637.20	631.84	2,577,041	9,676.6	266.32
80.0	624.26	619.37	2,530,472	9,510.6	266.07
84.0	597.97	593.55	2,430,344	9,138.5	265.95
88.0	565.47	561.54	2,304,312	8,669.4	265.80
92.0	539.01	536.47	2,202,168	8,289.2	265.67
96.0	515.03	511.87	2,109,693	7,944.9	265.54
100.0	489.72	486.88	2,011,079	7,577.5	265.40
104.0	459.83	457.32	1,891,307	7,133.3	265.14
108.0	426.36	424.15	1,756,306	6,631.5	264.84
112.0	367.07	365.03	1,506,404	5,727.9	262.99
114.0	264.85	263.61	1,081,918	4,147.6	260.85
116.0	170.55	169.74	670,474	2,680.9	250.09
118.0	109.72	109.20	421,968	1,731.3	243.73
118.4	99.75	99.28	383,288	1,575.3	243.31
118.8	90.37	89.94	346,920	1,428.3	242.89
119.2	82.02	81.64	314,600	1,297.5	242.47
119.6	73.60	73.26	282,061	1,165.4	242.03
120.0	65.33	65.02	250,136	1,035.5	241.57
120.4	57.39	57.12	222,727	910.5	244.61
120.8	50.15	49.91	197,245	796.5	247.64
121.2	41.20	41.00	164,191	655.3	250.54
121.6	32.59	32.43	131,574	519.3	253.36
122.0	25.39	25.27	103,860	405.5	256.14
122.4	19.63	19.53	81,296	314.0	258.88

Pressure Profile



February 20, 1993

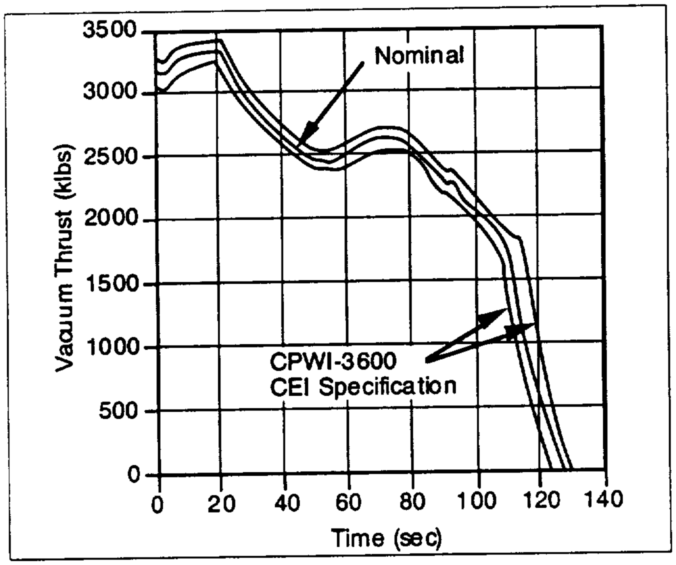
Start-Up/Shutdown Profiles

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel

Chemical

Thrust Profile



Flowrate Profile

(Nominal 60 °F and 0.368 ips Burn Rate)

Time seconds	Headend Pressure psia	Nozzle Stagnation Pressure psia	Vacuum Thrust lbf	Total Mass Flow Rate lbm/sec	Specific Impluse sec-lbf/lbm
1.0	910.93	817.86	3,177,675	11,848.3	268.20
2.0	896.99	812.63	3,162,380	11,783.2	268.38
4.0	890.58	818.74	3,196,184	11,891.1	268.79
8.0	896.58	840.37	3,298,001	12,243.4	269.37
12.0	887.95	840.91	3,314,362	12,291.9	269.64
16.0	879.63	839.04	3,321,175	12,306.2	269.90
20.0	873.85	837.88	3,330,801	12,328.8	270.16
24.0	832.69	802.25	3,198,860	11,844.9	270.06
28.0	778.24	753.37	3,009,303	11,160.2	269.65
32.0	736.86	716.26	2,862,160	10,630.1	269.25
36.0	699.16	681.96	2,733,822	10,167.9	268.87
40.0	664.90	650.61	2,612,666	9,731.1	268.49
44.0	638.28	626.28	2,519,380	9,396.4	268.12
48.0	615.63	606.40	2,439,656	9,111.0	267.77
52.0	594.16	586.27	2,362,641	8,836.1	267.42
56.0	600.75	592.61	2,396,414	8,967.5	267.23
60.0	610.67	603.19	2,443,418	9,149.3	267.06
64.0	622.55	615.64	2,498,140	9,360.1	266.89
68.0	629.32	622.96	2,532,199	9,494.3	266.71
72.0	635.40	629.55	2,563,350	9,617.9	266.52
76.0	637.20	631.84	2,577,041	9,676.6	266.32
80.0	624.26	619.37	2,530,472	9,510.6	266.07

(Nominal 60 °F and 0.368 ips Burn Rate)

Time seconds	Headend Pressure psia	Nozzle Stagnation Pressure psia	Vacuum Thrust lbf	Total Mass Flow Rate lbm/sec	Specific Impluse sec-lbf/lbm
84.0	597.97	593.55	2,430,344	9,138.5	265.95
88.0	565.47	561.54	2,304,312	8,669.4	265.80
92.0	539.01	535.47	2,202,168	8,289.2	265.67
96.0	515.03	511.87	2,109,693	7,944.9	265.54
100.0	489.72	486.88	2,011,079	7,577.5	265.40
104.0	459.83	457.32	1,891,307	7,133.3	265.14
108.0	426.35	424.15	1,756,306	6,631.5	264.84
112.0	367.07	365.03	1,506,404	5,727.9	262.99
114.0	264.86	263.61	1,081,918	4,147.6	260.85
116.0	170.56	169.74	670,474	2,680.9	250.09
118.0	109.72	109.20	421,968	1,731.3	243.73
118.4	99.75	99.28	383,286	1,575.3	243.31
118.8	90.37	89.94	346,920	1,428.3	242.89
119.2	82.02	81.64	314,600	1,297.5	242.47
119.6	73.60	73.26	282,061	1,165.4	242.03
120.0	65.33	66.02	250,136	1,036.5	241.57
120.4	57.39	57.12	222,727	910.5	244.61
120.8	50.15	49.91	197,245	796.5	247.64
121.2	41.20	41.00	164,191	655.3	250.54
121.6	32.59	32.43	131,574	519.3	253.36
122.0	25.39	25.27	103,860	406.5	256.14
122.4	19.63	19.53	81,296	314.0	258.88

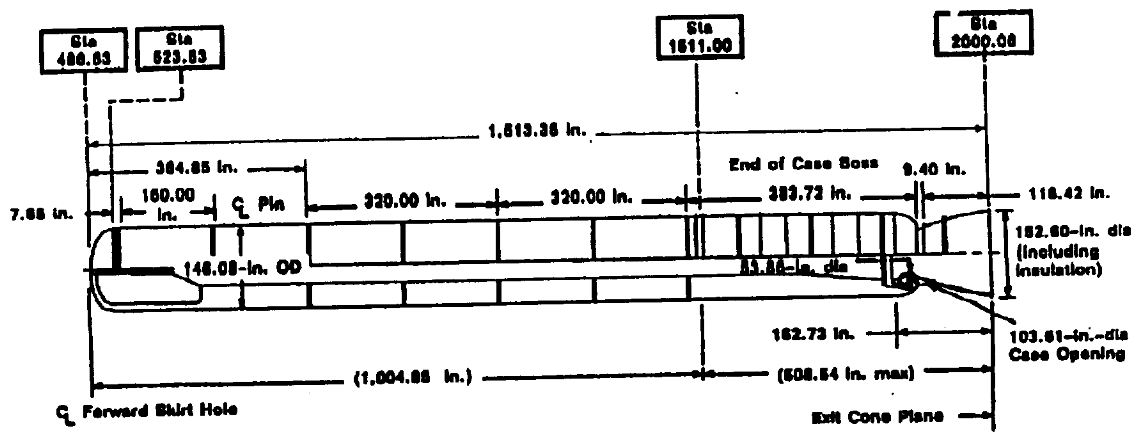
February 14, 1993

Interfaces

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: Solid Fuel Chemical

Interfaces



February 14, 1993

Technology Development

Engine Name: Space Shuttle Redesigned Solid Rocket Motor

Class of Engine: 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

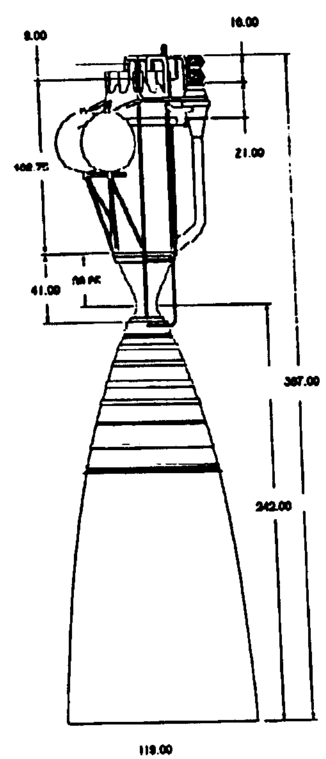
Advanced Development Plan

Figure 82.

Output for NERVA Derived Nuclear Thermal Rocket Propulsion System

TA3–0314

NTRND Propulsion System

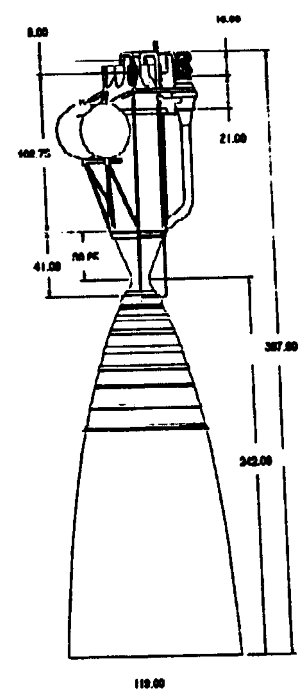


• Nominal Thrust (lbf)	
• Vacuum	50,000
• Specific Impulse (sec)	
• Vacuum	852.0
• Chamber Pressure (psia) (Nozzle Stagnation)	784
• Fuel	Liquid Hydrogen
• Expansion Ratio	300
• Length (in)	387.0
• Diameter (in)	119.0
• Weight (lbm)	9,570

3/27/93

Advanced Propulsion Subsystem Concepts Database

Engine Name:	**Nuclear Thermal Rocket, NERVA Derivative**	
Class of Engine:	**Nuclear Thermal**	**Fission Reactor**

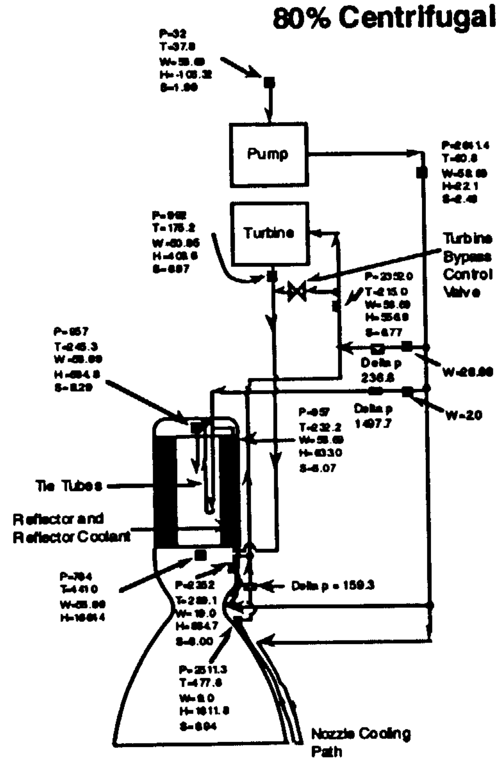


Advanced Propulsion Subsystem Concepts Database

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal — Fission Reactor

50K NTR, Expander Cycle, Pc = 784 Psia, 80% Centrifugal Pump Efficiency



DESIGN VALUES:

PUMP FLOWRATE	59.89	LB/SEC
PUMP DISCHARGE PRESSURE	2641	PSIA
PUMP EFFICIENCY	79.71	%
PUMP STAGES	2	--
TURBOPUMP RPM	55,000	RPM
TURBOPUMP POWER	10,665	HP
TURBINE INLET TEMP	215.0	R
TURBINE EFFICIENCY	81.82	%
TURBINE STAGES	2	--
TURBINE PRESSURE RATIO	2371	--
TURBINE FLOW RATE	50.85	LB/SEC
REACTOR/ENGINE THERMAL POWER	1,004.9	MW
FUEL ELEMENT TRANSFERRED POWER	987.9	MW
CORE THERMAL POWER (FUEL ELEM+TIE TUBE)	992.4	MW
ENGINE THRUST	50,000	LBF
NOZZLE CHAMBER TEMPERATURE	4410	R
CHAMBER PRESSURE (NOZZLE STAGNATION)	784	PSIA
NOZZLE EXPANSION AREA RATIO	300:1	--
NOZZLE PERCENT LENGTH	117	%
VACUUM SPECIFIC IMPULSE (DELIVERED)	852.01	SEC

Heatloads are as follows:	Nozzle (converging, coated):	16.89 MW
	Nozzle (diverging):	15.09 MW
	Reflector:	12.50 MW
	Tie-Tubes:	4.50 MW

P = PSIA
T = DEG R
W = LB/S
H = BTU/LB
S = BTU/LB-R

02-19-93 TT

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

Source: 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

Creation Date	Modification Date	Record Number
3/7/93	3/30/93	10

Engine Name	Nuclear Thermal Rocket, NERVA Derivative	
Class of Engine	Nuclear Thermal	Fission Reactor
Propulsion Type	Thermodynamic Expansion of Hot Gas	
Acronym	NTRND	
Application	Space Transfer	
Manufacturer	Conceptual Engine (Rocketdyne Study)	
Program Status	Conceptual Studies for NASA-LeRC	
Manrated	Current plans are to manrate this system	
IOC/Date Studied (Month/Year)	2-19-93	
Mixture Ratio – Engine/ Thrust Chamber		

Propellants

Oxidizer	None
Fuel	Liquid Hydrogen

Engine Design Life (Flights)	1
Restart Capability	10
Engine Cycle	Topping
Nominal Chamber Pressure	784
Expansion Ratio	300.00
TVC Method	Gimbal

Dimensions

Maximum Length (inches)	387.00
Maximum Width (inches)	119.00
Engine Mass (lbm)	9,570.00

Engine Thrust Data, lbf

	Sea Level	Vacuum
Nominal	-110,757	50,000
Maximum		
Minimum		

March 7, 1993

Engine Performance 1

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal — Fission Reactor

Fuel	Liquid Hydrogen
Nominal Chamber Pressure (psia)	784.00
Expansion Ratio	300.00
Engine Design Life (Flights)	1

Engine Restarts

Design	9
Demonstrated	

Engine Thrust Data

	Vacuum
Nominal	50,000.00
Maximum	
Minimum	

Thrust data in units of lbf

Engine Reliability, sec

Design	16,200
Demonstrated	

Throttle Ratio

	Vacuum
Maximum	
Minimum	

Nozzle Data

Type	Bell, Slotted Tubular Wall/Radiation
Length (in)	242.00
Diameter (sq. in)	118.00
Throat Area (sq. in)	36.43
Exit Area (sq. in)	10,927.8
Expansion Ratio	300.00

Specific Impulse Data

	Vacuum
@Nominal Thrust	852.00
@Maximum Thrust	
@Minimum Thrust	

Specific impulse data in units of seconds

March 7, 1993

Engine Performance 2

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal — Fission Reactor

Engine Mass (lbm)

Total Mass w/TVC	9,570.0
Total Mass wo/TVC	9,530.0

TVC

Method	Gimbal
Mass (lbm)	40.0
Max Gimbal Angle (deg)	4.0
Max Gimbal Rate (deg/s)	2.0

Engine Cycle

Type: Topping

Pressures, psia

Fuel Turbopump

Min Pump Inlet	32
Turbine Inlet	2,350.0

Envelope

Length

Nominal	387
Stowed	
Extended	
Maximum Gimbal	

Diameter

Nozzle Exit	118.0
Maximum	119.0
Maximum Gimbal	174.0

Envelope Dimensions in inches

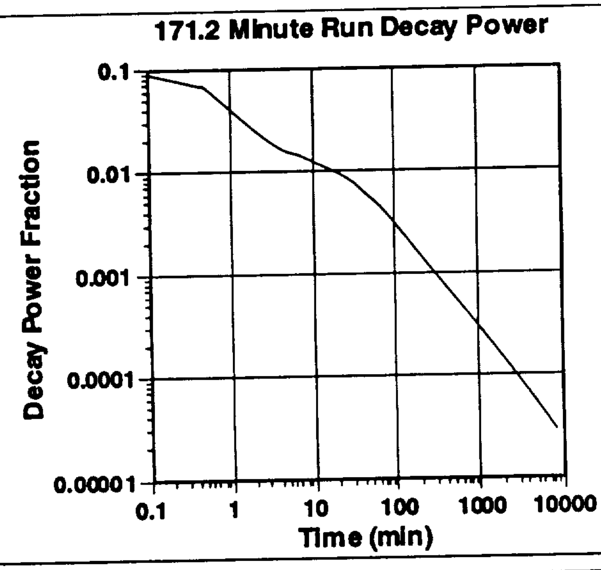
Engine Component Masses, lbm

Component Mass, lbm	
Reactor Assembly (Includes Pressure Vessel and Internal Shield)	7,310
Chamber/Nozzle	1,470
Turbopump	230
Lines and Controls	560

March 13, 1993 **Start-Up/Shutdown Profiles**

Engine Name:	Nuclear Thermal Rocket, NERVA Derivative
Class of Engine:	Nuclear Thermal — Fission Reactor

Thrust Profile



Flowrate Profile

March 7, 1993

Start-Up/Shutdown Profiles

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal — Fission Reactor

Thrust Profile

Flowrate Profile

March 7, 1993

Start-Up/Shutdown Profiles

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal — Fission Reactor

Isp Profile

Impulse Profile

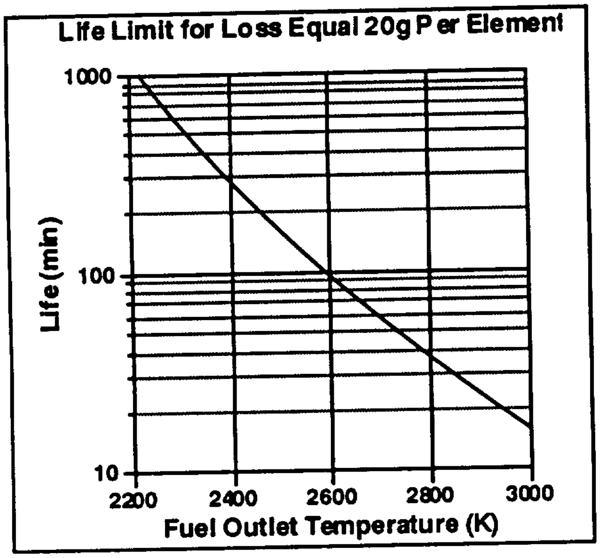
March 13, 1993

Interfaces

Engine Name: Nuclear Thermal Rocket, NERVA Derivative

Class of Engine: Nuclear Thermal — Fission Reactor

Interfaces



March 7, 1993

Technology Development

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

Technology Development

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.

Field Definitions of the File
"Prop System DB"

TA3–0425

Field Name	Field Type	Formula / Entry Option
Record Number	Number	Serial Number with Current Value: "11" Increment: "1"
Creation Date	Date	Auto-enter the: "Creation Date" Prevent data that is automatically entered from being changed.
Modification Date	Date	Auto-enter the: "Modification Date" Prevent data that is automatically entered from being changed.
Propulsion Type	Text	
Class of Engine	Text	Value List: Cryogenic Liquid Hydrocarbon Liquid Storable Liquid Solid Fuel Hybrid SRB Metalized Fuels Nuclear Thermal Nuclear Electric Combined Nuclear 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) 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	
Nom Sea Level Thrust	Calculation (Number)	= If (Nom Vac Thrust > 0, Nom Vac Thrust - 11.545353 * NozzleDiameter ^ 2, " ")
Nom Vac Thrust	Number	
Max Sea Level Thrust	Calculation (Number)	= If (Max Vac Thrust > 0, Max Vac Thrust - 11.545353 * NozzleDiameter ^ 2, " ")
Max Vac Thrust	Number	
Min Sea Level Thrust	Calculation (Number)	= If (Min Vac Thrust > 0, Min Vac Thrust - 11.545353 * NozzleDiameter ^ 2, " ")
Min Vac Thrust	Number	
Isp Sea Level	Calculation (Number)	= Isp SL Nom Thrust
Isp Vacuum	Calculation (Number)	= Isp Vac Nom Thrust
Engine Background	Text	
Background Comments	Text	
Reference Source	Text	
Date of Reference	Text	
Entered by	Text	

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 Thrust / Nom Vac Thrust, " ")
Isp Vac Nom Thrust	Number	
Isp SL Max Thrust	Calculation (Number)	= If (Max Vac Thrust > 0, If (IspVacMaxThrust > 0, IspVacMaxThrust * Max Sea Level Thrust / Max Vac Thrust, " ")," ")
IspVacMaxThrust	Number	
Isp SL Min Thrust	Calculation (Number)	= If (Min Vac Thrust > 0, If (Isp Vac Min Thrust > 0, Isp Vac Min Thrust * Min Sea Level Thrust / Min Vac Thrust, " "), " ")
Isp 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 Gimbal	Number	
Nozzle Exit Diameter	Number	
Maximum Diameter	Number	
Max Diameter Max Gimbal	Number	
Total Mass TVC	Number	
Total Mass w/o TVC	Number	
Start Up Sequence	Picture/Sound	
Shutdown Sequence	Picture/Sound	
Thrust Startup Profile	Picture/Sound	
Thrust Shutdown Profile	Picture/Sound	
Isp Startup Profile	Picture/Sound	

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)	= If(Class of Engine = "Cryogenic Liquid" OR Class of Engine = "Hydrocarbon Liquid" OR Class of Engine = "Storable Liquid", 17, If(Class of Engine = "Solid Fuel", 46, If(Class of Engine = "Hybrid SRB", 75, If(Class of Engine = "Nuclear Thermal" OR Class of Engine = "Nuclear Electric" OR Class of Engine = "Nuclear Electric", 104, If(Class of Engine = "Exotic",133,5)))))
Which Data Entry?	Calculation (Number)	= If(Class of Engine = "Cryogenic Liquid" OR Class of Engine = "Hydrocarbon Liquid" OR Class of Engine = "Storable Liquid", 8, If(Class of Engine = "Solid Fuel", 12, If(Class of Engine = "Hybrid SRB", 13, If(Class of Engine = "Nuclear Thermal" OR Class of Engine = "Nuclear Electric" OR Class of Engine = "Nuclear Electric", 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	Text	
Prop Weight Percent 6	Text	
Prop Weight Percent 7	Text	
Prop Function 1	Text	
Prop Function 2	Text	
Prop Function 3	Text	
Prop Function 4	Text	
Prop Function 5	Text	
Prop Function 6	Text	
Prop Function 7	Text	
Burn Rate	Number	

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 - 11.545353 *NozzleDiameter ^ 2, " ")
Max Exp Op Thrust SL	Calculation (Number)	= If (Max Exp Op Thrust Vac > 0, Max Exp Op Thrust Vac - 11.545353 * NozzleDiameter ^ 2," ")
Max Op Thrust SL	Calculation (Number)	= If (Max Op Thrust Vac > 0, Max Op Thrust Vac - 11.545353 * NozzleDiameter ^ 2, " ")
Burn Time Avg Thrust SL	Calculation (Number)	= If (Burn Time Avg Thrust Vac > 0, Burn Time Avg Thrust Vac - 11.545353 * NozzleDiameter ^ 2, " ")
Burn Time Impulse SL	Calculation (Number)	= If (Burn Time Avg Thrust SL > 0, Burn Time Avg Thrust SL * Burn Time, " ")
Action Time Impulse SL	Calculation (Number)	= If (Action Time Avg F SL > 0, Action Time Avg F SL * Action Time, " ")
Press Startup 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, Burn Time Avg Isp Vac * Burn Time Avg Thrust SL / Burn Time Avg 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 > 0,Action Time Avg Isp Vac * Action Time Avg F SL / Action Time Avg F Vac," ")," ")
Action Time Avg Isp Vac	Calculation (Number)	= Isp Vac Nom Thrust
Reactor Type	Text	
Fuel Type	Text	
Max Fuel Temp R	Number	
Propellant Temp R	Number	
Impulse Startup Profile	Picture/Sound	
Impulse Shutdown Profile	Picture/Sound	

Figure 84.

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

TA3–0426

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

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 Name" matches "Engine Name" If no match, copy: "" ""
Action Time Avg F Vac	Number	Lookup: "Action Time Avg F Vac" in "Prop System DB" when "Engine Name" matches "Engine Name" If no match, copy: "" ""
Action Time Avg Isp SL	Number	Lookup: "Action Time Avg Isp SL" in "Prop System DB" when "Engine Name" matches "Engine Name" If no match, copy: "" ""
Action Time Avg Isp Vac	Number	Lookup: "Action Time Avg Isp Vac" in "Prop System DB" when "Engine Name" matches "Engine Name" If no match, copy: "" ""
Action Time Avg Press	Number	Lookup: "Action Time Avg Press" in "Prop System DB" when "Engine Name" matches "Engine Name" If no match, copy: "" ""
Action Time	Number	Lookup: "Action Time" in "Prop System DB" when "Engine Name" matches "Engine Name" If no match, copy: "" ""
Fuel	Text	Lookup: "Fuel" in "Prop System DB" when "Engine Name" matches "Engine Name" If no match, copy: "" ""

Appendix

Use of Fortran Externals with Resolve™ and Excel™

TA3–0319

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

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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.'
```

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
c
c     a = SNGL(args(1))                !from real*8 to real*4
c     b = IDINT(args(2))               !from real*8 to integer*4
c     c = IIDINT(args(3))              !from real*8 to Integer*2
c     args(4) = DBLE(d)                !any to real*8

      arg1 = args(1)               !This is the setting of the subroutine
      arg2 = args(2)               !arguments. Add more statements as
      arg3 = args(3)               !as needed.
      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)

      revals(1) = arg6             !This sets the output array
      revals(2) = arg7             !with the appropriate
      revals(3) = arg8             !subroutine arguments.
      revals(4) = arg9
      revals(5) = arg10
      revals(6) = arg11
      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 yoursub.f
#   Created:    Friday, March 5, 1993 2:21:05 PM
```

```
OBJECTS = CHookc.c.o FHook.f.o SetUp.f.o yoursub.f.o

ResExtern ƒƒ ResExtern.make {OBJECTS}
   Link -t RsTl -c Rslv ∂
         {OBJECTS} ∂
         "{Libraries}"Runtime.o ∂
         "{Libraries}"Interface.o ∂
         "{FLibraries}"FORTRANlib.o ∂
         "{FLibraries}"IntrinsicLib.o ∂
         -o ResExtern
FHook.f.o ƒ ResExtern.make FHook.f
    FORTRAN FHook.f -opt=1
SetUp.f.o ƒ ResExtern.make SetUp.f
    FORTRAN SetUp.f -opt=1
yoursub.f.o ƒ 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 `RsTl`
   Change the '????' to `Rslv`
   Remove the lines:
   `Echo "Include ∂"{FLibraries}Fresources.r∂";" >`
   `"{FLibraries}Resource.inc"`
   `Rez "{FLibraries}Resource.inc" -a -m -o` "*filename.*"
   `FSIZE` "*filename.*"
   Remove the following libraries:
   `"{FLibraries}"FSANELib.o ∂`
   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 Funcname.

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.**

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 RsTl. 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()
       IF(y = 61)
              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

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

!!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)

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
c
c      a = SNGL(args(1))             !from real*8 to real*4
c      b = IDINT(args(2))            !from real*8 to integer*4
c      c = IIDINT(args(3))           !from real*8 to Integer*2
c      args(4) = DBLE(d)             !any to real*8

       arg1 = args(1)              !This is the setting of the subroutine
       arg2 = args(2)              !arguments. Add more statements as
       arg3 = args(3)              !as needed.
```

```
      arg4 = args(4)
      arg5 = args(5)

c  Calling your subroutine.  Change this call as necessary to match
c  your subroutine.

      if(SysEnvRecPtr^.hasFPU) then

c  Use FPU
          call yoursub81(arg1,arg2,arg3,arg4,arg5,
     &               arg6,arg7,arg8,arg9,arg10,arg11,arg12)

      else

c  NO FPU
          call yoursub(arg1,arg2,arg3,arg4,arg5,
     &               arg6,arg7,arg8,arg9,arg10,arg11,arg12)
      end if

      revals(1) = arg6            !This sets the output array
      revals(2) = arg7            !with the appropriate
      revals(3) = arg8            !subroutine arguments.
      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:

```
#   File:       ResExtern.make
#   Target:     ResExtern
#   Sources:    FHook.f SetUp.f yoursub.f
#   Created:    Friday, March 5, 1993 2:21:05 PM

OBJECTS = CHookc.c.o FHook.f.o SetUp.f.o yoursub.f.o  yoursub81.f.o

ResExtern ƒƒ ResExtern.make {OBJECTS}
      Link -t RsTl -c Rslv ∂
            {OBJECTS} ∂
            "{Libraries}"Runtime.o ∂
            "{Libraries}"Interface.o ∂
            "{FLibraries}"FORTRANlib.o ∂
            "{FLibraries}"IntrinsicLib.o ∂
            -o ResExtern
FHook.f.o ƒ ResExtern.make FHook.f
```

```
        FORTRAN FHook.f -opt=1
SetUp.f.o ƒ ResExtern.make SetUp.f
        FORTRAN SetUp.f -opt=1
yoursub.f.o ƒ ResExtern.make yoursub.f
        FORTRAN yoursub.f -opt=1
yoursub81.f.o ƒ 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**.

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

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Date: February 10, 1993

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. Funcname 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, 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 *-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
INQUIRE	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
c
c     a = SNGL(args(1))             !from real*8 to real*4
c     b = IDINT(args(2))            !from real*8 to integer*4
c     c = IIDINT(args(3))           !from real*8 to Integer*2
c     args(4) = DBLE(d)             !any to real*8

      arg1 = args(1)             !This is the setting of the subroutine
      arg2 = args(2)             !arguments. Add more statements as
      arg3 = args(3)             !as needed.
      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)

      revals(1) = arg6           !This sets the output array
      revals(2) = arg7           !with the appropriate
      revals(3) = arg8           !subroutine arguments.
      revals(4) = arg9
      revals(5) = arg10
      revals(6) = arg11
      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
#    Created:    Monday, January 18, 1993 9:16:12 AM


OBJECTS = CHookc.c.o FHook.f.o SetUp.f.o yoursub.f.o


FFLAGS = -q -k -N14

ResExtern ƒƒ ResExtern.make {OBJECTS}
      Link -t 'RsTl' -c Rslv ∂
            {OBJECTS} ∂
            "{Libraries}"Runtime.o ∂
            "{Libraries}"Interface.o ∂
            "{FLibraries}"f77math.o ∂
            -o ResExtern
FHook.f.o ƒ ResExtern.make FHook.f
       f77compiler {FFLAGS} FHook.f
SetUp.f.o ƒ ResExtern.make SetUp.f
       f77compiler {FFLAGS} SetUp.f
yoursub.f.o ƒ ResExtern.make yoursub.f
       f77compiler {FFLAGS} your.sub.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 `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 ƒƒ filename*.make Duplicate -r -y
   "{FLibraries}F77mrwe.o" *filename*
   Change the APPL to `'RsTl'`
   Change the '????' to `'Rslv'`

Remove -f -model far
Remove the following libraries:
"{FLibraries}"F77mrwe.o ∂
"{FLibraries}"frt0.o ∂
"{FLibraries}"f77io.o ∂
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.

STEP 6 Run **Build...** under the **MacFortran** 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 Funcname.

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 RsTl. 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()
      IF(y = 61)
            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.

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

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Date: August 12 1992

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).

STEP 1 Launch MPW

STEP 2 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 Excel.

```
ACCEPT          OPEN
BACKSPACE       PAUSE
CLOSE           PRINT
DECODE          READ
ENCODE          REWIND
ENDFILE         STOP
FORMAT          TYPE
INQUIRE         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 3 Create (**File, New**) an Excel to FORTRAN interface function. The following 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/          !This is the input list from Excel.
          INTEGER*2 row
          INTEGER*2 col
          REAL*8 ary(100)
      END STRUCTURE

      STRUCTURE /outlist/         !This is the output list from the
          INTEGER*2 row           !FORTRAN program.
          INTEGER*2 col
          REAL*8 ary(100)
      END STRUCTURE
```

```
      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
c     a = SNGL(ary(1))           !from real*8 to real*4
c     b = IDINT(ary(2))          !from real*8 to integer*4
c     c = IIDINT(ary(3))         !from real*8 to Integer*2
c     ary(4) = DBLE(d)           !any to real*8

      arg1 = in.ary(1)           !This is the setting of the subroutine
      arg2 = in.ary(2)           !arguments. Add more statements as
      arg3 = in.ary(3)           !as needed.

c  Calling your subroutine.  Change this call as necessary to match
c  your subroutine.

      call yoursub(arg1,arg2,arg3,arg4,arg5,arg6)

      out.row = 3                !This sets the worksheet area.
      out.col = 1                !Adjust as needed.

      out.ary(1) = arg4          !This sets the output array
      out.ary(2) = arg5          !with the appropriate
      out.ary(3) = arg6          !subroutine 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:

$$\texttt{ary(1)} = row_1,col_1$$
$$\texttt{ary(2)} = row_1,col_2$$
$$\vdots$$
$$\texttt{ary(m)} = row_1,col_m$$
$$\texttt{ary(m+1)} = row_2,col_1$$
$$\vdots$$
$$\texttt{ary(n*m)} = row_n,col_m$$

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:       xfunc.make
#   Target:     xfunc
#   Sources:    xfunc.f yoursub.f ...
#   Created:

#   Add to this OBJECTS list all necessary subroutines
OBJECTS = xfunc.f.o yoursub.f.o


FFLAGS = -q -N14 -k


xfunc ƒƒ xfunc.make {OBJECTS}
      Link -t XLLB -c XCEL -rt CODE=128 -m MAIN -sg main ∂
            {OBJECTS} ∂
#  This library list can be modified to remove unnecessary
#  libraries
            "{Libraries}"Runtime.o ∂
            "{Libraries}"Interface.o ∂
            "{FLibraries}"F77stubs.o ∂
            "{FLibraries}"frt0.o ∂
            "{FLibraries}"f77io.o ∂
            "{FLibraries}"f77math.o ∂
            -o xfunc
xfunc.f.o ƒ xfunc.make xfunc.f
       f77compiler {FFLAGS} xfunc.f
#  Repeat the next two lines for each subroutine and change
#  yoursub to each of the subroutine names
yoursub.f.o ƒ xfunc.make yoursub.f
       f77compiler {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 **XCEL**. (Note characters must be all upper case.)

5. In the box next to **Type** put **XLLB**. (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 **xfunc** 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 + ⌘ + p" will load the external function.

STEP 13 Save this Macro sheet as **load.xfunc** using **Save As...**

STEP 14 Press "option + ⌘ + p". This loads the external function.

STEP 15 Press " ⌘ + ` ". 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 consistency between names and arguments. Press "  + ` " 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 " + 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 18 Select **Define Name** under **Formula** menu
In the **Name:** box type auto_load
In the **Refers to:** box type **load.xfunc!load**
Click **Add**
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

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Thiokol Space Operations and Workingsolutionz Software were team members on this effort.

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13. ABSTRACT *(Maximum 200 words)*

The objective of this task was to produce a propulsion system database which is easy to use and modify while also being comprehensive in the level of detail available. Two separate databases were generated: one to provide parametric data using the Macintosh spreadsheet Resolve 1.1, and one to produce detailed data for fixed point design propulsion systems using the Macintosh database FileMaker Pro 2.0.

The parametric database has models for LOX/H_2 and LOX /RP liquid engines, solid rocket boosters using three different propellants, a hybrid rocket booster, and a NERVA derived nuclear thermal rocket engine. The fixed point database has extensive formatting and reporting options and contains data on the STME, F-1, F-1A, J-2, J-2S, SSME, RD-170, IME, RSRM, and a nuclear engine.

Further parametric models and specific engine data will be incorporated in the next year.

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