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16. Abstract

Hydrogen, RP-1, propane, and methane have been identified by propulsion technology studies as the most probable fuel candidates for the boost phase of future launch vehicles. The objective of this study was to determine the effects of booster engines using these fuels and coolant variations on representative future launch vehicles. An automated procedure for integrated launch vehicle, engine sizing and design optimization was used to optimize two stage and single stage concepts for minimum dry weight. The two stage vehicles were unmanned and used a flyback booster and partially reusable orbiter. The single stage designs were fully reusable, manned flyback vehicles. Comparisons of these vehicle designs, showing the effects of using different fuels, as well as sensitivity and trending data, are presented. In addition, the automated design technique utilized for the study is described.

17. Key Words (Suggested by Author(s))

PROPULSION IMPACT, PROPELLANT STUDIES, SPECIFIC IMPULSE, LAUNCH VEHICLES, HYDROCARBON FUEL, HYDROGEN FUEL

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FOREWORD

This report documents the results of the Booster Propulsion/Vehicle Impact Study conducted by the Space Systems Preliminary Design Group of Boeing Aerospace from September 1, 1987 through March 31, 1988. This study was conducted for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under the technical direction of Fred Braam.

The Boeing Aerospace Program manager was Vincent Weldon and key Boeing technical contributions were made by Dwight Phillips (principal investigator), Lawrence Fink (system modeling), Eric Wetzel (vehicle design), Michael Dunn (propulsion analysis), Jared Smith (configuration layout), and Gary Sanders (configuration layout). A subcontract to Boeing for purposes of subcooled propane infrastructure and variable mixture ratio LOX/LH_2 engine assessments was conducted by William Knuth and John Beverage of the Aerotherm Division of Acurex Corporation.

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1.0 INTRODUCTION

1.1 BACKGROUND

The current Advanced Launch System (ALS), as well as prior Space Transportation Architecture studies (both jointly conducted by the Air Force and NASA), have identified a similar partially reusable unmanned configuration as potentially the most cost-effective approach for a new unmanned, heavy-lift launch vehicle to commence operations by the year 2000.

This approach uses a side-mounted, unmanned flyback booster staging at a relatively low velocity (typically about Mach 5) in conjunction with a partially reusable "core" element in line with a large and heavy (typically 100 to 150K-lb) payload (fig. 1.1-1).

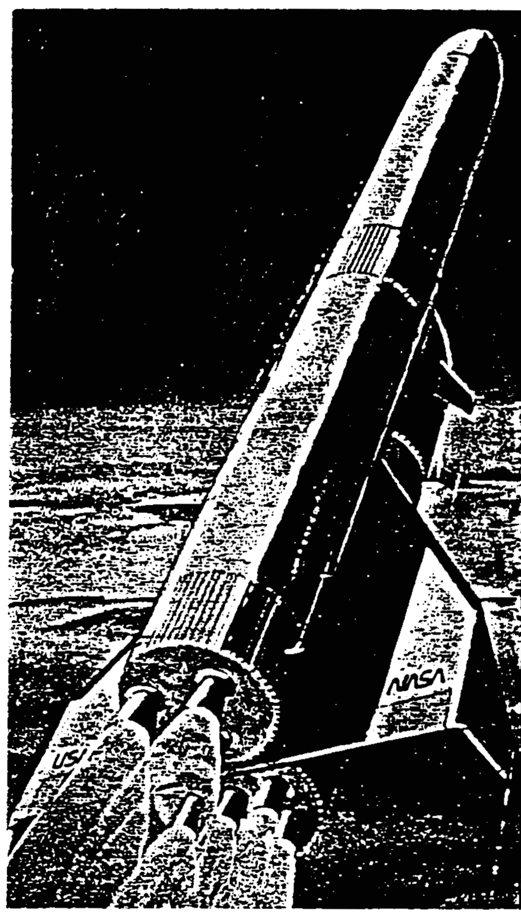

Figure 1.1-1 Partially Reusable Heavy Lift Launch Vehicle Concept

The reusable portion of this element is a propulsion/avionics (P/A) module that NASA/MSFC has been studying since 1986. The P/A module contains three or four Space Shuttle main engines (SSME) depending on payload weight.

The flyback booster dry weight required for this launch vehicle approach can be quite low for several reasons. One reason is that little or no thermal protection and only a limited amount of flyback capability is required because of the low staging velocity. Other reasons for the low weight could be the use of a new engine using high-density fuel (stored within relatively small tankage) and a relatively high chamber pressure to allow a low vehicle base area.

Another type of launch vehicle of national interest is a manned, vertically launched, single-stage-to-orbit (SSTO) concept. This approach is a fully reusable (via horizontal landing) vehicle to provide low-cost access to low orbit for manned military sortie capability (for such missions as satellite servicing) and low cost manned/cargo access to the Space Station. Previous studies have indicated potential benefits for such a vehicle using subcooled propane, but facility infrastructure requirements to enable the use of this fuel have not yet been defined.

1.2 STUDY OBJECTIVES/SCOPE

The primary objective of this study was to determine relative vehicle dry weight impacts due to the use of several different propellant combinations/engine types for both the above described classes of boosters. These combinations all use liquid oxygen as the oxidizer and include liquid hydrogen, methane, kerosene (RP-1), or propane as the fuel (or, in some cases, the fuel plus hydrogen as a separate engine coolant). These vehicle dry weight impacts were to be determined in conjunction with variations of certain key engine parameters including mixture ratio, chamber pressure, and nozzle expansion ratio. Also, potential benefits of mixture ratio variation (for LOX/LH_2)

during the booster burn, as well as possible benefits from using a two-position nozzle for low and high dual discreet expansion ratios, were to be determined.

To constrain the data development to meet the study objectives, a two-stage, parallel burn vehicle, capable of deploying a 150K-lb payload from the Eastern Test Range (ETR) to a fully operational Space Station (220-nmi, 28.5-deg inclination circular orbit) was assumed. A P/A module, using four SSMEs with weights extrapolated from Boeing's recent three-engine reusable P/A module study for NASA/MSFC, was utilized to perform the second-stage burn for each flyback booster/engine option analyzed.

For the SSTO vehicle, a payload of 10K lb to 100-nmi polar circular orbit was assumed in order to provide acceptable performance capabilities in support of high-inclination orbit military sortie missions and also to cover potential requirements for low-inclination orbit manned/cargo access to the Space Station.

Additional objectives of this study were to determine preliminary vehicle impacts and facility infrastructure requirements/costs due to the use of subcooled propane as the booster fuel and to develop parametric variable mixture ratio LOX/LH_2 booster engine data.

2.0 STUDY ANALYSES

2.1 VEHICLE ANALYSIS

In order to compare the effects of different fuels and engines on a specific space launch vehicle concept, an approach was used in which alternative optimized configurations were developed to meet the same mission requirements. These optimized configurations were developed by simultaneous adjustment of the vehicle's engine and airframe variables to the demands of each other as well as to the performance requirements of the mission. Subsequently, the optimized configurations were compared to each other to determine the relative advantages and disadvantages of using different engine fuels on the vehicle concept.

2.1.1 Computer Program

To accomplish vehicle design optimizations economically, it is necessary to avoid the large number of design iterations required to analyze the effects of variable interactions using traditional parametric analyses (involving plots representing the effect of several variables on another). Boeing, therefore, under independent IR&D accomplished from mid 1986 to mid 1987, developed a specialized analysis program called HAVCD (Hypervelocity Aerospace Vehicle Conceptual Design), which combines launch vehicle design subprograms with a modified version of a previously developed optimization technique (ref. 1) to perform the optimization analysis with only a small fraction of the number of design evaluations required by traditional parametric comparison methods.

The HAVCD computer program was used to conduct design optimizations and generate trade data for this study. Having been previously developed under IR&D, this program was already in use to examine alternative in-house vehicle concepts upon initiation of this study. However, some modifications to this program were required to adapt it to the specific requirements of the study. These modifications were accomplished under contract funding as summarized below.

HAVCD uses six specialized conceptual/preliminary design type subprograms as follows:

a. AIREZ - aerodynamics.

b. PROP - engine geometry, weights, and performance.

c. TAVB - airframe and subsystem weights.

d. ELES - tankage sizing and pressurization system.

e. NTOP - trajectory performance.

f. FLYBACK - flyback system design.

AIREZ relies on a blend of simplified aerodynamic theory and empirical relationships which result in acceptable agreement with wind tunnel test data. The subprogram generates a table of axial and normal aerodynamic force coefficients as a function of Mach number (Mach 0.3 to 20) and angle of attack (-10 to 60 deg) based on airframe geometry determined by TAVB.

The PROP subprogram was modified for this study to use the engine models from:

a. UTC/P&W, "Hydrocarbon Rocket Engine Study," contract NAS8-36355.

b. Rocketdyne, "Hydrocarbon Engine Study," contract NAS8-36357.

c. Aerojet, "Hydrocarbon Engine Study," contract NAS8-36359.

d. Aerojet, "STME Configuration Study," reference 2.

Besides computing engine specific impulse, nozzle and engine geometry and weight, the model also computes the fuel/coolant/oxidizer split for the tanks of the vehicles based on the output of the trajectory subprogram.

TAVB was previously developed under IR&D by the Boeing Military Airplane Company for analysis of a specific type of vehicle. For purposes of this study, the same basic equations were modified to accommodate both the single-stage and two-stage vehicles described above. Conceptual design equations for the expendable tankage used in the two stage vehicle were provided by the Boeing Aerospace Weights Analysis technical staff.

ELES (Extended Liquid Engine Simulation) was written by Aerojet under Air Force contract (ref. 3). Only the tankage, feedline, and pressurization system sizing and weight models were used in this study since preference was given to the modeling of other items in TAVB.

NTOP (New Trajectory Optimization Program) was the trajectory program used in this analysis. The trajectory is integrated using a point mass model. A perigee altitude of 50 nmi was chosen to be low enough for good trajectory performance yet not be so low as to introduce unaccountable aerodynamic drag errors in the orbit circularization calculations. Propellant requirement for an orbit circularization burn with OMS engines was calculated by a closed form solution following main engine cutoff. Although the resulting trajectories are not optimum they are adequate to determine accurate dry weight differences between the concepts analyzed.

The FLYBACK system calculates the number of turbofan engines, fuel weight, and total flyback system weight in the booster vehicle. This routine used the conditions at staging to estimate these quantities.

Design optimization was required to enable valid comparison of the different propulsion systems. The objective was to determine the best designed vehicle for each propellant/engine type, and then compare these vehicles with each other in order to avoid any misleading results which could occur if a suboptimal design for one propellant was compared with a closer to optimal design for another.

Figure 2.1.1-1 diagrams the process used in the BPVIS study to optimize each vehicle design. The first step was to decide which computer variables would be fixed and which would be optimized. Certain variables like number of crew (2 for single-stage-to-oribt (SSTO), none for two-stage vehicles), number of directional control surfaces (2), number of SSMEs in the recoverable P/A module of the orbiter element of the two stage vehicle (4), were held constant throughout the study.

Figure 2.1.1-2 summarizes the independent and some of the dependent variables used in the optimization process. This process requires that study limits be defined for each of the independent variables. A routine in HAVCD called "Design Selector" uses the range limit of each independent variable and the method of orthogonal Latin squares to define specific designs having independent variable values distributed in the "design space." The main feature of this technique is that a minimal number of designs have to be run on the HAVCD program.

The primary function of the HAVCD program is to converge on a design by cycling through the various subprograms. Figure 2.1.1-3 shows the automated process used within HAVCD to obtain a design.

The program converges on the criteria that altitude equals 50 nmi and that the specified amount of payload can be put into orbit. These criteria are met by varying the duration of Phase number 1 (constant flight path angle) to achieve 50 nmi perigee altitude, and by varying propellant weight to obtain the desired payload weight capability. Another criteria met during the convergence process is that the variables are "consistent." That is, aerodynamics is correct for the geometry used, the geometry is correct for the propellant used, etc. Checks are shown on the diagram in some of the diamond shaped blocks for maximum percent change, of all (several hundred) variables in HAVCD to ensure that consistency is obtained.

After the designs are evaluated using HAVCD "Design Converge," a multivariable regression analysis is used to fit a second order equation to the data. Each dependent

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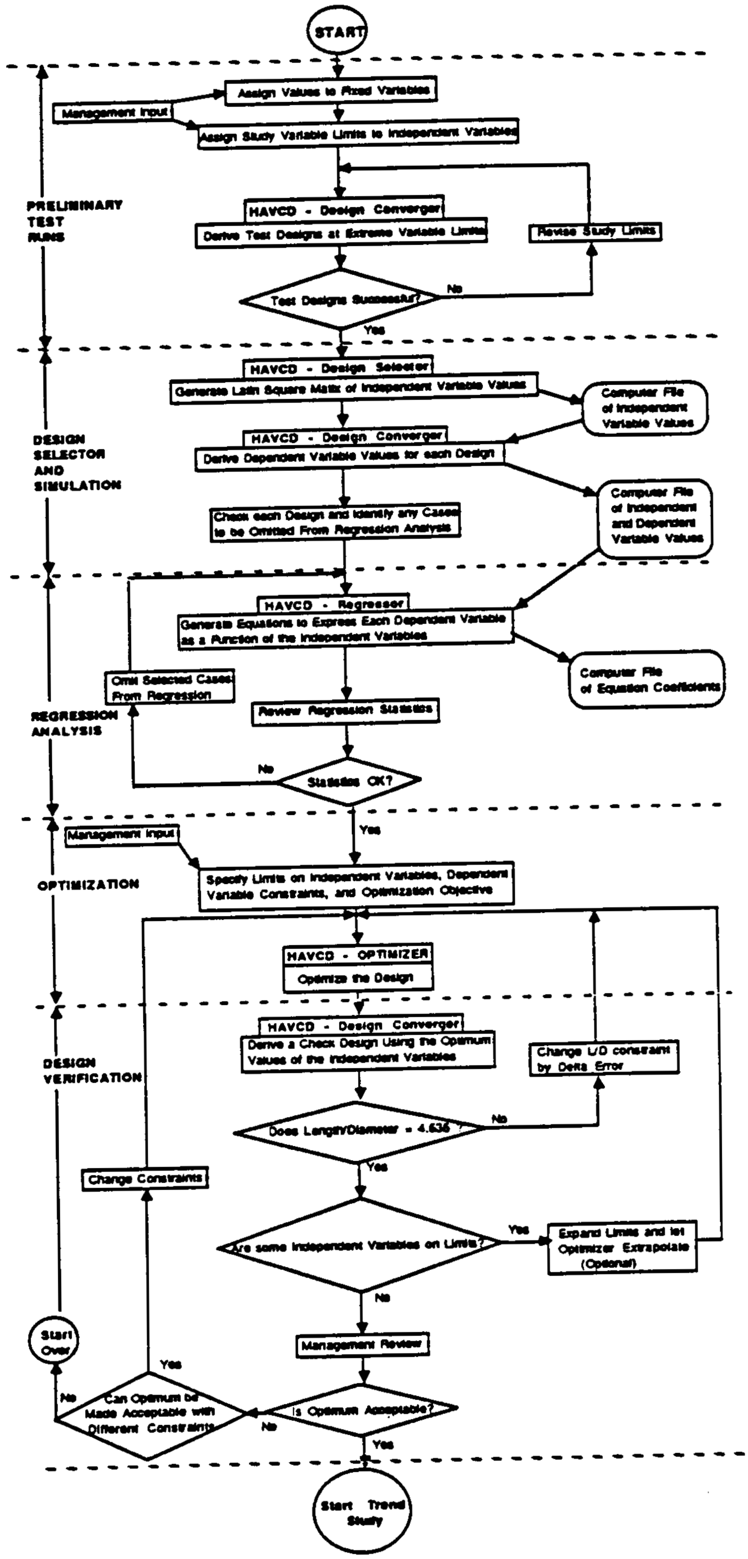

Figure 2.1.1-1 BPVIS Design Synthesis Logic Flow

Independent Variables	Application			
	Hydrogen fuel		Hydrocarbon fuel	
	2-stage	SSTO	2-stage	SSTO
Body diameter	√	√	√	√
Liftoff thrust/weight with one engine out	√	√	√	√
Booster engine mixture ratio	√	√	√	√
Number of booster engines	√	√	√	√
Booster engine nozzle expansion ratio	√	√	√	√
Orbiter propellant at staging	√	—	√	—
Booster engine mixture ratio	√	√	—	—
Second engine nozzle expansion ratio	—	√	—	√
Percent of propellant on-board at mixture ratio change	√	√	—	—
Percent of propellant on-board at booster engine shutdown	—	—	—	√
Percent of propellant on-board at expansion ratio change	—	√	—	√

Dependent Variables
Total propellant weight
Total dry weight
Propellant weight in each vehicle (Two-Stage)
Dry weight of each vehicle (Two-Stage)
Gross liftoff weight
Length/diameter ratio of booster
Booster engine weight
Booster engine vacuum specific impulse at liftoff
Total length
Propellant mass fraction
Weight at main engine cutoff
Staging velocity
Ratio of nozzle/atmospheric pressure at expansion ratio change
Engine rated thrust
Delivered booster thrust at liftoff

Figure 2.1.1-2 Independent and Dependent Study Variables

Note that the list of independent variables is a subset of the list of dependent variables. This arises because a given variable (e.g., body diameter) may be held out as an independent variable for the development of a sensitivity in which all other variables are dependent and allowed to "float" to find their optimum value. In other cases, other variables are chosen to be independent, and the given variable then falls back into the ranks of floating dependent variables.

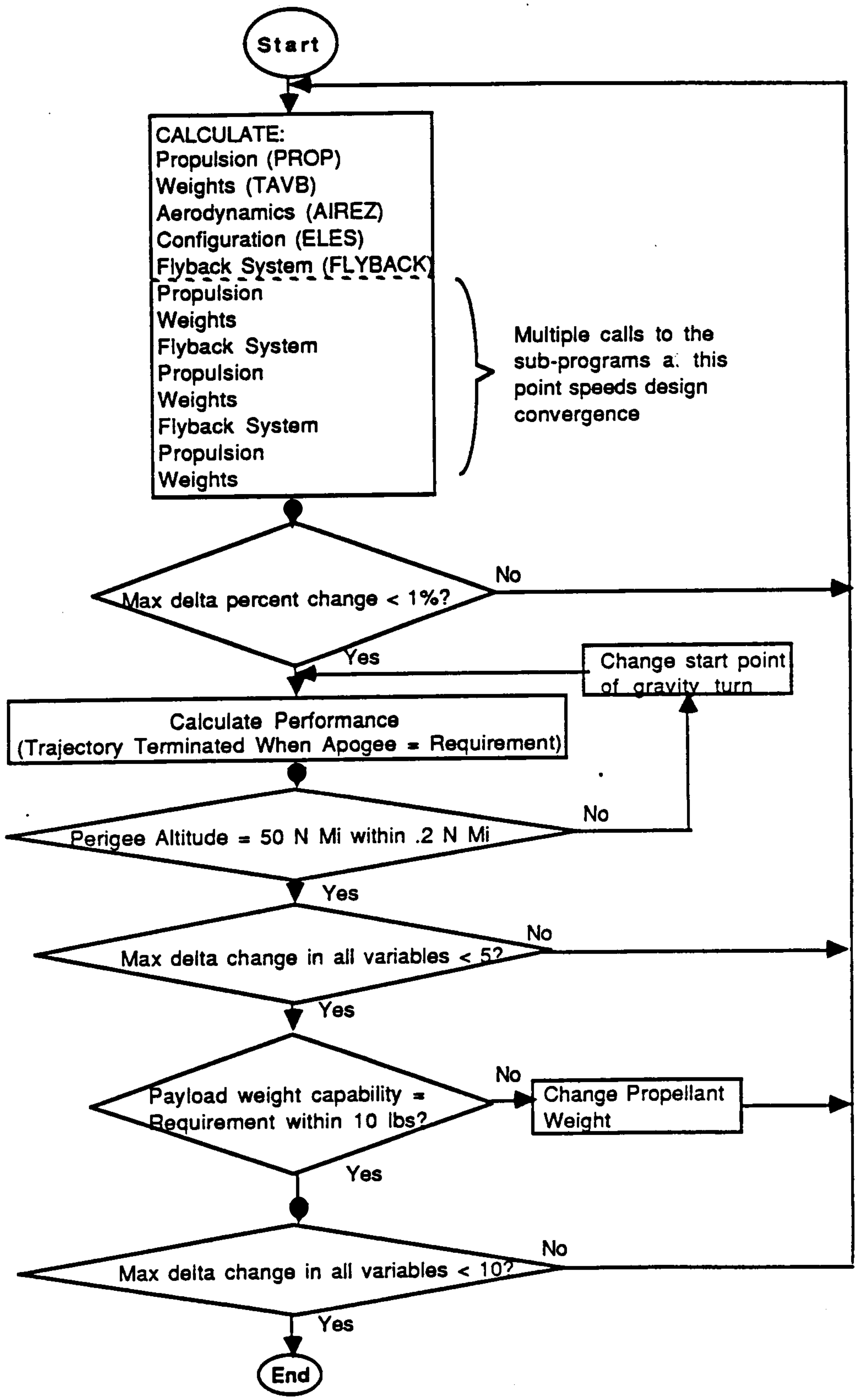

Figure 2.1.1-3 Design Converger

variable is expressed as a function of the independent variables. To provide the best equation for each dependent variable, the regression analysis will only include terms considered significant to that variable. Up to 28 terms are possible with six independent variables, 45 terms for eight variables. Regression statistics provide an indication of how well the equation represents the actual relation between the dependent and independent variables. Key statistics are the residuals for each case (difference between the HAVCD value and value obtained by the equation), residual divided by standard deviation for each case, and multiple correlation coefficient squared (R squared) which is a single number for each variable.

The equations are optimized using the method of steepest descent. The main feature of this optimization technique is that a minimal number of designs have to be run on the HAVCD program, thereby allowing optimized designs to be derived quickly. The time savings is evident when one considers that a traditional carpet plot approach would require 65536 designs to be evaluated for eight variables (4 levels per variable requires 4 to the 8th power number of cases). At about 20 minutes to derive a design on a VAX 8300 computer, the time savings is substantial. Once the equations are obtained, an optimization can be performed in under ten seconds. Any of the dependent variables can be optimized or used as a constraint.

The drawback to this optimization method is that optimizations are performed on equations that have a small error when compared to values obtained with the HAVCD program at the same independent variable values. However, the error is usually less than 5%. The equations are used to obtain very close to optimum values of the independent variables. For the best accuracy, all dependent variable values presented in this report are the result of substituting the independent variables back into the HAVCD program.

Optimizations are initially performed to minimize total dry weight. For the two stage vehicles, a constraint was applied that booster length/diameter equal about 4.5 (a value chosen to generally provide aerodynamic stability without canard). It was found that the first optimization may yield a fractional number of engines, such as 5.53, or be less than the desired number. For the two stage configuration a minimum of five engines was chosen to ensure that booster engine thrust was not too high. For the SSTO vehicle, a minimum engine thrust limit of 400,000 lb (vacuum) was used. After this first optimization, the number of engines was fixed to be a whole number and the optimization rerun. If the first optimization yielded a value for the number of engines between five and six, both five and six engines would be tried and the one with lowest total dry weight selected. The independent variables from the optimum design are next input into HAVCD and the length/diameter ratio checked against the value used as a constraint during optimization. The HAVCD value will be within .05 of the desired value, but to ensure that all designs are compared on a basis as consistent as possible, another optimization is performed to drive the HAVCD value to a value of 4.535. If the HAVCD value is higher than 4.535, a new optimization is performed with a slightly lower constraint on length diameter. Similarly, if the HAVCD value is lower than 4.535, a larger value of length/diameter is used as the constraint. After a few of these iterations, HAVCD yield a length/diameter equal to the desired value.

A trend study was used to generate graphs to give visibility of the interactions among the variables. As shown in figure 2.1.1-4, the process requires each variable to be fixed at ten levels between its upper and lower study limit. An optimization was performed at each value to yield a locus of optimum points for minimum total dry weight with a booster length/diameter equal to 4.535. Each design obtained for the graphs was run on the HAVCD program to enhance the accuracy of the dependent variables (rather than using the values determined by the regression equations). The graphs show how the dependent and other independent variables change in response to changes in this variable. It is important to realize that the graphs do not simply represent the result of varying one variable with all others fixed, but are actually a

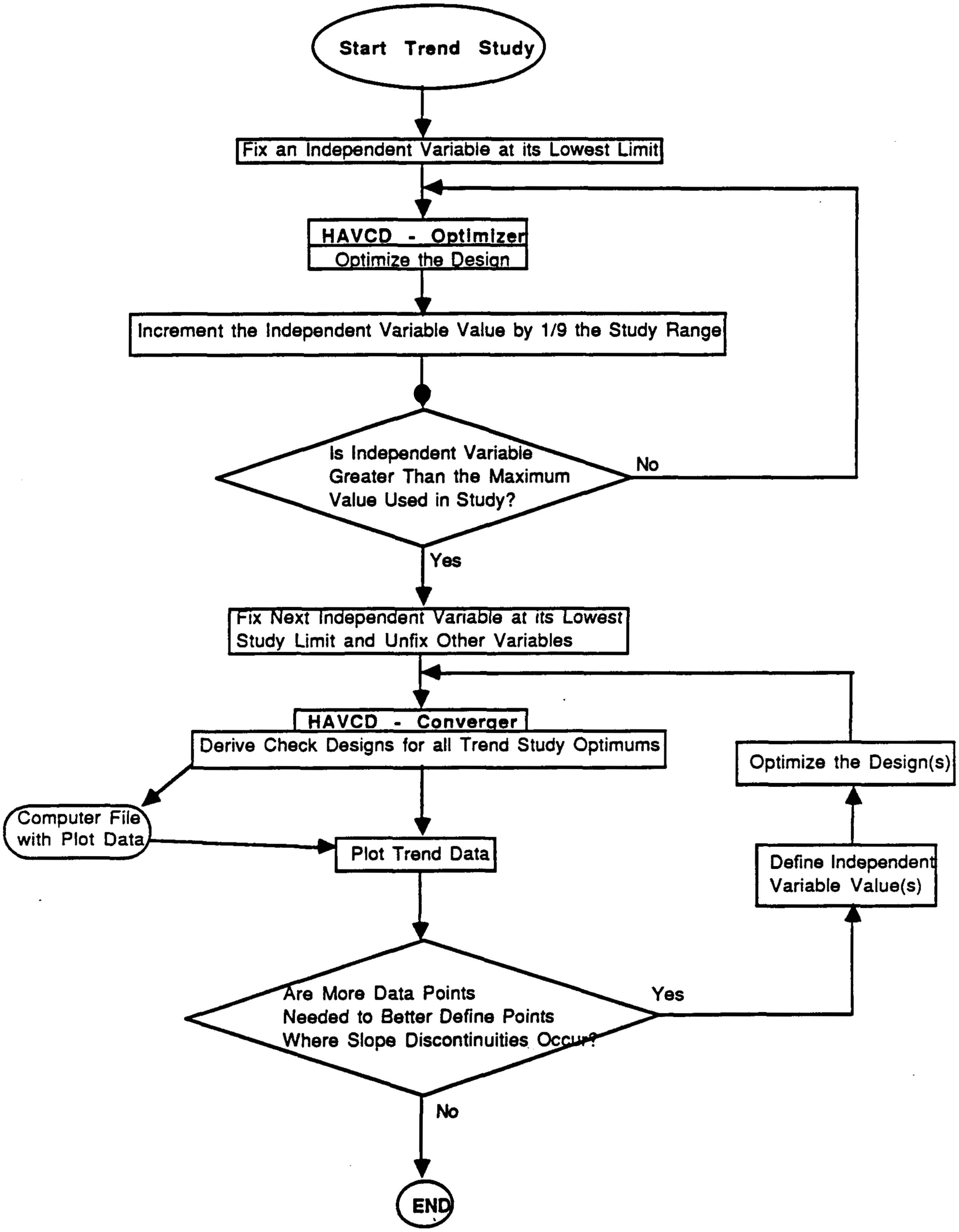

Figure 2.1.1-4 Trend Study Design Synthesis

locus of optimum designs. This method shows the true sensitivity of the design to the variable being evaluated.

2.2 SUBCOOLED PROPANE SUBCONTRACT

A subcontract effort was accomplished by the Aerotherm Division of Acurex Corporation to determine preliminary facility requirements/costs due to the use of subcooled propane as a booster fuel. This analysis included assessment of alternative concepts and comparisons with requirements due to the use of normal boiling point propane.

2.3 VARIABLE MIXTURE RATIO LOX/LH_2 PARAMETRIC ENGINE DATA SUBCONTRACT

Under subcontract, Acurex also supplied the subject data based on previously accomplished in-house study results.

2.4 COMPUTER MODEL EQUATIONS AND ASSUMPTIONS

Figure 2.4-1 and 2 provide a summary of key system and propulsion assumptions.

2.4.1 Engine Performance and Weights

Booster engine performance and engine weights used in this study were from the following sources:

a. SSME engine data - Liquid Propellant Engine Manual, CPIA/Ms

b. Aerojet LOX/LH_2 high mixture ratio data, NAS8-36867, Space Transportation Main Engine study, January 1987

c. Hydrocarbon Engine data, NAS8-36357, Hydrocarbon Engine Study, September 1986

Tankage and Feedlines -

Primary Material:	Aluminium/Lithium
Ullage Fraction:	2%
Line Material:	Stainless Steel
Feed System:	Includes lines weights, supports and service valves. External to propellant tanks.

Double walled tank on hydrogen tank on booster and SSTO otherwise they are monocoque tanks.

Cryogenic tanks are insulated with one inch SOFI.

All hydrogen propellant and coolant feedlines double walled.

Performance -

Trajectories are flown with one sustainer or 2nd stage engine out. Booster and sustainer engines fire in parallel. No crossfeed.

P/A Module -

Weight, excluding propulsion, is 43208 pounds.

Re-orbit P/A module after de-orbit of tanks.

Figure 2.4-1 Assumptions for Vehicle Analysis

Ascent Propellant -

Propellant consumed up to main engine cutoff. Includes fuel and oxidizer weights in both stages. Does not include coolant propellant, residuals, reserves, or propellant vaporized for pressurization.

Total Tank Weight -

Pressurant Weight - Fuel or oxidizer propellant vaporization for tank pressurization.

Pressurant Control Hardware Weight -

Control hardware for autogenous and/or helium pressurization.

Pressurant Weight -

Helium gas weight (RP-1 stages only)

Inert Weight -

Weight of vehicle after orbit circularization. Does not include payload weight. Includes propellant reserves, propellant residuals, flyback fuel, propellant for de-orbit, and in-flight, fluid losses like RCS propellant and propellants vented from the main engines.

Dry Weight -

Does not include any fluids.

Landing Weight -

Includes propellant reserves.

Hydrogen Coolant Weight -

Includes reserves and residuals.

Equipment Weight -

Includes miscellaneous equipment like electrical, hydraulics, avionics, helium for propellant purge, APQs, and crew related equipment.

Figure 2.4-2 Weight Assumptions

2.4.2 Baseline SSME Engines

The SSME information used in this study is as follows:

	Booster	Orbiter
Expansion Ratio	35:1	77.5:1
Vacuum I_{sp}	437.7 sec	453.5 sec
Chamber Pressure	3270 psia	3270 psia
Engine Weight	6790 lbm	7000 lbm
Throat Diameter	0.8518 ft	0.8518ft

2.4.3 LOX/LH_2 High Mixture Ratio Engines

The aerojet LOX/LH_2 high mixture ratio tables were used in this evaluation. The tables limited the evaluation over a chamber pressure range of 2000 to 4000 psia, an expansion ratio range of 30:1 to 150:1 and a mixture ratio range of 6 to 18.

The theoretical specific impulse of the engine used a curvefit equation. This equation is:

$$Isp = FACxe^{(3.54 + 3.507B - 1.514B^2 + .1948B^3}$$

$$\text{where} \quad A = \ln(\text{expansion ration})$$

$$B = \ln(\text{mixture ratio})$$

$$FAC = e^{(-.251+.0968A-.0068A^2)}$$

A shift in mixture ratio is assumed to be caused by an oxidizer flowrate only. Fuel flowrate remains constant and engine efficiency does not change. A new chamber pressure and CSTAR is calculated as the mixture ratio changes

$$CSTAR = e^{(10.065 + .00556C - 1.570B + .7794B^2 - .1493B^3)}$$

where C = ln (chamber pressure)

chamber pressure = CSTAR * WDOT/(ATHROAT* go)

where WDOT = total propellant flowrate

ATHROAT = engine throat area

go = 32.174 ft/s^2

2.4.4 Hydrocarbon Engines

Three contractors were involved in the Hydrocarbon engine study under contract NAS8-36357. Two engine cooling methods were used in this study, propellant and hydrogen. The contractors were Aerojet Tech Systems Company, Pratt and Whitney, and Rocketdyne Division of Rockwell International Corporation. The data from the LOX/LH_2 high mixture ratio study was generated by Aerojet. It was decided that Aerojet's data would be used for performance in the hydrocarbon study to keep a link between all of the propellants. Pratt and Whitney had parametric equations that were easy to adapt to computer programs and these were used for performance variations, engine weights, and for throat area determination. Rocketdyne provided sufficient information to model the liquid hydrogen required for engine cooling.

Pratt and Whitney performance equations were corrected to the Aerojet theoretical equations by applying an I_{sp} correction factor (I_{sp}FACT). The theoretical I_{sp} would then be corrected by and engine efficiency factor (EFF_{FACT}), also from Aerojet. The EFF_{FACT} would contain the factor for near-term technology up to 1995, and far-term technology (1995 and beyond).

The equations used in this study for the hydrocarbon engines follow:

RP-1 propellant, LH_2 cooled where required

<u>Near Term</u> (P_c limit 4550 psia)

$$H_2 \text{ coolant flowrate} = e^{(-.2449-9.8766\times10^{-5}P_c+5.5342\times10^{-8}P_c^2)}$$

ratioed to total propellant flowrate

<u>Far Term</u> (P_c limit 6200 psia)

$$H_2 \text{ coolant flowrate} = e^{(-.3066-1.0936\times10^{-5}P_c+2.9226\times10^{-8}P_c^2)}$$

ratioed to total propellant flowrate.

The theoretical vacuum specific impulse for each engine is found in figure 2.4.4-1.

CONF	FACT	A	B	C	D	E	F	G	H	I	J	K	L
2C,2D	1.0207	512.8	0.0	-319.88	-5.3906	0.0	0.2348	-.000633	0.0	0.0	-131.19	0.0	-2339.47
2E.2F	1.1111	486.6	0.0	-309.3	-6.4005	0.0	0.0	0.0	0.0	0.932	-136.16	0.029	-723.57
2G	1.0309	152.2	117.0	0.0	-15.887	0.0	0.238	-.000667	0.0	0.0	-113.89	0.0	-1587.88
2H	1.0719	-399.5	-206.9	0.0	0.0	783.7	0.0	0.0	60.49	2.499	-117.67	0.0	-1000.51
2I	1.0224	925.8	-124.7	-802.06	7.2665	0.0	0.0	0.0	0.0	2.869	-100.74	0.0	-2061.75
2J	1.1006	-6320.3	-2310.6	1854.4	80.452	7066.1	0.0	0.0	0.0	2.1704	-118.11	0.0	-1145.2
2K	1.0220	923.2	-124.3	-799.75	7.2455	0.0	0.0	0.0	0.0	2.8608	-100.45	0.0	-2055.81
2L,2M	1.0991	1068.6	-178.2	-920.79	12.589	0.0	0.0	0.0	-442.57	0.0	0.0	0.038	-1254.08

$$I = FACT\ (A + B \cdot + C/MR + D \cdot MR^2 + E \cdot \quad MR + F*EX + G \cdot EX + H/EX + I + \quad EX + J \cdot MR/EX$$
$$+ K \cdot MR \cdot EX + L \cdot MR/PC)$$

MR - mixture ratio
EX - nozzle expansion ratio
PC - chamber pressure - psia

Figure 2.4.4-1 Specific Impulse Equations for Hydrocarbon Engines

This vacuum impulse is corrected for engine efficiency, which is found in figure 2.4.4-2, and is used in the flight performance program. Delivered specific impulse is corrected for atmospheric pressure during engine operation.

CONF	FACT	A	B	C
2C	1.000	.9233	$7.5x10^{-7}$	$-5.0x10^{-11}$
2D	1.000	.9233	$7.5x10^{-7}$	$-5.0x10^{-11}$
2E	1.000	.9378	$-3.9x10^{-5}$	0
2F	1.033	.9378	$-3.9x10^{-5}$	0
2G	1.000	.9602	$7.714x10^{-7}$	$-4.2856x10^{-10}$
2H	1.000	.9526	$-6.286x10^{-7}$	$-2.429x10^{-9}$
2I	1.000	.9329	$-7.75x10^{-7}$	$-8.928x20^{-11}$
2J	1.000	.9208	$3.4499x10^{-6}$	$-5.750x10^{-9}$
2K	1.000	.9238	$-7.285x10^{-7}$	$-7.1432x10^{-11}$
2L	1.000	.9274	$-6.4286x10^{-6}$	$-1.4286x10^{-9}$
2M	1.032	.9274	$-6.4286x10^{-6}$	$-1.4286x10^{-9}$

$$\text{Engine Efficiency} = \text{FACT}\ (A + B * PC + C * PC^2)$$

Figure 2.4.4-2 Hydrocarbon Engine Efficiency

The weight of each engine is found in figure 2.4.4-3. If the engine is to have an extendable nozzle the engine weight is increased by the following equation:

169+.642(.1534(Throat area)-2.019) (EXMAX-EXMIN)

where EXMAX is deployed expansion ratio

EXMIN is initial expansion ratio

Engine throat area is calculated in figure 2.4.4-3.

CONF	A	B	C	D	E	F	G
2C,2D	8400	1.44	-0.152	-155.7	57.5	3.0	.4822
2E,2F	8064	1.38	-0.146	-149.4	55.2	3.0	.4853
2G	8316	1.43	-0.150	-154.1	56.9	3.5	.4969
2H	7980	1.37	-0.144	-147.9	54.6	3.5	.4718
2I	8484	1.45	-0.153	-157.2	58.0	3.0	.4869
2J	8148	1.40	-0.147	-151.0	55.8	3.0	.4785
2K	8358	1.43	-0.151	-154.9	57.2	3.0	.4859
2L,2M	8022	1.37	-0.145	-148.7	54.9	3.0	.4894

$$\text{Engine Weight} = A * \left(\frac{TH}{1{,}000{,}000}\right)^{.95} * \left(\frac{MR}{F}\right)^{-.012} + B + C*EX + D*\frac{TH}{1000*P_c} + E*\frac{EX*TH}{1000*P_c}$$

Engine Throat Area = G . TH/PC

TH - engine thrust - lbs
MR - mixture ratio
EX - expansion ratio
P_c - chamber pressure - psia

Figure 2.4.4-3 Hydrocarbon Engine Weight and Throat Area

2.4.5 Propellant Tanks

The propellant tank weight was calculated by the Expanded Liquid Engine Simulation (ELES). Monocoque tank design was used for all configurations except when a liquid hydrogen tank was used on a flyback system. A suspended liquid hydrogen tank was used on the first stage on the SSTO. Aluminum/lithium alloy was used as the propellant tank and structure.

Propellant tank pressure was chosen based on required pump inlet pressure and line pressure drop. The pressure was always set above atmospheric and obtained by autogenous except RP-1 tanks which required helium pressurization. Propellant tank pressure was not optimized in this study. total dry weight would be reduced further if the tank pressure was optimized. Time did not permit this optimization. Propellant tank (fuel, oxidizer, and coolant tanks) used a 2% ullage volume. All cryogenic tanks used one inch of insulation to prevent ice build-up.

Feed lines were routed external to the propellant tanks. The propellant lines were stainless steel with all hydrogen lines being double walled. A bellows was placed at the end of each line with a flange every 10 to 12 feet. Line pressure drops we set at 5 psia.

2.4.6 Flyback System

The flyback system was used only on the first stage of the two stage vehicle. It used Pratt and Whitney 4056 turbofan engines with go-around capability with 5% fuel reserve. Flyback mach number was 0.5 at 2500 feet and a lift to drag ratio of 5:1.

2.4.7 Weight Assumptions

Ascent propellant was defined as that propellant required up to main engine cut-off. It does not include coolant propellant, residuals, reserves or propellant vaporized for pressurization.

The total tank weights include propellant tanks, support structure and insulation. It does not include helium tanks or hydrogen coolant tanks.

Autogenous pressurant weight is the fuel or oxidizer propellant vaporized for tank pressurization.

The inert weight is the weight after orbit circularization. It does not include the payload weight. It includes propellant reserves, residuals, flyback fuel, propellant used for de-orbit and in-flight fluid losses such as RCS propellants and propellants vented from the main engines.

Dry weight is the weight that contains no fluids.

Equipment weight includes miscellaneous equipment such as electrical, hydraulic, avionics, helium for propellant purge, APU and crew related equipment.

The thermal protection tile weight for the reentry vehicle is calculated based on the exposed area to reentry (normally the body and wing bottom surface) and a tile weight similar to the space shuttle. The thermal protection system for the booster is calculated based on its staging Mach number, and is booster staging weight x (.01382*Mach-.0776), value.

The orbital maneuvering system (OMS) propellant is calculated on the delta-velocity required of the OMS system and the orbital system weight. The OMS delta velocity is composed of circularization, manuevers, deorbit, etc. A 1% value of the OMS propellant is used for the residual OMS propellant weight and a 4% value is used for reserves. OMS tankage, lines, hardware is estimated at 10% of the OMS propellant weight.

Reaction Control System (RCS) is estimated in a similar manner to OMS propellant except a factor is included to account for propellant expended for additional orbits. Trapped and reserve propellant are set at 29% of the RCS propellant.

2.4.8 Flight Performance

It was assumed that a second stage engine was not operating throughout the flight. To size the booster engine, it was assumed the largest of a booster or second stage engine was not operating at liftoff. The vehicle would lift vertically for about 200 feet then pitch over in a gravity turn.

3.0 STUDY TASKS

This study was organized into three major tasks as detailed in the following sections. The three tasks are (1) comparative design studies of two-stage and one-stage launch vehicles employing various fuel/coolant combinations, (2) an assessment of the ground operations impact of using subcooled propane as the launcher fuel, and (3) an evaluation of a full topping cycle, variable mixture ratio engine.

3.1 TASK 1: PERFORMANCE IMPACTS

The comparative vehicle studies were organized into five subtasks:

Subtask 1A. Development of a representative baseline vehicle for each of two launcher classes:

a. Two-stage, partially reusable, 150,000 lb to low Earth orbit.

(altitude = 220 nmi circular, inclination = 28.5 deg, KSC launch)

b. One-stage, fully reusable, 10,000 lb to low Earth orbit.

(altitude = 100 nmi circular, inclination = 90 deg, VAFB launch)

In both vehicles, the upper stage or sustainer operation mode uses LOX/LH_2 propellants.

Subtask 1B. Development of reference vehicles in each of the above classes that use LOX/hydrogen propellants for the booster component of the system, optimizing the mixture ratio to achieve minimum vehicle dry weight. Subsequently, develop comparative LOX/hydrocarbon designs employing the following booster fuel candidates:

a. RP-1.

b. Methane.

c. Propane (near boiling point:NBP).

d. Propane (subcooled:SC).

The physical properties of these fuels are summarized in figures 3.1-1 and 3.1-2. Hydrocarbon engine parametric data used in this study were based on the results of Contracts NAS8-36355 (Pratt & Whitney), NAS8-36357 (Rocketdyne), NAS8-36359 (Aerojet).

Near-term performance levels (i.e., believed achievable by 1991) were used for all designs. Two specific two stage designs (RP-1 and SC propane) were conducted using far-term performance levels (i.e., believed achievable by 1998). The designs were focused on boost propulsion system elements with consideration given to stage pressurization, propellant feed ducts, tankage, and fill and drain systems, and accounting for influences on other vehicle systems as appropriate (e.g., structure).

Subtask 1C. Development of LOX/hydrocarbon vehicle designs using the same hydrocarbon fuels as well as supplementary hydrogen as an engine coolant, with consideration being given to the aforementioned propulsion system elements and to propellant crossfeed from the booster to the second stage. Design impacts were addressed in respect to the comparable fuel choice from subtask 1B.

Subtask 1D. Development of design variations of the reference vehicles based on the use of high mixture ratio and variable mixture ratio of the LOX/hydrogen boost propellants over the range of 6 to 18. Design impacts were addressed in respect to the reference vehicles.

Subtask 1E. Conduct of sensitivity analyses to determine the benefit of a step change in booster engine specific impulse during the boost phase (as might be obtained by a translating nozzle) as applied to the two reference vehicles and the LOX/RP-1 and LOX/methane versions (both hydrogen-cooled) of the two-stage vehicle. A similar sensitivity analysis of the same vehicles was also conducted for variations in booster-engine chamber pressure.

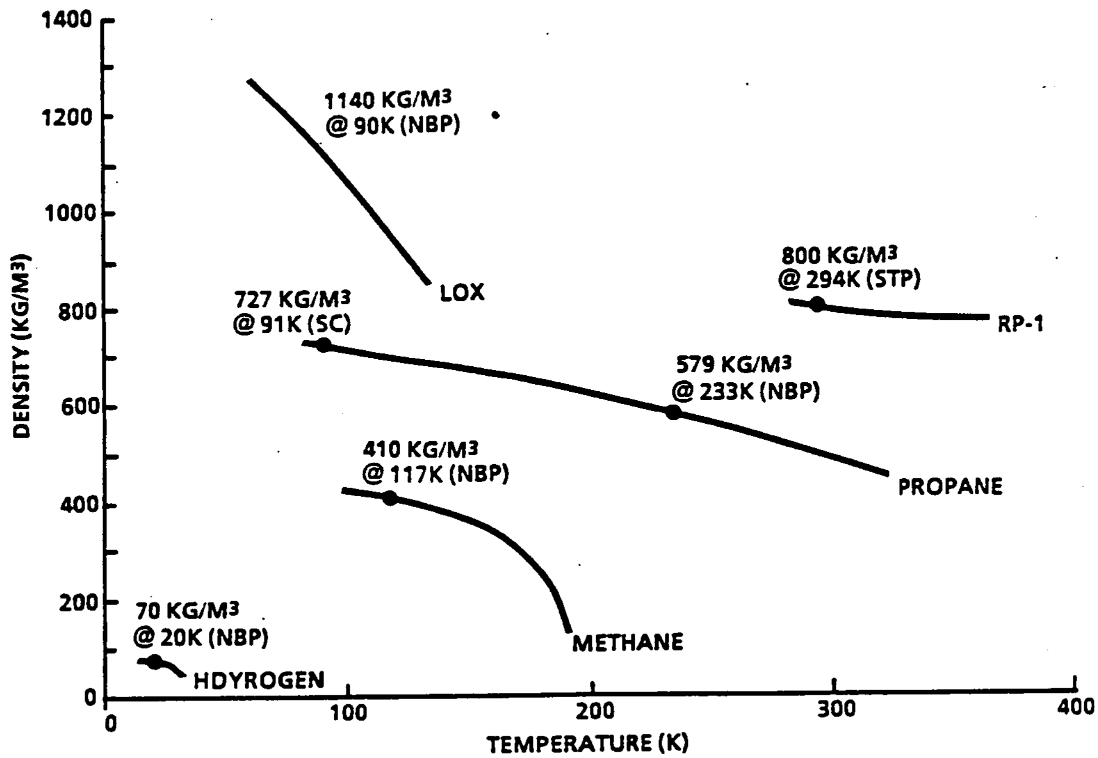

Figure 3.1-1. Propellant Density

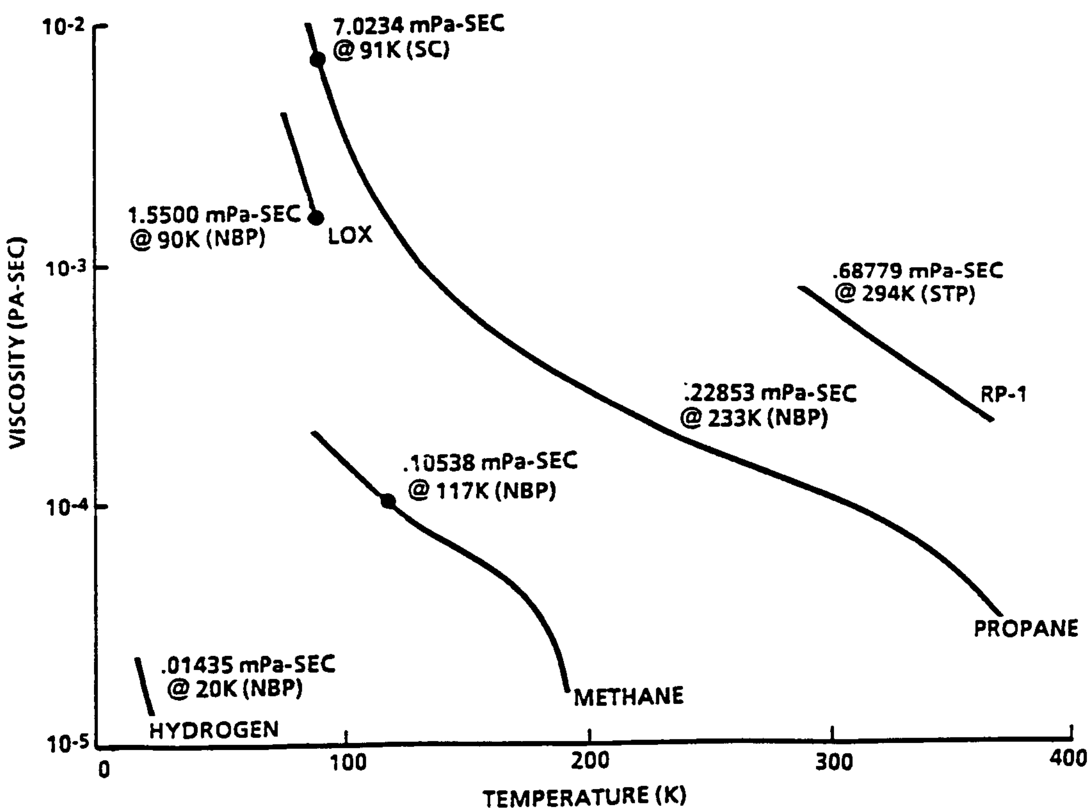

Figure 3.1-2. Propellant Viscosity

Specific vehicle configurations are detailed in the following subsections.

3.1.1 Two-Stage Vehicles

The configuration concept for the parallel burn two-stage system incorporates a winged, flyback booster and a partially reusable "orbiter" stage. The reference payload is 150,000 lb to Space Station, i.e., 220-nmi circular orbit at an inclination of 28.5 deg. The payload bay envelope is 33 ft in diameter by 70 ft long, effectively doubling the volumetric capability of the Space Shuttle or the Titan IV. Figure 3.1.1-1 depicts the basic two-stage configuration. The call-outs are typical for all two stage options considered.

Typical mission operations (fig. 3.1.1-1) are similar to familiar launch systems. The booster is assembled with its payload, moved to a launch site at Cape Kennedy, and fueled at the pad before liftoff. Lifting off vertically, the stack accelerates to around Mach 5, where the booster element is empty. The winged booster separates from the support members holding it to the adjacent orbiter and flies back to a runway near the launch site using onboard automatic flight guidance and control. The orbiter continues to orbit propelled by four Space Shuttle main engines (SSME). At a dynamic pressure of 5 lb/ft^2 the payload shroud is jettisoned. The P/A module has a low L/D, thermally protected shape and reenters intact. After decelerating using drag, parachutes are deployed from the P/A module to facilitate its recovery. The P/A module, as well as the booster, are later refurbished and then reused on the next flight.

The baseline staging velocity of around 5000 ft/s is based upon minimum weight as well as material considerations. Figure 3.1.1-2 plots weight versus staging velocity. Note that in the speed regime of 4000 to 6000 ft/s the weight minimum is a shallow, broad "bucket" function. Any staging velocity selected in this region would result in an acceptable, low-weight booster design. However, increasing staging velocity increases

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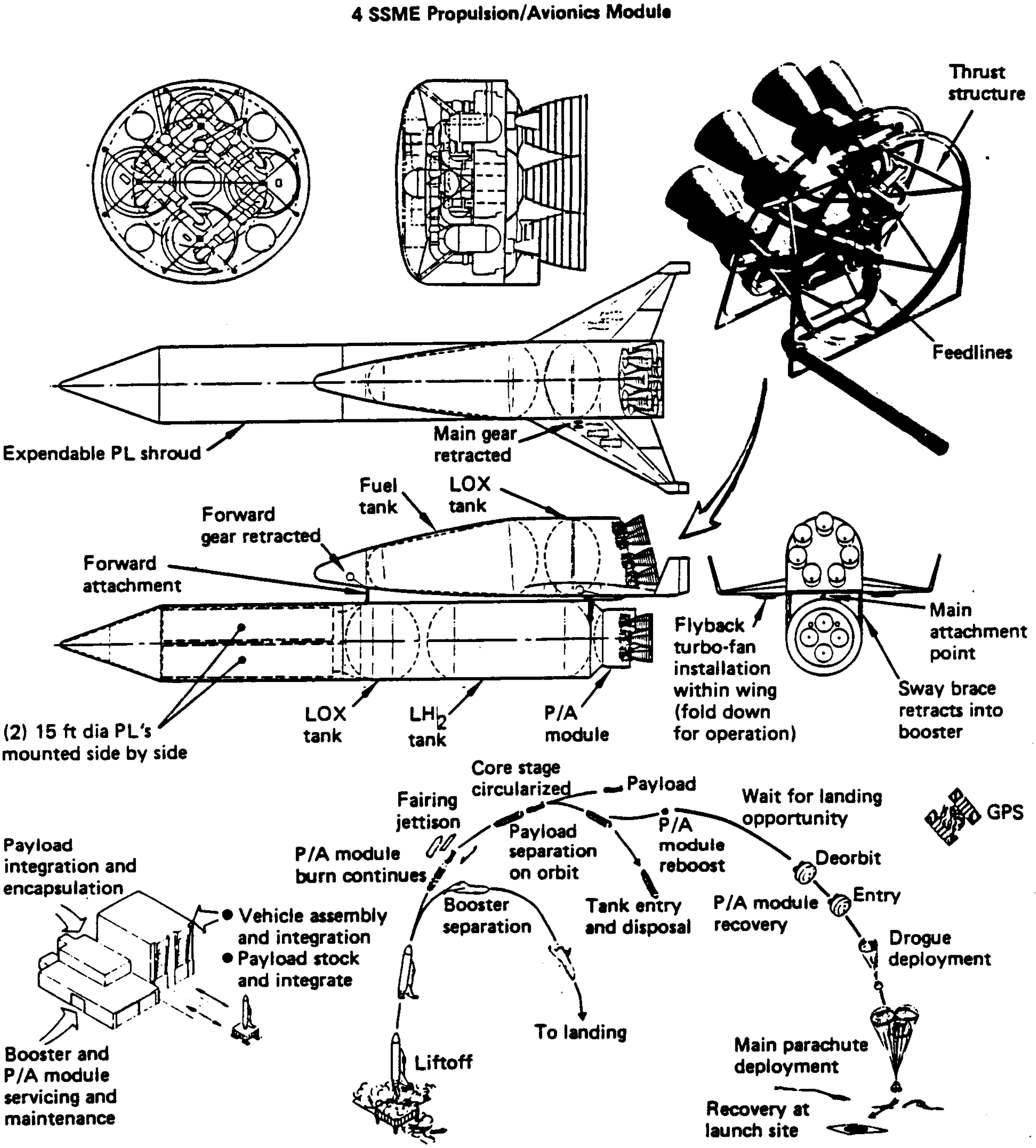

Figure 3.1.1-1. Two-stage Partially Reusable Launch Vehicle—Typical Features

the aerothermal loads on the booster, requiring different structural materials and/or more thermal protection (e.g., more dry weight for insulation). Graphite/polymide is a material choice consistent with the time frame for this vehicle because of its lightweight and relatively inexpensive to manufacture.

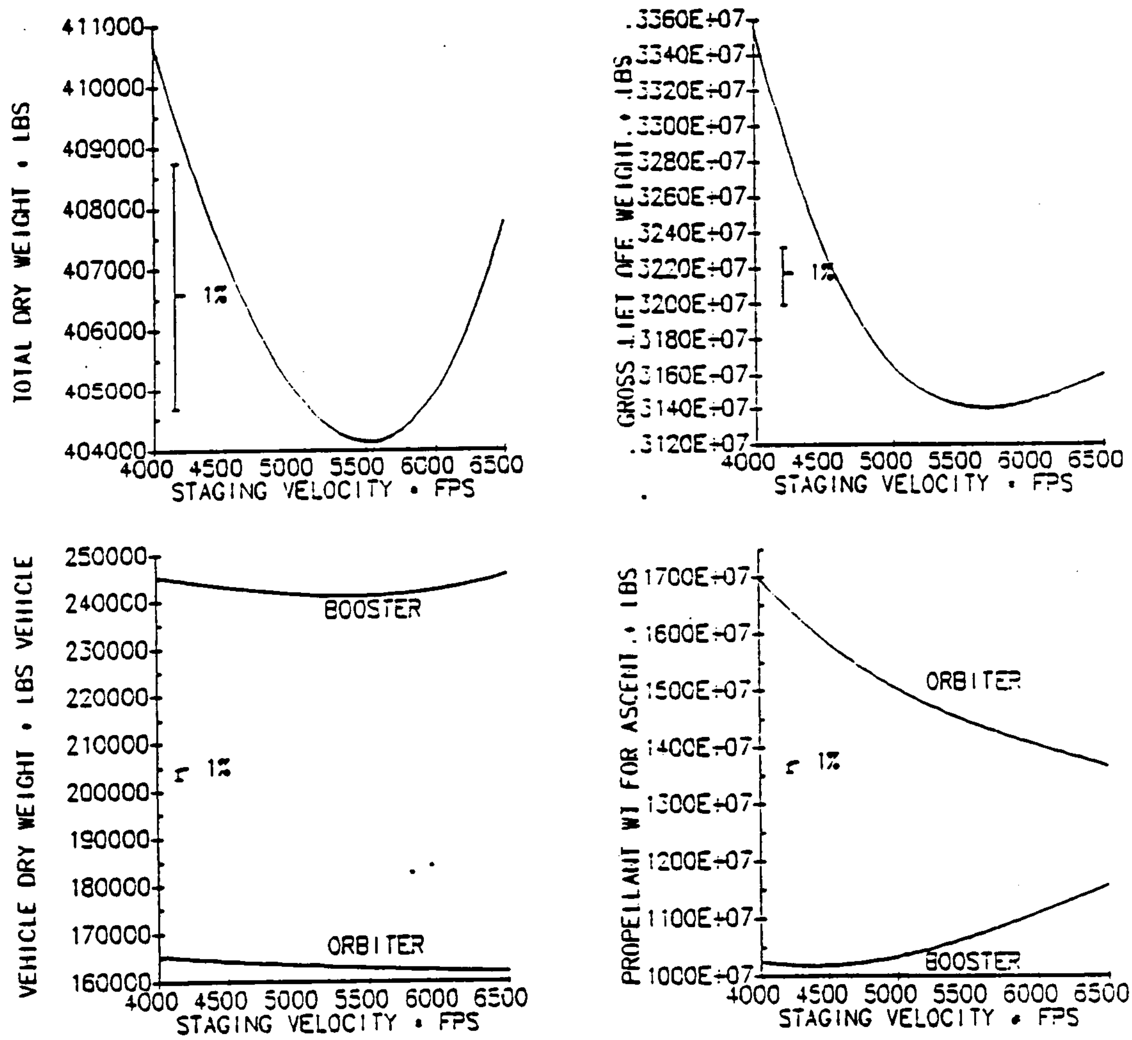

Figure 3.1.1-2. Staging Velocity Impact on Two-Stage Vehicle Parameters for Baseline Vehicle

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The booster element is a winged, flyback vehicle. The propellants and the number and size of rocket engines are varied for each of the study configurations, hereafter designated 2.A through 2.M. The aft tank, which is always a LOX tank, is cylindrical with hemielliptic domes. (This tank is located far enough forward to allow a structural wing box to pass continuously from side to side of the vehicle.) Forward of the LOX tank is the fuel tank; the tapered, or frustrum shape of the fuel tank follows the external contours of the vehicle, which is tapered to increase aerodynamic efficiency for a given booster length. In cases where an engine coolant is used that is different from the fuel, a third, smaller tank is located forward of the fuel tank in the nose of the booster.

The fuselage is a conventional structure: propellant tanks surrounded by a protective shell, including some thermal protection system (TPS) large-acreage tiles. The forebody houses the nose gear, the flyback avionics, and attach structure for one of the attachment beams to the orbiter. The aft fuselage contains the thrust structure for the multiple rocket engines as well as the propellant plumbing. An example of the structural and plumbing interfaces for a seven engine configuration is shown in figure 3.1.1-3. A slanted closeout bulkhead is positioned perpendicular to the takeoff booster thrust vector. A constant chord body flap for pitch control and trim is attached at the base of the closeout bulkhead. Fuselage fineness ratio, or (1/d), is the same for all configurations; a value of 4.535 was found to be near optimum for maximizing aerodynamic performance while minimizing wetted area (and thus drag).

The wing is a trapezoidal planform with trailing edge ailerons and flaperons. Wing-tip mounted vertical fins with rudders provide directional stability and control. The main landing gear is attached to the wing box near the body join, and is stowed between the front and rear spars of the inboard wing. At the near spar/body join is the structural attachment fittings for the attach beams to the orbiter.

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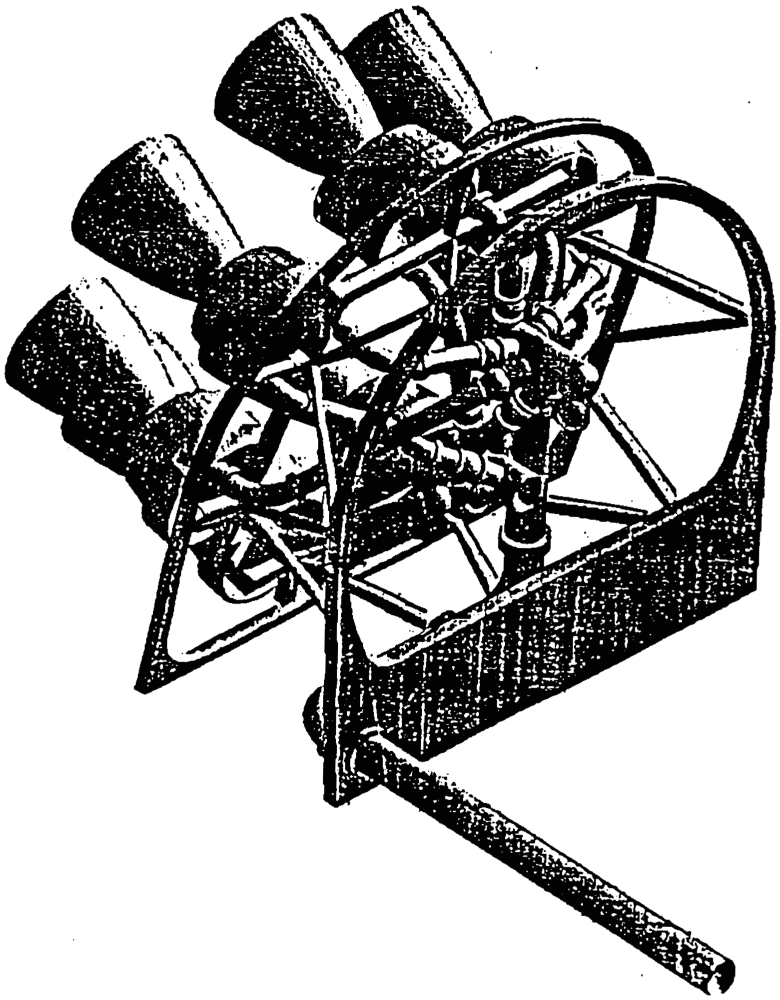

- Thrust structure/feedline integrated design similiar in design philosophy to space shuttle orbiter aft fuselage
- Representative of installations envisioned for all vehicle/engine combinations assessed
- Sufficient space available for shell frames, thrust structure and feedlines
- Additional space available for remaining subsystems

Figure 3.1.1-3. Typical Booster Propulsion Thrust Structure/Plumbing Arrangement

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To enhance flyback performance, most importantly range, fold-down turbofan engines are housed in the wing. Because the engine/fold-down mechanism is larger than the wing thickness, a protruding fairing is located on the underside of the wing.

Other subsystems, such as hydraulics, pneumatics, avionics, and electrical, are conceptually the same as present technology systems in use on systems like the Space Shuttle.

The orbiter stage consists of three elements: (1) the recoverable P/A module, (2) the LOX/LH_2 tankage, and (3) the payload bay/shroud. Only the P/A module is recovered after flight. This module, which contains the thrust structure and plumbing for four SSMEs, vehicle control avionics, and a parachute recovery system, is similar to designs being studied for the ALS by Boeing under contract to USAF Space Division. A typical design is shown in figure 3.1.1-4. Four SSMEs are used to ensure one-engine-out vehicle performance.

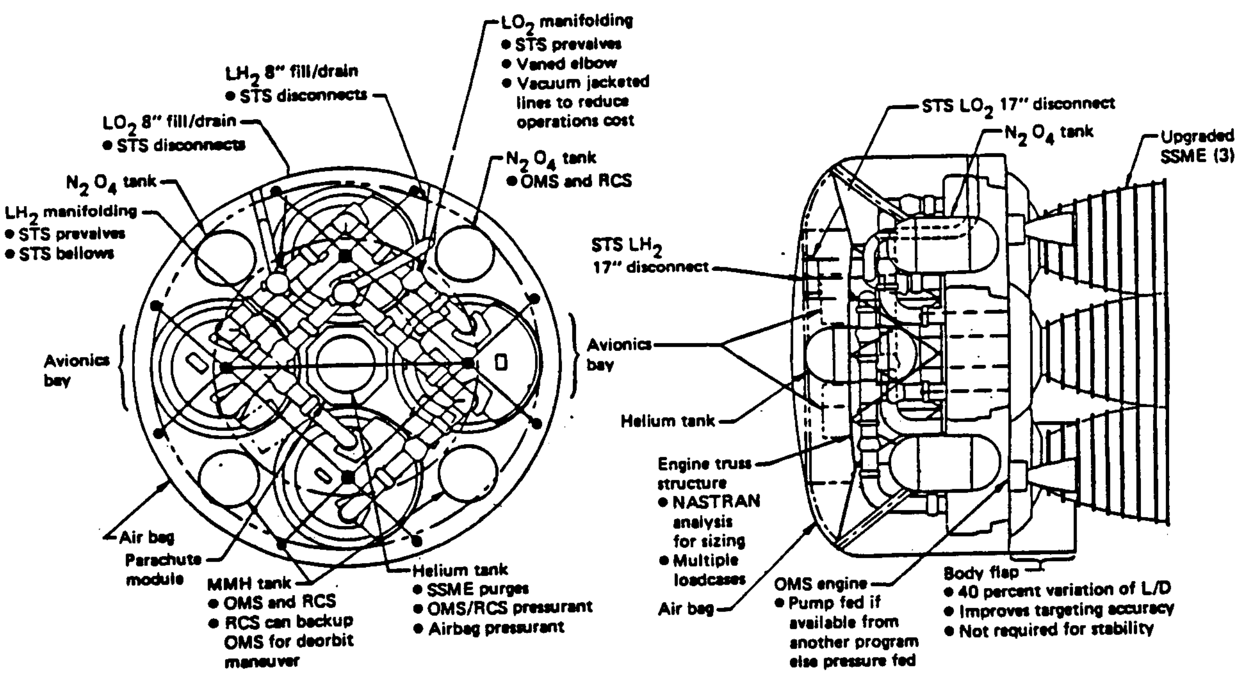

Figure 3.1.1-4. Typical P/A Module Design

The tankage section of the orbiter is of conventional design: both the LOX tank (forward) and LH_2 tank (aft) are cylindrical, load bearing tanks with hemielliptic ends. The interstage structure also contains the attachment beams to the booster.

The payload is mounted on an aft and adapter attached to the tankage section. The payload shroud is jettisoned when the altitude of the flight profile results in an extremely low dynamic pressure.

Specific vehicle designs will be presented in the following sections. Each discussion will include a configuration description and an optimization sensitivity analysis.

Six single-stage configurations (designated 1.A through 1.F) and thirteen two-stage configurations (designated 2.A through 2.M) were developed in the study. Each configuration has a different type of engine. Initially, single-stage and two-stage baseline vehicles, designated 1.A and 2.A respectively, using SSMEs were developed for comparison to subsequent optimized designs. Near the conclusion of the study, it was decided to use the optimized hydrogen fuel vehicles (1.B and 2.B) as the reference configurations since it appeared to be more meaningful to compare the other optimized designs with these optimized designs.

Figure 3.1.1-5 is a summary comparison of optimized (for minimum total dry weight) configurations 2.A through 2.M. This figure shows the salient features of the concepts from a configuration viewpoint. Figure 3.1.1-6 compares weight.

The orbiter dry weight, or loaded weight for that matter, does not vary greatly with concept selection; this is expected because this stage is always LOX/LH_2 fueled, powered by SSMEs, and provides most of the delta-velocity to orbit. The booster dry weight varies more significantly, reflecting different fuel and/or coolants and variations in vehicle size and number of engines. The baseline (2.A) SSME-powered vehicle is by far the heaviest in terms of booster dry weight because of the large volumetric storage requirements for LH_2. The lowest dry weight is produced by the methane-fueled, LH_2-cooled concept (2.G).

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Configuration	2.A	2.B	2.C	2.D	2.E	2.F	2.G	2.H	2.I	2.J	2.K	2.L	2.M
Fuel	H_2	H_2	RP-1	RP-1	RP-1	RP-1	CH_4	CH_4	NBP C_3H_8	NBP C_3H_8	SC C_3H_8	SC C_3H_8	SC C_3H_8
Coolant	H_2	H_2	H_2	H_2	RP-1	RP-1	H_2	CH_4	H_2	NBP C_3H_8	H_2	NBP C_3H_8	C_3H_8
Mixture Ratio	6:1	8.97:1	3.26:1	3.15:1	3.15:1	2.5:1	3.77:1	3.7:1	3.09:1	3.42:1	3.42:1	3.35:1	3.44:1
Number of Booster Engines	7	5	5	6	5	5	5	5	6	5	5	5	5
Booster Engines Vac. Thrust (lb)	494,000	661,400	656,340	690,530	675,400	855,660	596,070	690,740	545,710	740,560	653,940	766,010	734,680
P_C (psia)	3,270	4,000	4,000	2,500	1,300	1,650	4,300	3,300	4,000	2,600	4,000	3,300	3,900
Vacuum Isp - sec	437	416	326	311	294	304	347	338	328	316	330	318	325
Nozzle Expansion Ratio	35.0	50.3	28.8	45.0	15.0	15.0	22.7	28.9	21.6	22.8	25.0	28.2	29.9
N Near-Term F Far-Term	N	N	N	N	N	F	N	N	N	N	N	N	F
Booster Dry Weight (lb)	241,720	196,610	167,630	171,620	190,500	187,330	159,150	167,130	163,480	170,590	165,280	171,980	166,720
Orbiter Dry Weight (lb)	163,420	164,030	164,150	164,410	163,310	162,610	163,450	163,830	163,470	164,870	163,470	163,710	164,780
Total Dry Weight (lb)	405,140	360,630	331,780	336,030	353,810	349,940	322,600	330,960	326,950	335,460	328,750	335,690	331,490
GLOW (lb)	3,167,600	3,341,800	3,469,800	3,609,300	3,934,400	3,569,300	3,289,100	3,564,200	3,336,700	3,731,900	3,353,700	3,541,100	3,593,600
$V_{Staging}$ (ft/s)	5,000.0	4,922.3	4,232.2	4,172.7	5,278.2	5,075.1	4,743.8	5,135.6	4,425.3	4,280.9	4,518.5	4,624.8	4,180.6

Figure 3.1.1-5 Two-Stage Vehicle Optimized Results

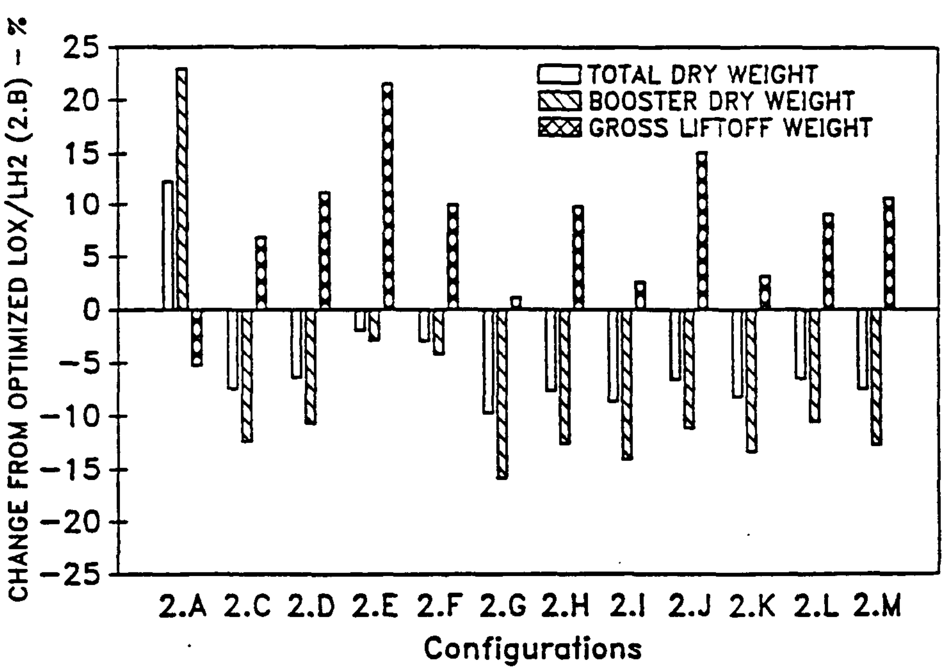

Figure 3.1.1-6 Two-Stage Weight Comparisons

The far term benefit of greater chamber pressures and higher specific impulse for RP-1 and propane fuel engines is shown in figure 3.1.1-7 . As shown, the benefit is small and probably not worth the expenditure of resources in this area.

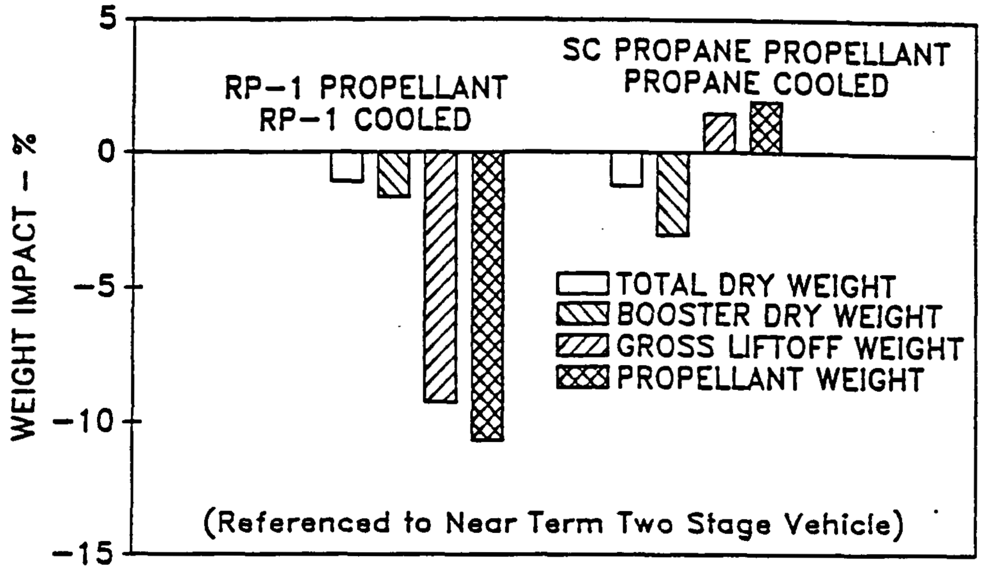

Figure 3.1.1-7 Far -Term Technology Impact on System Weights

3.1.1.1 Baseline Vehicle (Configuration 2.A)

Configuration Description. Figure 3.1.1.1-1 is a three-view drawing of configuration 2.A. A summary of the configuration features is shown in figure 3.1.1.1-2. Detailed performance and weight numbers are tabulated in the appendix on A-2 through A-5.

Note: This report locates the tabulated results in Appendix A and the computer optimized curves are shown in Appendix B. These tables and figures are separated from the text for clarity.

Optimization Sensitivities. Because this vehicle was configured only to establish a point-design solution to the performance requirement, detailed optimization was reserved for the design of the reference vehicle described in section 3.1.1.2.

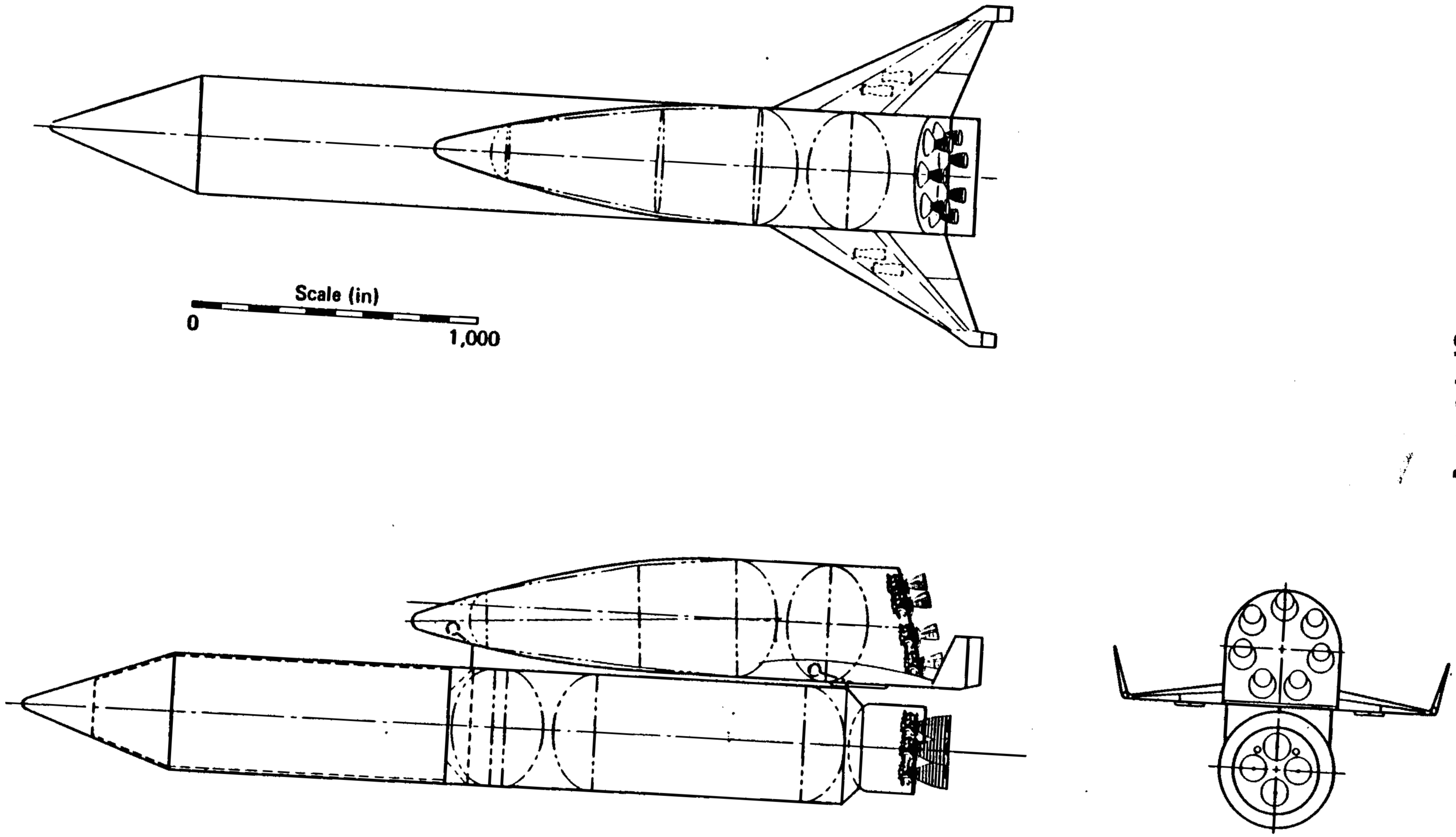

Figure 3.1.1.1-1. Three-View Drawing of Configuration 2.A

Vehicle Features			
• Weights		• Engines	
Dry Weight (lb) =	241,720	Type =	LH_2/LO_2
Propellant Weight (lb) =	1,035,000	Number =	7
- LO2 (lb) =	887,450	Thrust (vacuum, each) (lb) =	494,400
- LH2 (lb) =	147,910	MR =	6.00
Inert Weight (lb) =	227,620	P_C (psia) =	3,270
λ' =	0.783	I_{sp} =	437
• Body		ε =	35
$\frac{\ell}{D}$ =	4.53	$d_{powerhead}$ (in) =	100
		D_{nozzle} (in) =	60.5
D (ft) =	33.0	• Fins	
$S_{body\ flap}$ (ft^2) =	264	S_F (ft^2) (ea) =	167
• Wing		AR =	1.39
S_{ref} (ft^2) =	3,832	λ =	0.55
AR =	2.06	t/c =	11%
λ = 0.11		S_{rudder} (ft^2) (ea) =	50.0
t/c =	11%		
$S_{flaperons}$ (ft^2) =	766	• Flyback Engines	4
Orbiter:			
• Weights		• P/A Module (4 SSMEs)	
Dry Weight (lb) =	163,420	Weight (lb) =	122,000
Propellant Weight (lb) =	1,505,000	Circularization OMS	
- LO_2 (lb) =	1,289,700	Propellant (lb) =	9,470
- LH_2 (LB) =	214,950	Total OMS	
Inert Weight (lb) =	190,510	Propellant (lb) =	18,600
λ' =	0.888		
GLOW (lb) =	**3,167,600**		
$V_{staging}$ (ft/s) =	**5,000**		
P/L to Space Station (lb) =	**150,000**		

Figure 3.1.1.1-2. Summary of Configuration Features for Configuration 2.A

3.1.1.2 H_2/H_2 (Configuration 2.B)

Configuration Description. Figure 3.1.1.2-1 is a three-view drawing of configuration 2.B. Note the larger LOX tank as compared to the baseline because of the higher mixture ratio. A summary of configuration features for the optimized vehicle is shown in figure 3.1.1.2-2. Detailed performance and weight numbers are tabulated in the Appendix A-6 through A-9.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows (Appendix B-2 through B-25):

a.	Body diameter (booster):	29 to 33 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.3g
c.	Mixture ratio (booster):	6 to 12
d.	Orbiter propellant at staging:	34 to 44%
e.	Number of engines (booster):	4 to 8
f.	Expansion ratio (booster):	30 to 50

Detailed sensitivity analyses are presented in the appendix. These figures represent a locus of optimized designs. All independent variables were allowed to change (to optimize on minimum total dry weight) as the variable plotted on the abcisa was varied. For example, in appendix B-2 through B-5, as diameter was varied, other independent variables (number of engines, mixture ratio, liftoff acceleration) changed to achieve the minimum total dry weight design. This results in a different sensitivity than if all the other variables were fixed and the one parameter were varied, but is more representative to illustrate the time sensitivity of vehicle design to changes in a design variable. The design presented for a particular configuration, such as shown in figures 3.1.1.2-1 through 3.1.1.2-2 may not correlate to the designs shown in the sensitivity study due to a number of reasons:

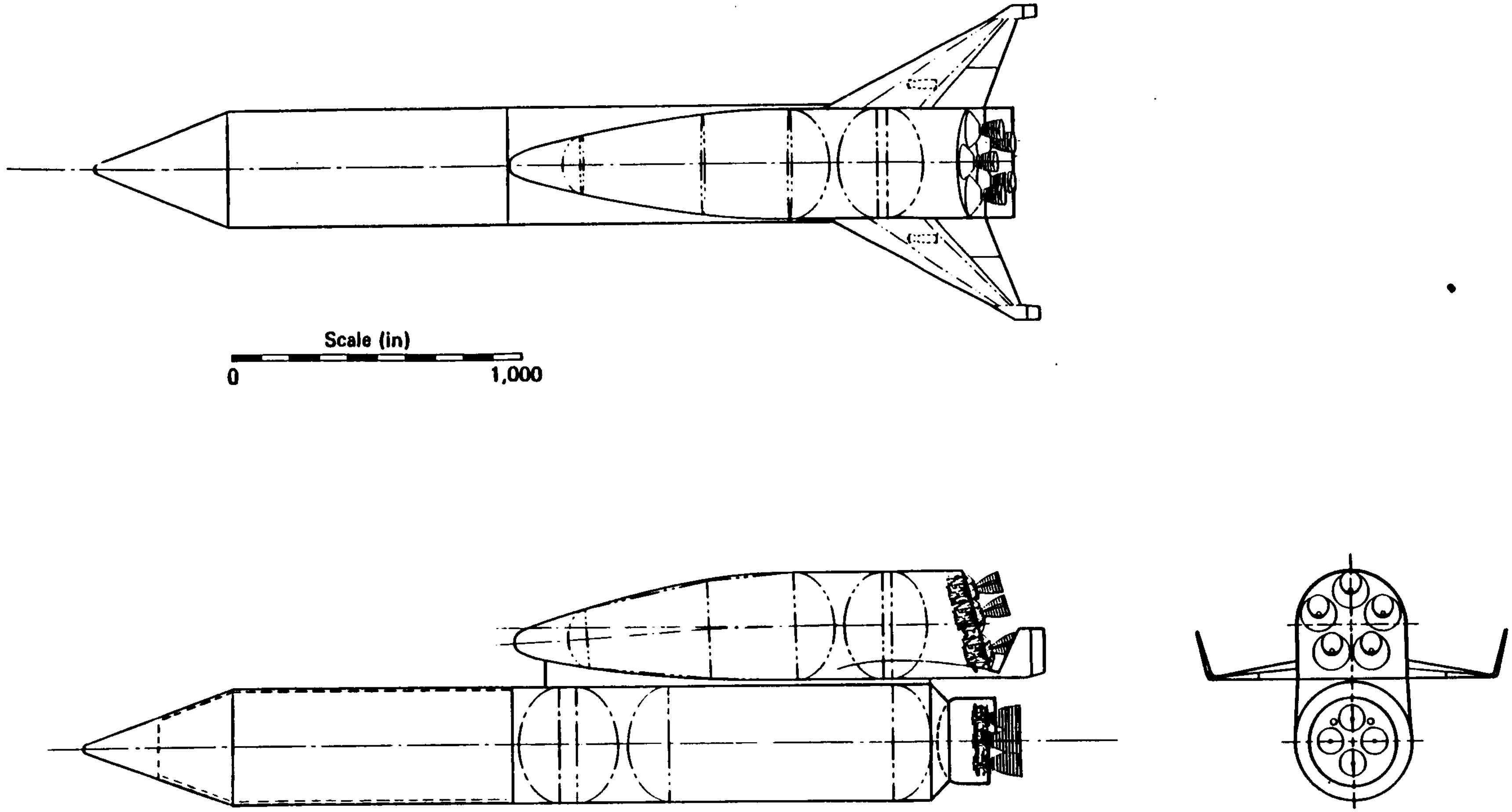

Figure 3.1.1.2-1. Three-View Drawing of Configuration 2.B

Configuration: 2.B

Booster:

Weights:

Dry Weight (lb) =	197,470
Propellant Weight (lb) =	1,074,000
- LO_2 (lb) =	966,380
- LH_2 (lb) =	107,690
Inert Weight (lb) =	227,380
λ' =	0.819

Body:

$\frac{\ell}{D}$ =	4.53
D (ft) =	30.5
$S_{body\ flap}$ (ft^2) =	244

Wing:

S_{ref} (ft^2) =	3,132
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	626

Engines:

Type:	LH_2/LO_2
Number =	5
Thrust (vacuum, each) (lb) =	671,110
MR:	8.97
P_C (psia) =	4,000
I_{sp} =	416
ε =	50.3
$d_{powerhead}$ (in) =	108.0
D_{nozzle} (in) =	74.0

Fins:

S_F (ft^2) (ea) =	144
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	43.3

Flyback Engines: 2

Orbiter:

Weights:

Dry Weight (lb) =	164,380
Propellant Weight (lb) =	1,601,000
- LO_2 (lb) =	1,372,000
- LH_2 (LB) =	228,670
Inert Weight (lb) =	192,050
λ' =	0.893

P/A Module (4 SSMEs):

Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,253,700
$V_{staging}$ (ft/s) =	4,524
P/L to Space Station (lb) =	150,000

Figure 3.1.1.2-2. Summary of Configuration Features for Configuration 2.B

a. Design shown in the sensitivity study may have the number of engines less than 5 (a constraint applied to the selected design to limit the booster engine thrust).

b. The sensitivity study designs may use a fractional number of engines.

c. The sensitivity study designs were constructed for a booster length/diameter (L/D) ratio constraint that it should equal 4.535. Due to the approximate nature of the optimization technique, the actual L/D, which results from input of the independent variables in the HAVCD Design Converger, will may be different from 4.535 by as much as 2%. For the final designs, the optimization was rerun on the computer with a constraint on L/D higher or lower than the desired value so that the value calculated by the HAVCD Design Converger will equal 4.535.

Consequently, the sensitivity study curves should only be used for sensitivity analysis rather than used to select design variable values.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing within the range of 30 to 31 ft diameter. Other sensitivities tend to be monotonic or bucket, with several exceptions. A minor breakpoint occurs at 29.9 ft, associated with reaching the lower limit on number of engines and breaking free from the upper limit on orbiter propellant at staging. Orbiter propellant at staging is relatively insensitive. Nozzle expansion ratio optimized at the upper limit (50:1) over the range of variation. (Appendix B-2 through B-5).

Engine-out Liftoff Acceleration. Total dry weight minimizes at about 1.19g. A major breakpoint occurs at 1.235g, associated with breaking free from the lower limit on number of booster engines. This results in trend reversals in engine thrust level. Landing weight, throttle setting, and body diameter are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (44%) and nozzle expansion ratio at its upper limit (50:1) over the range of variation (Appendix B-6 through B-9).

Mixture Ratio. Total dry weight minimizes at a mixture ratio of about 8.8, but is relatively insensitive over the range of variation. Two breakpoint conditions exist: one at 9.4 and one at 11.3. The former is associated with breaking free from the upper limit on orbiter propellant at staging. The latter is associated with breaking free from the lower limit on number of booster engines and breaking free from the upper limit on nozzle expansion ratio. Throttle setting is relatively insensitive over the range of variation (Appendix B-10 through B-13).

Orbiter Propellant at Staging. Total dry weight minimizes between 41% and 42%, but is relatively insensitive over the range of variation. Other sensitivities tend to be monotonic or bucket. The nozzle expansion ratio optimized at its lower limit (30:1) over the range of variation (Appendix B-14 through B-17).

Number of Booster Engines. Total dry weight minimizes at four engines, and is moderately sensitive over the range of variation. Propellant mass fraction and initial throttle setting are relatively insensitive, however. Nozzle expansion ratio optimized at its lower limit (30:1) over the range of variation (Appendix B-18 through B-21).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of 50:1, but is relatively insensitive over the range of variation. A breakpoint occurs at an expansion ratio of 48:1, associated with the beginning of an abrupt transition to the lower limit on number of booster engines. Throttle setting is relatively insensitive over the range of variation, between 41% and 42%, but is relatively insensitive over the range of variation. Other sensitivities tend to be monotonic or bucket. The nozzle expansion ratio optimized at its lower limit (30:1) over the range of variation (Appendix B-22 through B-25).

3.1.1.3 RP-1/H_2 (P_c = 4000 psia) (Configuration 2.C)

Configuration Description. Figure 3.1.1.3-1 is a three-view drawing of configuration 2.C. A summary of configuration features is shown in figure 3.1.1.3-2. Detailed performance and weight numbers are tabulated in the Appendix A-10 through A-13.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a. Body diameter (booster): 28 to 32 ft

b. Minimum liftoff acceleration: 1.1 to 1.4g

c. Mixture ratio (booster): 2.5 to 4.0

d. Percent propellant at staging: 30 to 40

e. Number of engines (booster): 3 to 8

f. Expansion ratio (booster): 15 to 40

(Mixture ratio is defined for LOX/hydrocarbon propellant only. LH_2 coolant is apportioned as a percentage of the main propellant mass flow). Detailed sensitivity analyses are presented in the appendix B-26 through B-49 and are discussed below.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing within the range of 29 to 30-ft diameter. Minimization of total dry weight coincides with the maximization of gross liftoff weight. Staging velocity optimized at approximately 4232 ft/s for all body diameters (Appendix B-26 through B-29).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.1g, with only moderate sensitivity over the range of variation. A minor breakpoint occurs at 1.151g, when the maximum limit is reached for orbiter propellant at staging. Staging velocity is optimized at approximately 4232 ft/s for all accelerations (Appendix B-30 through B-33).

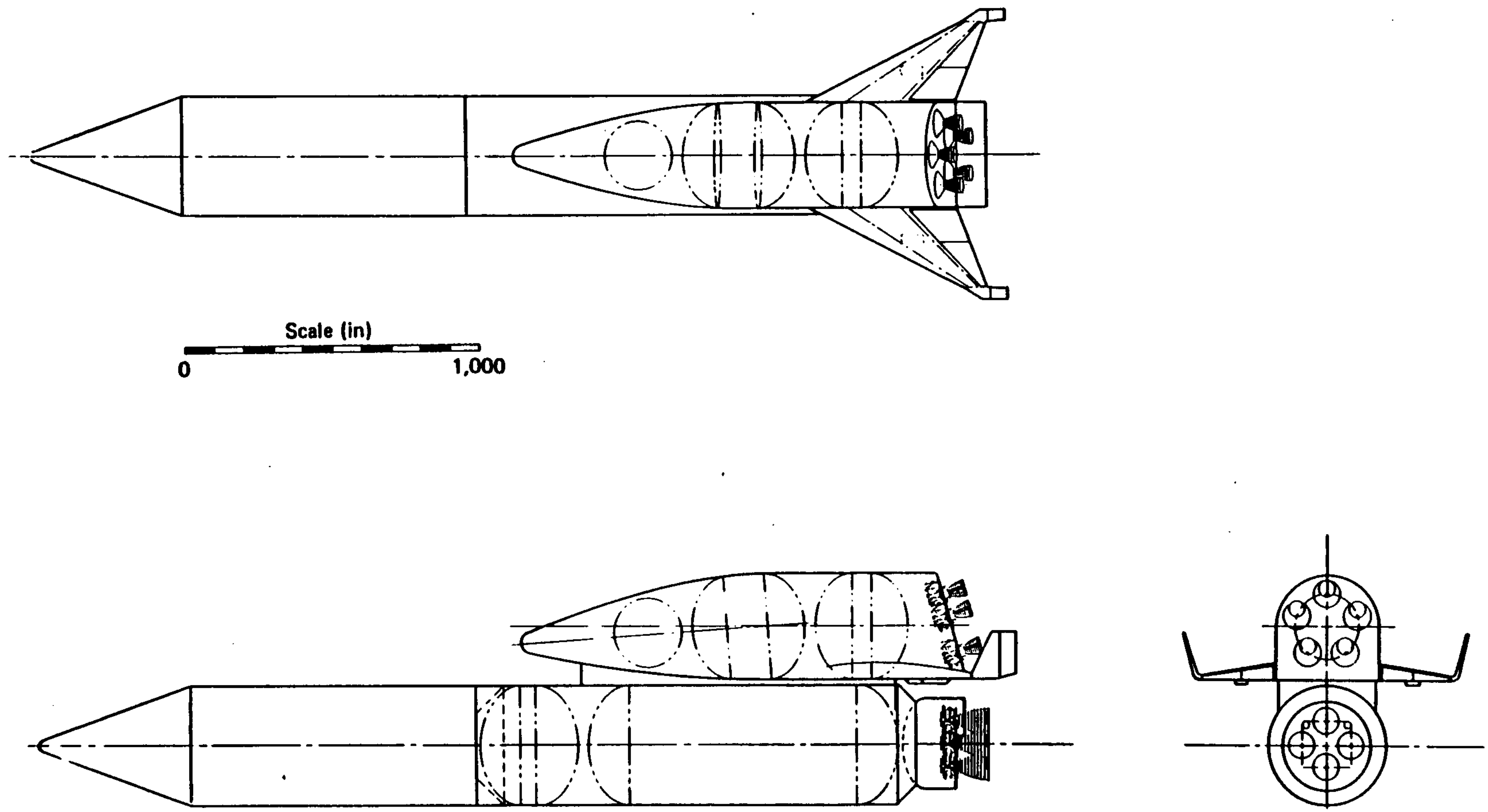

Figure 3.1.1.3-1. Three-View Drawing of Configuration 2.C

Configuration: 2.C

Booster:

Weights:	
Dry Weight (lb) =	167,630
Propellant Weight (lb) =	1,346,280
- LO_2 (lb) =	1,030,000
- Methane (lb) =	299,220
- LH_2 (lb) =	17,060
Inert Weight (lb) =	195,350
λ' =	0.870

Engines:	
Type:	RP-1/LH_2
Number =	5
Thrust (vacuum, each) (lb) =	656,340
MR:	3.44
P_C (psia) =	4,000
I_{sp} =	326
ε =	28.82
$d_{powerhead}$ (in) =	98
D_{nozzle} (in) =	53.9

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	29.4
$S_{body\ flap}$ (ft2) =	235

Fins:	
S_F (ft2) (ea) =	129
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft2) (ea) =	38.8

Wing:	
S_{ref} (ft2) =	2,663
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft2) =	533

Flyback Engines:	2

Orbiter:

Weights:	
Dry Weight (lb) =	164,150
Propellant Weight (lb) =	1,577,100
- LO_2 (lb) =	1,351,800
- LH_2 (LB) =	225,300
Inert Weight (lb) =	195,350
λ' =	0.890

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,469,800
$V_{staging}$ (ft/s) =	4,263
P/L to Space Station (lb) =	150,000

Figure 3.1.1.3-2. Summary of Configuration Features for Configuration 2.C

Mixture Ratio. Total dry weight minimizes at a mixture ratio of 3.2 to 3.3, but is relatively insensitive over the range of variation. A minor breakpoint occurs at approximately 2.7, when the orbiter propellant at staging decreases from its maximum limit. Staging velocity optimizes at approximately 4232 ft/s and the engine-out liftoff acceleration is optimized at its lower limit (1.1g) for all mixture ratios (Appendix B-34 through B-37).

Orbiter Propellant at Staging. Total dry weight minimizes at 38%, but is relatively insensitive over the range of variation. Staging velocity is optimized at approximately 4232 ft/s and the engine-out liftoff acceleration is optimized at its lower limit (1.1g) over the range of variation (Appendix B-38 through B-41).

Number of Booster Engines. Total dry weight minimizes at four engines, but is relatively insensitive over the range of three to five engines. A major breakpoint occurs at seven engines, where the engine-out liftoff acceleration increases from its lower limit (1.1g). This results in trend reversals for gross liftoff weight, body diameter, LH_2 coolant weight, throttle setting, orbiter propellant at staging, and nominal liftoff acceleration. Staging velocity optimized at approximately 4232 ft/s over the range of variation (Appendix B-42 through B-45).

Expansion Ratio. Total dry weight minimizes near an expansion ratio of 25:1 but is relatively insensitive over the range from 20:1 to 30:1. Other sensitivities are minor: Propellant mixture ratio is optimized at approximately 3.25, staging velocity is optimized at approximately 4232 ft/s, and engine-out liftoff acceleration is optimized at its lower limit (1.1g) over the range of variation (Appendix B-46 through B-49).

3.1.1.4 RP-1/H_2 (P_c = 2500 psia) (Configuration 2.D)

Configuration Description. Figure 3.1.1.4-1 is a three-view drawing of configuration 2.D. A summary of configuration features is shown in figure 3.1.1.4-2. Detailed performance and weight numbers are tabulated in the appendix A-14 through A-17.

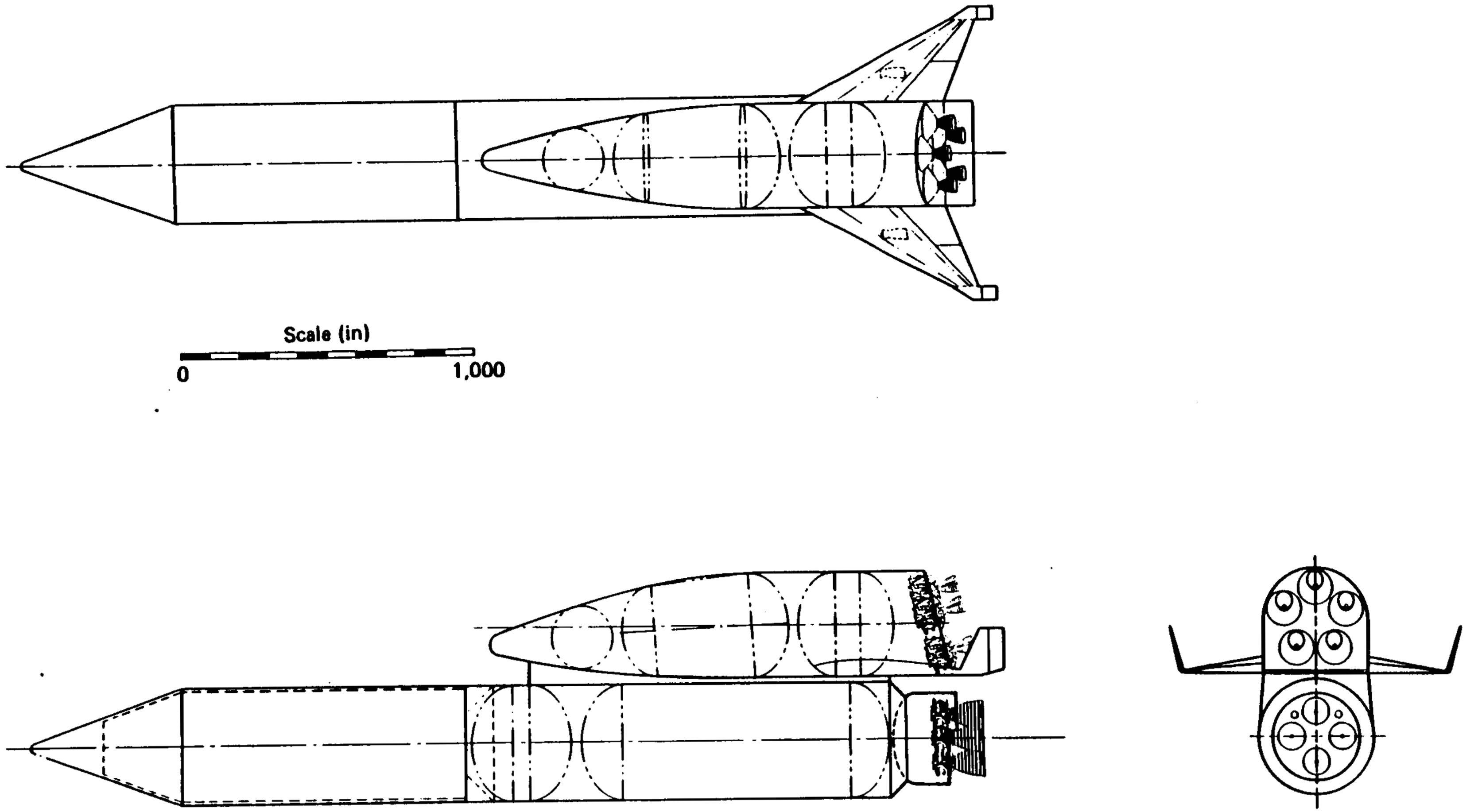

Figure 3.1.1.4-1. Three-View Drawing of Configuration 2.D

Configuration: 2.D

Booster:

Weights:	
Dry Weight (lb) =	171,620
Propellant Weight (lb) =	1,455,000
- LO_2 (lb) =	1,104,200
- RP-1 (lb) =	338,020
- LH_2 (lb) =	12,520
Inert Weight (lb) =	200,130
λ' =	0.874

Engines:	
Type:	RP-1/LH_2
Number =	5
Thrust (vacuum, each) (lb) =	690,530
MR:	3.27
P_C (psia) =	2,500
I_{sp} =	311
ε =	14.85
$d_{powerhead}$ (in) =	125.0
D_{nozzle} (in) =	50.4

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	29.3
$S_{body\ flap}$ (ft^2) =	234

Fins:	
S_F (ft^2) (ea) =	131
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	39.4

Wing:	
S_{ref} (ft^2) =	2.725
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	545

Flyback Engines:	2

Orbiter:

Weights:	
Dry Weight (lb) =	164,410
Propellant Weight (lb) =	1,603,000
- LO_2 (lb) =	1,373,900
- LH_2 (LB) =	228,980
Inert Weight (lb) =	192,080
λ' =	0.893

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,609,300
$V_{staging}$ (ft/s) =	4,173
P/L to Space Station (lb) =	150,000

Figure 3.1.1.4-2. Summary of Configuration Features for Configuration 2.C

Optimization Sensitivities. The optimization constraints on the selected independent variables are identical to those given in section 3.1.1.3. Detailed sensitivity analyses are presented in the appendix B-50 through B-73 and are discussed below.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing within the range of 29 to 30-ft diameter, much as the previous vehicle configuration. Many sensitivities have dramatic discontinuities and trend reversals associated with the following breakpoints (Appendix B-50 through B-53):

a. 28.9 ft: maximum limit, orbiter propellant at staging.

b. 29.3 ft: minimum limit, engine-out liftoff acceleration.

c. 29.9 ft: minimum limit, expansion ratio.

d. 30.7-31.0 ft: minimum limit, number of booster engines.

Engine-out *Liftoff* Acceleration. Total dry weight minimizes at 1.1g, with only moderate sensitivity over the range of variation. A minor breakpoint occurs at approximately 1.23g, when the maximum limit is reached for percent of orbiter propellant at staging. Nozzle expansion ratio is optimized at its lower limit (15:1) for the range of variation (Appendix B-54 through B-57).

Mixture Ratio. Total dry weight minimizes at a mixture ratio of 3.2, but is relatively insensitive over the range of variation. A minor breakpoint occurs for the range 3.7 to 3.8, when nozzle expansion ratio increases from its lower limit. Engine-out liftoff acceleration optimized at its lower limit (1.1g) for the range of variation (Appendix B-58 through B-61).

Orbiter Propellant at Staging. Total dry weight minimizes at 39 to 40%, but is relatively insensitive over the range of variation. Other sensitivities are either monotonic or bucket in form. Engine-out liftoff acceleration optimized at its lower limit (1.1g) and nozzle expansion ratio optimized at its lower limit (15:1) over the range of variation (Appendix B-62 through B-65).

Number of Booster Engines. Total dry weight minimizes at three engines, but is relatively insensitive over the range of three to six engines. Major breakpoints occur near 5.9 to 6.3 and 7.0, where engine-out liftoff acceleration increases from its lower limit and nozzle expansion ratio increases from its lower limit, respectively (Appendix B-68 through B-69).

Expansion Ratio. Total dry weight minimizes near an expansion ratio of 17:1, but is relatively insensitive over the range from 15:1 to 35:1. Other sensitivities are minor. Engine-out liftoff acceleration is optimized at its lower limit (1.1g) over the range of variation (Appendix B-70 through B-73).

3.1.1.5 RP-1/RP-1 (Configuration 2.E)

Configuration Description. Figure 3.1.1.5-1 is a three-view drawing of configuration 2.E. A summary of configuration features is shown in figure 3.1.1.5-2. Detailed performance and weight numbers are tabulated in the appendix A-18 through A-21.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	26 to 30 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.3g
c.	Mixture ratio (booster):	2.5 to 4.0
d.	Orbiter propellant at staging:	27 to 35
e.	Number of booster engines:	4 to 8
f.	Expansion ratio:	15 to 40

Detailed sensitivity analyses are presented in the appendix B-74 through B-97 and are discussed below.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing within the range of 26.5 to 27.0-ft diameter. The major breakpoints occur at 26.9, 27.35, and 27.75 ft. The first is difficult to explain. The second is associated with reaching the higher limit on number of booster engines. The third is associated with reaching the minimum limit on engine-out liftoff acceleration. Nozzle expansion ratio is optimized at its lower limit (15:1) over the range of variation (Appendix B-74 through B-77).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.15g with only moderate sensitivity over the range of variation. A major break in most of the sensitivity curves occurs between 1.125 and 1.165g, associated with a rapid decrease in the number of engines (from six to three) and limiting at four engines. Propellant mixture ratio and vehicle body diameter are relatively insensitive, and nozzle expansion

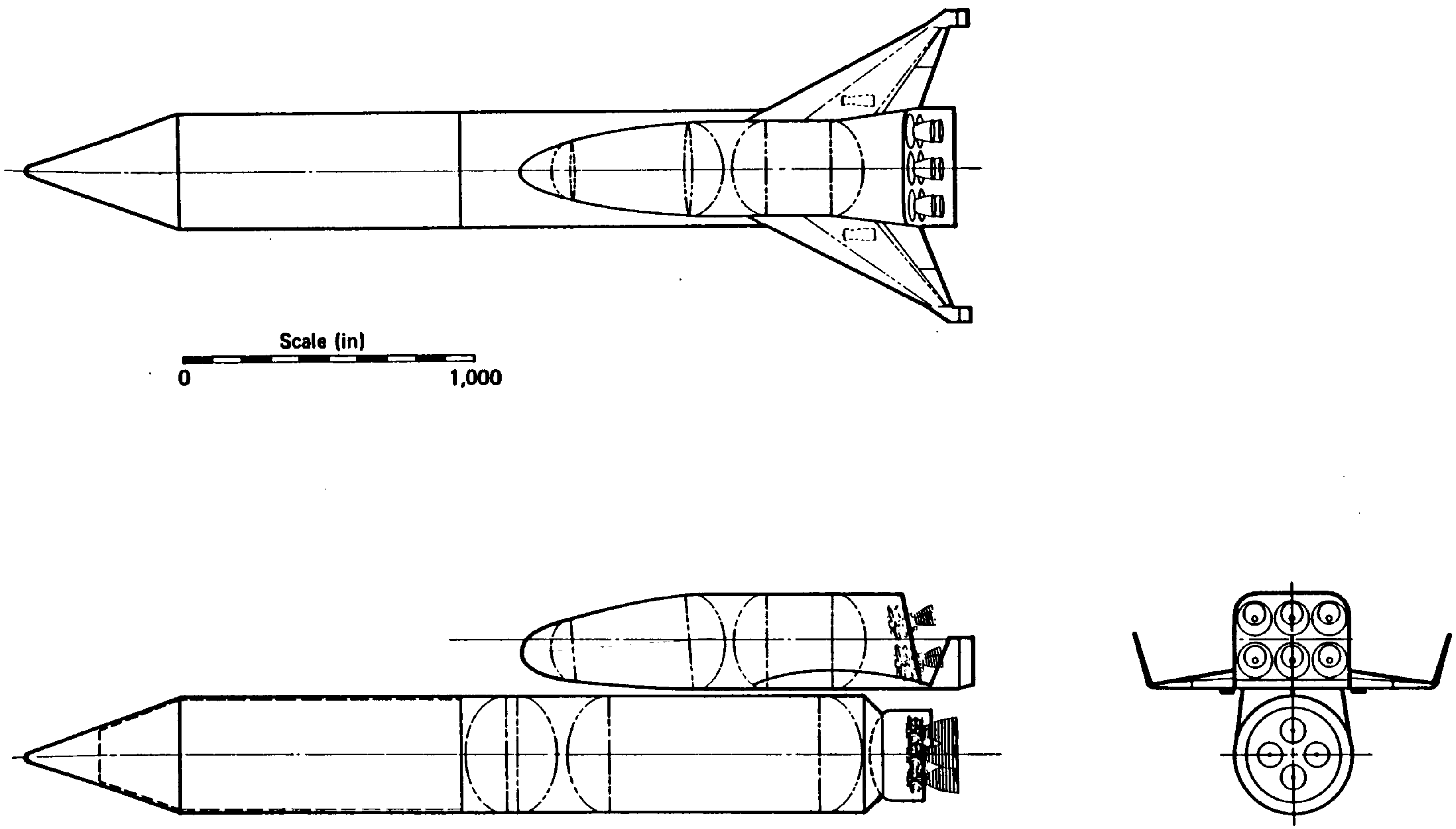

Figure 3.1.1.5-1. Three-View Drawing of Configuration 2.E

Configuration: 2.E

Booster:

Weights:	
Dry Weight (lb) =	191,000
Propellant Weight (lb) =	1,865,000
- LO_2 (lb) =	1,415,000
- RP-1 (lb) =	449,000
Inert Weight (lb) =	199,000
λ' =	0.888

Engines:	
Type:	RP-1/RP-1
Number =	6
Thrust (vacuum, each) (lb) =	620,000
MR:	3.15
P_C (psia) =	1,300
I_{sp} =	294
ε =	15.00
$d_{powerhead}$ (in) =	120.0
D_{nozzle} (in) =	69.4

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	27.2
$S_{body\ flap}$ (ft^2) =	218

Fins:	
S_F (ft^2) (ea) =	141
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	42.23

Wing:	
S_{ref} (ft^2) =	3,023
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	605

Flyback Engines:	2

Orbiter:

Weights:	
Dry Weight (lb) =	163,000
Propellant Weight (lb) =	1,493,000
- LO_2 (lb) =	1,280,000
- LH_2 (LB) =	213,000
Inert Weight (lb) =	190,000
λ' =	0.887

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,934,000
$V_{staging}$ (ft/s) =	5,278
P/L to Space Station (lb) =	150,000

Figure 3.1.1.5-2. Summary of Configuration Features for Configuration 2.E

ratio optimized at its lower limit (15:1) over the range of variation (Appendix B-78 through B-81).

Mixture Ratio. Total dry weight minimizes at a mixture ratio of 3.0, but is only moderately sensitive over the range of variation. Two breakpoints are evident: a minor one at 2.83 and a major one at 3.16. The minor one is associated with breaking free of the lower limit on number of booster engines. The major one is difficult to explain. Nozzle expansion ratio optimized at its lower limit (15:1) over the range of variation (Appendix B-82 through B-85).

Orbiter Propellant at Staging. Total dry weight minimizes at 31.5% propellant onboard, with only moderate sensitivity over the range of variation. A major break in most of the sensitivity curves occurs between 30% and 32%, associated with breaking free of the lower limit on engine-out liftoff acceleration and with reaching the lower limit on number of booster engines, respectively. Nozzle expansion ratio optimizes at its lower limit (15:1) over the range of variation (Appendix B-86 through B-89).

Number of Booster Engines. Total dry weight minimizes at four or five engines, but is relatively insensitive over the range of variation. Propellant mass fraction, body diameter, propellant mixture ratio, throttle setting, orbiter propellant at staging, and engine-out liftoff acceleration are relatively insensitive to number of engines. Nozzle expansion ratio optimizes at its lower limit (15:1) over the range of variation (Appendix B-90 through B-93).

Expansion Ratio. Total dry weight minimizes near an expansion ratio of 20:1, but is relatively insensitive over the range from 15:1 to 25:1. Major breakpoints occur at 17.2:1 and 20.5:1, associated with reaching the lower limit on engine-out liftoff acceleration and with reaching the lower limit on number of booster engines, respectively. Throttle setting and engine-out liftoff acceleration are relatively insensitive to nozzle expansion ratio (Appendix B-94 through B-97).

3.1.1.6 RP-1/RP-1 Far-Term Performance (Configuration 2.F)

Configuration Description. Figure 3.1.1.6-1 is a three-view drawing of configuration 2.F. A summary of configuration features is shown in figure 3.1.1.6-2. Detailed performance and weight numbers are tabulated in the appendix A-22 through A-25.

Optimization Sensitivities. The optimization constraints on the selected independent variables are identical to those given in section 3.1.1.5. Detailed sensitivity analyses are presented in the appendix B-98 through B-121 and are discussed below.

Body Diameter. Total dry weight, in this case, is a "semibucket" function, minimizing at 26-ft diameter. The sensitivity curves are quite broken up in accordance with the following breakpoints (Appendix B-98 through B-101):

a. 26.4-ft: minimum limit, propellant mixture ratio.

b. 26.9-ft: minimum limit, number of booster engines.

c. 27.8-ft: minimum limit, orbiter propellant at staging, engine-out liftoff acceleration, and expansion ratio.

d. 28.2-ft: minimum limit, engine-out liftoff acceleration and maximum limit, expansion ratio.

e. 29.1-ft: minimum limit, orbiter propellant at staging.

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.165g, but is relatively insensitive over the range 1.12 to 1.25g. Significant breakpoints are as follows:

a. 1.12g: minimum limit, number of booster engines.

b. 1.17g: maximum limit, percent propellant at staging.

c. 1.19g: minimum limit, expansion ratio.

d. 1.21g maximum limit, percent propellant at staging.

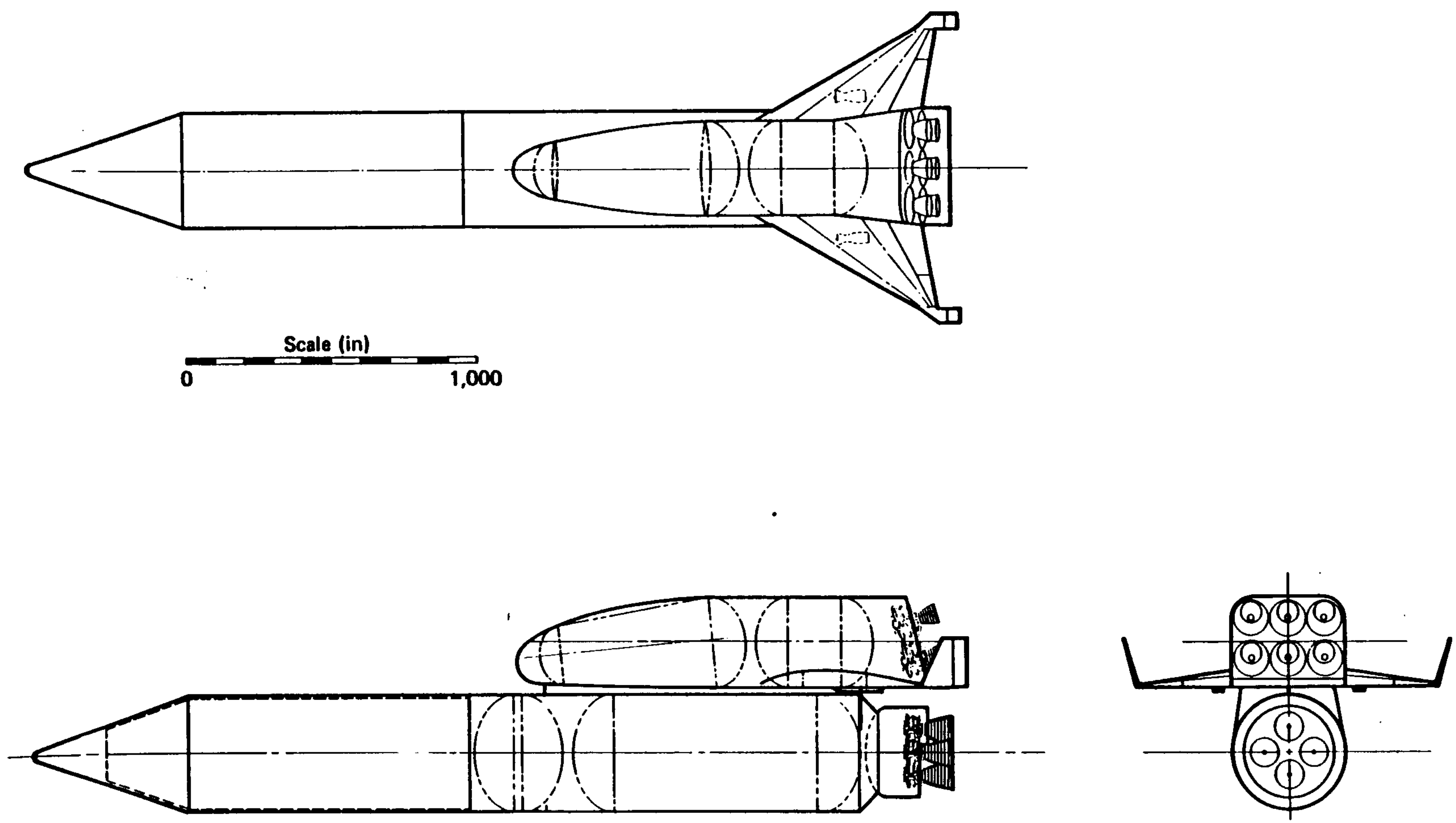

Figure 3.1.1.6-1. Three-View Drawing of Configuration 2.F

Configuration: 2.F			
Booster:			
Weights:		**Engines:**	
Dry Weight (lb) =	187,000	Type:	RP-1/RP-1
Propellant Weight (lb) =	1,577,000	Number =	6
- LO_2 (lb) =	1,126,000	Thrust (vacuum, each) (lb) =	620,000
- RP-1 (lb) =	450,000	MR:	2.50
Inert Weight (lb) =	105,000	P_C (psia) =	1,650
λ' =	0.873	I_{sp} =	304
		ε =	15.00
		$d_{powerhead}$ (in) =	120
		D_{nozzle} (in) =	69.39
Body: $\frac{\ell}{D}$ =	4.53		
D (ft) =	26.0	**Fins:** S_F (ft^2) (ea) =	138.87
$S_{body\ flap}$ (ft^2) =	208	AR =	1.39
		λ =	0.55
Wing: S_{ref} (ft^2) =	2,964.60	t/c =	11%
AR =	2.06	S_{rudder} (ft^2) (ea) =	41.66
λ =	0.11		
t/c =	11%		
$S_{flaperons}$ (ft^2) =	592.92	**Flyback Engines:**	2
Orbiter:			
Weights:		**P/A Module (4 SSMEs):**	
Dry Weight (lb) =	163,000	Weight (lb) =	122,000
Propellant Weight (lb) =	1,423,000	Circularization OMS	
- LO_2 (lb) =	1,220,000	Propellant (lb) =	9,470
- LH_2 (lb) =	203,000	Total OMS	
Inert Weight (lb) =	189,000	Propellant (lb) =	18,600
λ' =	0.883		
GLOW (lb) =	3,569,000		
$V_{staging}$ (ft/s) =	5,075		
P/L to Space Station (lb) =	150,000		

Figure 3.1.1.6-2. Summary of Configuration Features for Configuration 2.F

Propellant mixture ratio optimized at its lower limit (2.5) over the range of variation (Appendix B-102 through B-105).

Mixture Ratio. Total dry weight minimizes near a mixture ratio of 2.8, with moderate sensitivity over the range of variation. Minor breakpoints include:

a. MR = 3.0: maximum limit, orbiter propellant at staging.

b. MR = 3.15: minimum limit, body diameter.

c. MR = 3.50: maximum limit, orbiter propellant at staging and minimum limit, body diameter.

Body diameter, throttle setting, orbiter propellant at staging, propellant mass fraction, engine-out liftoff acceleration, and nominal liftoff acceleration are relatively insensitive over the range of variation. Number of booster engines optimizes at its lower limit (four) and nozzle expansion ratio at its lower limit (15:1) over the range of variation (Appendix B-106 through B-109).

Orbiter Propellant at Staging. Total dry weight minimizes at approximately 31.5%, but is relatively insensitive over the range 29 to 35%. One breakpoint appears at 32.4%, associated with reaching the lower limit on number of engines (four). Propellant mixture ratio optimized at its higher limit (4.0) and nozzle expansion ratio at its lower limit (15:1) over the range of variation (Appendix B-110 through B-113).

Number of Booster Engines. Total dry weight minimizes for five or six engines, but is relatively insensitive over the range four to seven engines. A breakpoint appears at 5.4 engines (fractional engines are artifacts of the continuous-function algorithm used in the optimization program), associated with breaking free from the upper limit on orbiter propellant at staging and from the upper limit on engine-out liftoff acceleration. Propellant mixture ratio optimizes at its upper limit (4.0) and nozzle expansion ratio optimizes at its lower limit (15:1) over the range of variation (Appendix B-114 through B-117).

Expansion Ratio. Total dry weight minimizes over the range of 23:1 to 32:1, but is only moderately sensitive over the range of variation. Significant breakpoints are as follows:

a. 20.5: maximum limit, number of booster engines and minimum limit, engine-out liftoff acceleration.

b. 23.5: minimum limit, number of booster engines and maximum limit, orbiter propellant at staging.

c. 32.0: minimum limit, number of booster engines.

d. 34.5: minimum limit, engine-out liftoff acceleration.

Propellant mixture ratio optimized at its upper limit (4.0) over the range of variation (Appendix B-118 through B-121).

3.1.1.7 Methane/H_2 (Configuration 2.G)

Configuration Description. Figure 3.1.1.7-1 is a three-view drawing of configuration 2.G. A summary of configuration features is shown in figure 3.1.1.7-2. Detailed performance and weight numbers are tabulated in the appendix A-26 through A-29.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	28 to 32 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.3g
c.	Mixture ratio (booster):	3.0 to 4.5
d.	Orbiter propellant at staging:	35 to 50%
e.	Number of booster engines:	4 to 8
f.	Expansion ratio:	15 to 40

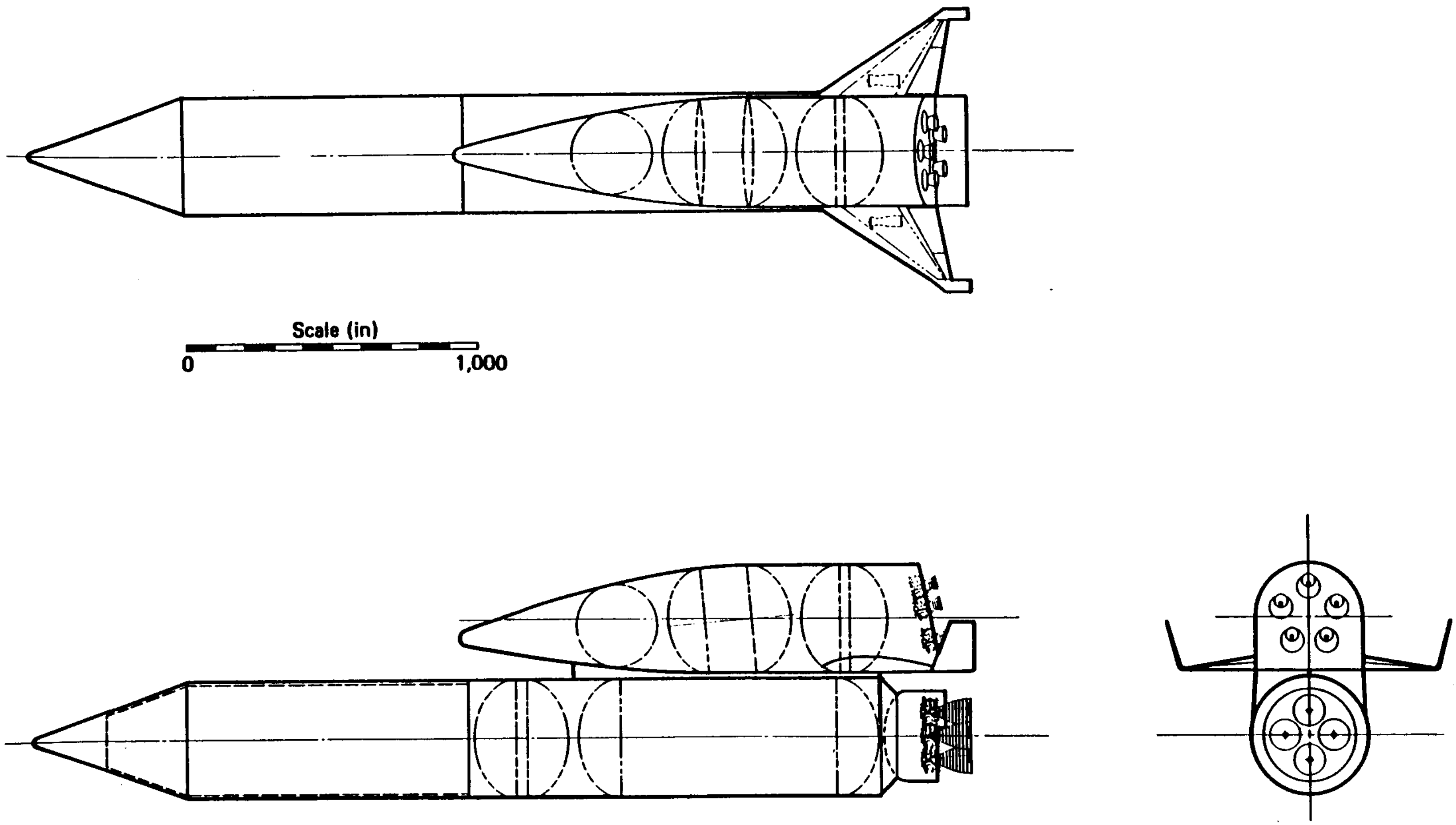

Figure 3.1.1.7-1. Three-View Drawing of Configuration 2.G

Configuration: 2.G

Booster:

Weights:	
Dry Weight (lb) =	159,150
Propellant Weight (lb) =	1,244,000
- LO_2 (lb) =	983,000
- Methane (lb) =	238,000
- LH_2 (lb) =	22,900
Inert Weight (lb) =	188,000
λ' =	0.863

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	30.3
$S_{body\ flap}$ (ft^2) =	243

Wing:	
S_{ref} (ft^2) =	2,245
AR =	2.36
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	449

Engines:	
Type:	Methane/LH_2
Number =	5
Thrust (vacuum, each) (lb) =	596,000
MR:	4.13
P_C (psia) =	4,300
I_{sp} =	347
ε =	22.75
$d_{powerhead}$ (in) =	92.7
D_{nozzle} (in) =	44.6

Fins:	
S_F (ft^2) (ea) =	125
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	37.6

Flyback Engines:	2

Orbiter:

Weights:	
Dry Weight (lb) =	163,000
Propellant Weight (lb) =	1,507,000
- LO_2 (lb) =	1,292,000
- LH_2 (lb) =	215,000
Inert Weight (lb) =	191,000
λ' =	0.888

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,289,000
$V_{staging}$ (ft/s) =	4,734
P/L to Space Station (lb) =	150,000

Figure 3.1.1.7-2. Summary of Configuration Features for Configuration 2.G

Detailed sensitivity analyses are presented in appendix B-122 through B-145 and are discussed below.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing within the range of 30- to 31-ft diameter but is only moderately sensitive over the range of variation. Two breakpoints appear to exist: at 29.3 and 30.2 ft. The former is difficult to explain. The latter is associated with reaching the lower limit on number of booster engines and the lower limit on engine-out liftoff acceleration (Appendix B-122 through B-125).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.1g, the lower limit, but is only moderately sensitive over the range of variation. A single breakpoint appears to exist at 1.19g, corresponding to optimizations breaking free from the lower limit on number of booster engines (Appendix B-126 through B-129).

Mixture Ratio. Total dry weight minimizes at 3.65 but is relatively insensitive over the range of variation, as are propellant mass fraction, throttle setting, orbiter propellant at staging, and nominal liftoff acceleration. The number of booster engines optimized at its lower limit (four) and engine-out liftoff acceleration optimized at its lower limit (1.1g) over the range of variation (Appendix B-130 through B-133).

Orbiter Propellant at Staging. Total dry weight minimizes at approximately 36.5%, but is only moderately sensitive over the range of variation. A single breakpoint occurs at 40%, corresponding to breaking free of the lower–limit on engine-out liftoff acceleration. The number of booster engines optimizes at its lower limit (four) over the range of variation (Appendix B-134 through B-137).

Number of Booster Engines. Total dry weight minimizes at four engines, but is relatively insensitive over the range of interest. A breakpoint occurs at 6.2 engines (fractional engines are artifacts of the continuous-function algorithm used in the optimization program), associated with breaking free from the lower limit on engine-out liftoff acceleration. Propellant mass fraction, body diameter, propellant mixture ratio, and throttle setting are relatively insensitive over the range of variation (Appendix B-138 through B-141).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of 23:1, but is relatively insensitive over the range of variation, as are propellant mass fraction, throttle setting, nominal liftoff acceleration, and body diameter. The number of engines optimized at its lowest limit (four) and engine-out liftoff acceleration optimized at its lowest limit (1.1g) over the range of variation (Appendix B-142 through B-145).

3.1.1.8 Methane/Methane (Configuration 2.H)

Configuration Description. Figure 3.1.1.8-1 is a three-view drawing of configuration 2.H. A summary of configuration features is shown in figure 3.1.1.8-2. Detailed performance and weight numbers are tabulated in appendix A-30 through A-33.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	25 to 29 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.3g
c.	Mixture ratio (booster):	3.0 to 4.5
d.	Orbiter propellant at staging:	27 to 37%
e.	Number of booster engines:	4 to 8
f.	Expansion ratio:	15 to 40

Detailed sensitivity analyses are presented in the appendix B-146 through B-169 and are discussed below.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing in the range of 26 to 27 ft and moderately sensitive over the range of variation. Three breakpoints occur: at 26.8, 27.7, and 28.6 ft in diameter. The first corresponds to

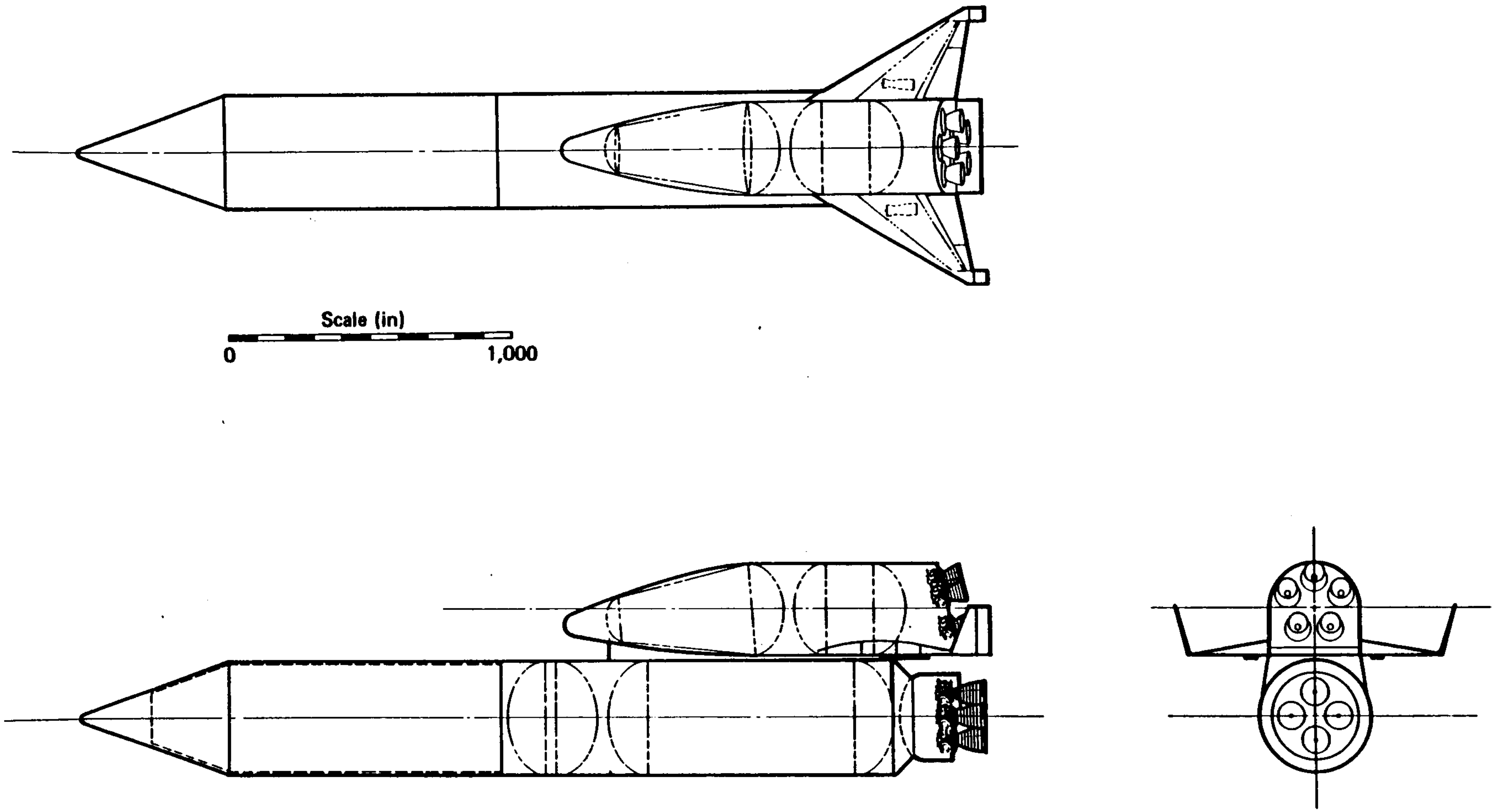

Figure 3.1.1.8-1. Three-View Drawing of Configuration 2.H

Configuration: 2.H

Booster:

Weights:

Dry Weight (lb) =	167,130
Propellant Weight (lb) =	1,469,000
- LO_2 (lb) =	1,156,000
- Methane (lb) =	313,000
Inert Weight (lb) =	199,000
λ' =	0.876

Body:

$\frac{\ell}{D}$ =	4.53
D (ft) =	26.6
$S_{body\ flap}$ (ft2) =	213

Wing:

S_{ref} (ft2) =	2,662
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft2) =	532

Engines:

Type:	Methane/Methane
Number =	5
Thrust (vacuum, each) (lb) =	691,000
MR:	3.70
P_C (psia) =	3,300
I_{sp} =	338
ε =	15.00
$d_{powerhead}$ (in) =	109
D_{nozzle} (in) =	69.4

Fins:

S_F (ft2) (ea) =	129
AR =	1.51
λ =	0.55
t/c =	11%
S_{rudder} (ft2) (ea) =	38.8

Flyback Engines: 2

Orbiter:

Weights:

Dry Weight (lb) =	164,000
Propellant Weight (lb) =	1,546,100
- LO_2 (lb) =	1,325,000
- LH_2 (lb) =	221,000
Inert Weight (lb) =	191,000
λ' =	0.890

P/A Module (4 SSMEs):

Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,564,000
$V_{staging}$ (ft/s) =	5,136
P/L to Space Station (lb) =	150,000

Figure 3.1.1.8-2. Summary of Configuration Features for Configuration 2.H

reaching the lower limit on number of booster engines and the lower limit on engine-out liftoff acceleration. The second corresponds to reaching the lower limit on propellant mixture ratio. The third is difficult to explain. Throttle setting is relatively insensitive over the range of variation (Appendix B-146 through B-149).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.1g and is moderately sensitive over the range of variation. Two breakpoints occur: at 1.125g (associated with breaking free from the lower limit on number of booster engines) and at 1.255g (associated with reaching a plateau value for the orbiter propellant at staging) (Appendix B-150 through B-153).

Mixture Ratio. Total dry weight minimizes at a ratio of 3.6, but is relatively insensitive over the range of variation. No significant breakpoints occur. Propellant mass fraction, body diameter, throttle setting, orbiter propellant at staging, and nominal liftoff acceleration are relatively insensitive over the range of variation. The number of booster engines optimized at its lower limit (four) and engine-out liftoff acceleration optimized at its lower limit (1.1g) over the range of variation (Appendix B-154 through B-157).

Orbiter Propellant at Staging. Total dry weight minimizes at 37%, and is only moderately sensitive over the range of variation. Two breakpoints occur: at 34.5% and 36%. The first is associated with reaching the lower limit on number of booster engines. The second is associated with breaking free of the lower limit on engine-out liftoff acceleration (Appendix B-158 through B-161).

Number of Booster Engines. Total dry weight minimizes at four engines, but is only moderately sensitive over the range of variation. A breakpoint occurs at 4.9 engines (fractional engines are artifacts of the continuous-function algorithm used in the optimization program) associated with breaking free of the lower limit on engine-out liftoff acceleration. Propellant mass fraction, body diameter, propellant mixture ratio, throttle setting, and staging velocity are relatively insensitive over the range of variation (Appendix B-162 through B-165).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of 23:1 but is relatively insensitive over the range of variation. A minor breakpoint occurs at 22:1, associated with reaching the lower limit of engine-out liftoff acceleration. Propellant mass fraction, throttle setting, engine out and nominal liftoff acceleration, and body diameter are also relatively insensitive over the range of variation. The number of booster engines optimized at its lower limit (four) over the range of variation (Appendix B-166 through B-169).

3.1.1.9 NBP Propane/H_2 (Configuration 2.I)

Configuration Description. Figure 3.1.1.9-1 is a three-view drawing of configuration 2.I. A summary of configuration features is shown in figure 3.1.1.9-2. Detailed performance and weight numbers are tabulated in the appendix A-34 through A-37.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	28 to 32 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.4g
c.	Mixture ratio (booster):	2.0 to 4.0
d.	Orbiter propellant at staging:	30 to 40%
e.	Number of booster engines:	4 to 8
f.	Expansion ratio:	15 to 50

Detailed sensitivity analyses are presented in the appendix B-170 through B-193 and are discussed below.

Body Diameter. Total dry weight is a "ragged bucket" function, minimizing at approximately 29.3 ft, with moderate sensitivity over the range of variation. Two breakpoints occur: at 30.2 and 30.7-ft diameter. The first is associated with reaching the lower limit on engine-out liftoff acceleration. The second is associated with reaching the lower limit on number of booster engines. Propellant mass fraction is relatively insensitive over the range of variation (Appendix B-170 through B-173).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.15g with moderate sensitivity over the range of variation. Minor breakpoints occur at 1.23g (associated with reaching the lower limit on nozzle expansion ratio) and 1.27g (associated with reaching the upper limit on orbiter propellant at staging). A major breakpoint occurs over the span 1.335 to 1.365g, associated with a rapid transition to

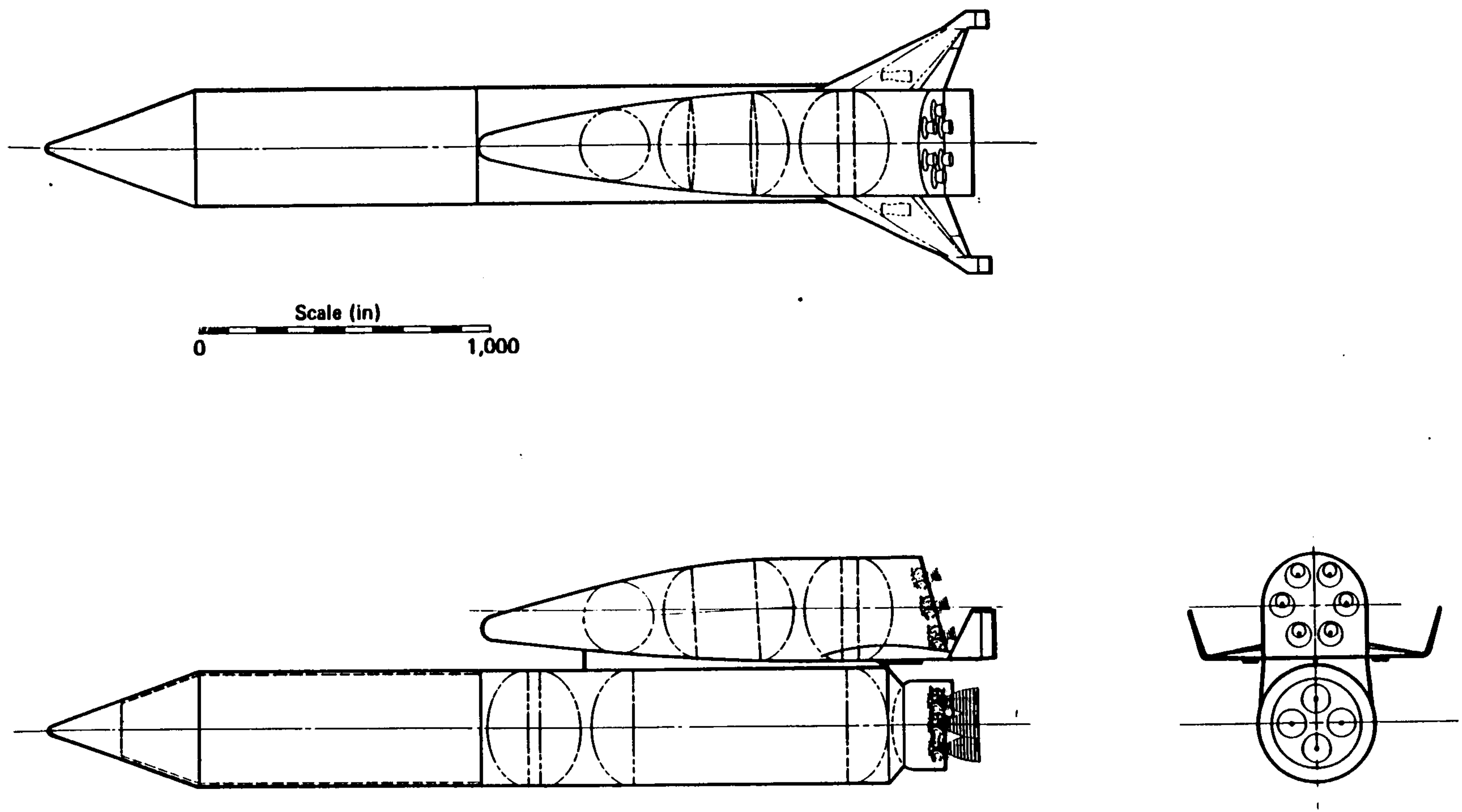

Figure 3.1.1.9-1. Three-View Drawing of Configuration 2.I

Configuration: 2.I

Booster:

Weights:	
Dry Weight (lb) =	163,000
Propellant Weight (lb) =	1,283,000
- LO_2 (lb) =	991,000
- NPB Propane (lb) =	273,000
- LH_2 Coolant (lb) =	18,300
Inert Weight (lb) =	194,000
λ' =	0.898

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	29.6
$S_{body\ flap}$ (ft^2) =	237

Wing:	
S_{ref} (ft^2) =	2,636
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	527

Engines:	
Type:	Propane/LH_2
Number =	6
Thrust (vacuum, each) (lb) =	546,000
MR:	3.40
P_C (psia) =	4,000
I_{sp} =	328
ε =	21.38
$d_{powerhead}$ (in) =	93
D_{nozzle} (in) =	42.7

Fins:	
S_F (ft^2) (ea) =	128
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	38.5

Flyback Engines: 2

Orbiter:

Weights:	
Dry Weight (lb) =	163,000
Propellant Weight (lb) =	1,568,000
- LO_2 (lb) =	1,294,00
- LH_2 (LB) =	273,000
Inert Weight (lb) =	191,000
λ' =	0.892

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,337,000
$V_{staging}$ (ft/s) =	4,425
P/L to Space Station (lb) =	150,000

Figure 3.1.1.9-2. Summary of Configuration Features for Configuration 2.I

the lower limit on number of booster engines. Propellant mixture ratio is relatively insensitive over the range of variation (Appendix B-174 through B-177).

Mixture Ratio. Total dry weight minimizes between 3.0 and 3.5 with moderate sensitivity over the range of variation. Minor breakpoints occur at 2.25 (associated with breaking free from the upper limit on orbiter propellant at staging) and 2.45 (associated with breaking free from the lower limit on nozzle expansion ratio). A major breakpoint occurs at 2.7 but is difficult to explain. Propellant mass fraction is relatively insensitive over the range of verification (Appendix B-178 through B-181).

Orbiter Propellant at Staging. Total dry weight minimizes at 40%, with moderate sensitivity over the range of variation. A minor breakpoint occurs at approximately 32.3%, associated with breaking free from the lower limit on engine-out liftoff acceleration. Propellant mixture ratio and throttle setting are relatively insensitive over the range of variation (Appendix B-182 through B-185).

Number of Booster Engines. Total dry weight minimizes at four engines, but is relatively insensitive over the range of variation. No breakpoints occur. Propellant mass fraction, body diameter, mixture ratio, throttle setting, orbiter propellant at staging, and engine-out liftoff acceleration are relatively insensitive over the range of variation (Appendix B-186 through B-189).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of 19:1 but is relatively insensitive over the range of variation. No constraint-related breakpoints occur. Gross liftoff weight, propellant mass fraction, mixture ratio, and throttle setting are relatively insensitive over the range of variation (Appendix B-190 through B-193).

3.1.1.10 NBP Propane/NBP Propane (Configuration 2.J)

Configuration Description. Figure 3.1.1.10-1 is a three-view drawing of configuration 2.J. A summary of configuration features is shown in figure 3.1.1.10-2. Detailed performance and weight numbers are tabulated in the appendix A-38 through A-41.

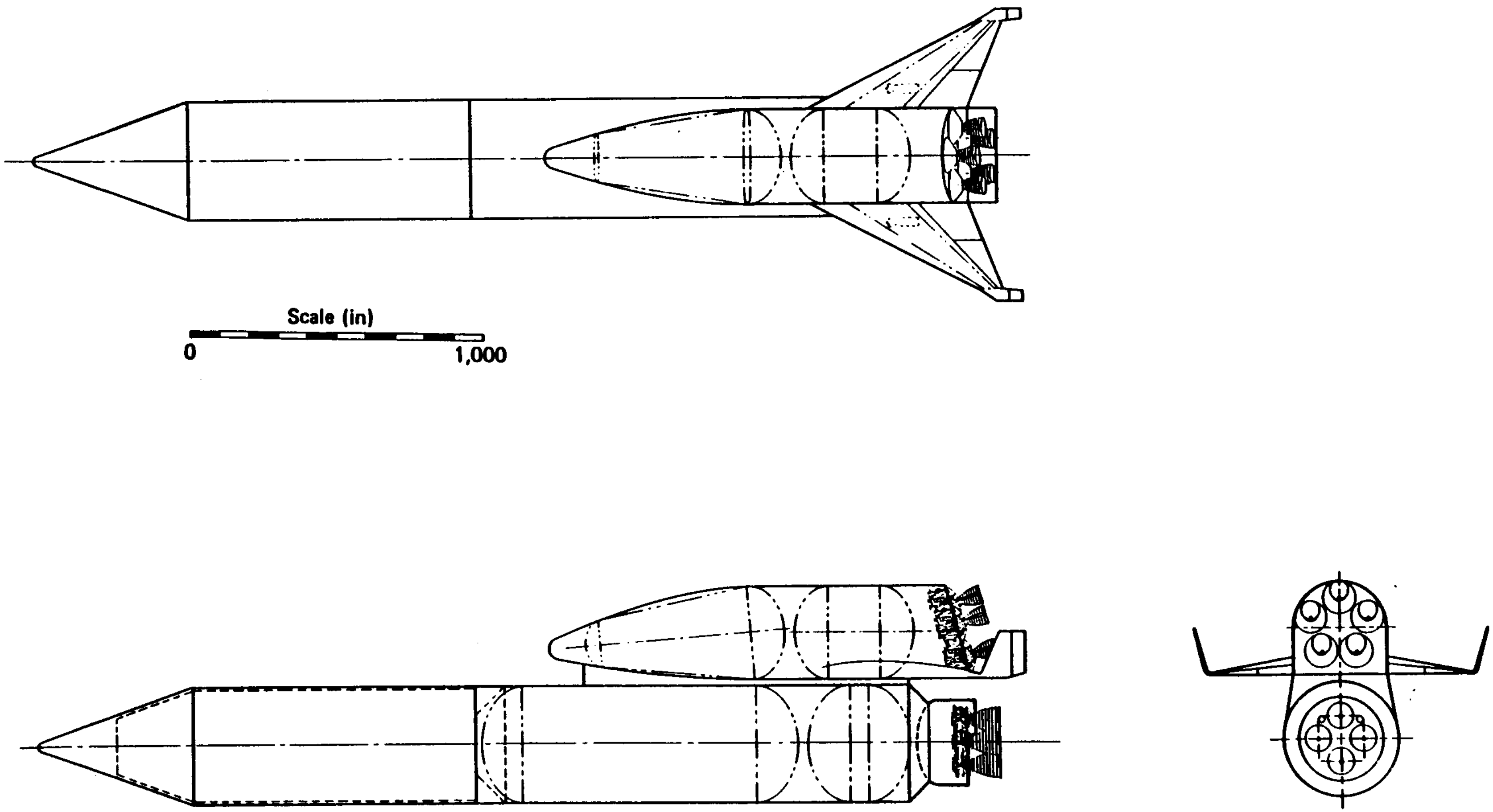

Figure 3.1.1.10-1. Three-View Drawing of Configuration 2.J

Configuration: 2.J

Booster:

Weights:

Dry Weight (lb) =	170,590
Propellant Weight (lb) =	1,528,000
- LO_2 (lb) =	1,154,400
- Propane (lb) =	373,240
Inert Weight (lb) =	202,910
λ' =	0.878

Engines:

Type:	Propane/Propane
Number =	5
Thrust (vacuum, each) (lb) =	740,560
MR:	3.09
P_C (psia) =	2,600
I_{sp} =	316
ε =	22.81
$d_{powerhead}$ (in) =	127
D_{nozzle} (in) =	62.9

Body:

$\frac{\ell}{D}$ =	4.53
D (ft) =	26.3
$S_{body\ flap}$ (ft^2) =	210

Fins:

S_F (ft^2) (ea) =	132
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	39.6

Wing:

S_{ref} (ft^2) =	2,750
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	550

Flyback Engines: 2

Orbiter:

Weights:

Dry Weight (lb) =	164,870
Propellant Weight (lb) =	1,649,000
- LO_2 (lb) =	1,413,400
- LH_2 (lb) =	235,560
Inert Weight (lb) =	192,830
λ' =	0.895

P/A Module (4 SSMEs):

Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,731,900
$V_{staging}$ (ft/s) =	4,281
P/L to Space Station (lb) =	150,000

Figure 3.1.1.10-2. Summary of Configuration Features for Configuration 2.J

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	25 to 29 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.3g
c.	Mixture ratio (booster):	2.0 to 4.0
d.	Orbiter propellant at staging:	28 to 38%
e.	Number of booster engines:	4 to 8
f.	Expansion ratio:	15 to 50

Detailed sensitivity analyses are presented in the appendix B-194 through B-217 and are discussed below.

Body Diameter. Total dry weight does not minimize according to a well-behaved relationship, displaying two acute minima at 25.9 ft and at 27.2 ft, which are difficult to explain. Breakpoints seems to occur over the bands 25.9 to 26.3 ft and 28.7 to 29.0 ft. The first is associated with reaching the upper limit on number of booster engines and also with reaching the lower limit on engine-out liftoff acceleration. The second is associated with an abrupt transition from the higher limit to the lower limit on number of booster engines. Nozzle expansion ratio optimized at its lower limit (15:1) over the range of variation (Appendix B-194 through B-197).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.1g and is only moderately sensitive over the range of variation. A breakpoint occurs at 1.28g, associated with breaking free from the lower limit on number of booster engines. Propellant mass fraction, mixture ratio, and throttle setting are relatively insensitive over the range of variation. Orbiter propellant at staging optimized at its upper limit (38%) over the range of variation (Appendix B-198 through B-201).

Mixture Ratio. Total dry weight minimizes at a ratio of 4.0, with moderate sensitivity over the range of variation. Two distinct breakpoints occur: at 3.4 and 3.8.

The first is associated with breaking free from the lower limit on nozzle expansion ratio. The second is associated with breaking free from the upper limit on number of booster engines. Propellant mass fraction and throttle setting are relatively insensitive over the range of variation. Orbiter propellant at staging optimized at its upper limit (38%) and engine-out liftoff acceleration optimized at its lower limit (1.1g) over the range of variation (Appendix B-202 through B-205).

Orbiter Propellant at Staging. Total dry weight minimizes at 33.55%, but is relatively insensitive over the range of variation. No breakpoints are evident. Propellant mass fraction, throttle setting, and nominal liftoff acceleration are relatively insensitive. The number of booster engines optimized at its upper limit (eight), engine-out liftoff acceleration at its lower limit (1.1g), and nozzle expansion ratio at its lowest limit (15:1) over the range of variation (Appendix B-206 through B-209).

Number of Booster Engines. Total dry weight minimizes at four engines, with moderate sensitivity over the range of variation. A breakpoint occurs at 6.6 engines (fractional engines are artifacts of the continuous-function algorithm used in the optimization program) associated with reaching the lower limit of nozzle expansion ratio. Propellant mass fraction, body diameter, and throttle setting are relatively insensitive. Orbiter propellant at staging optimizes at its lower limit (38%) and engine-out liftoff acceleration at its lower limit (1.1g) over the range of variation (Appendix B-210 through B-213).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of 23:1, with moderate sensitivity over the range of variation. A major breakpoint occurs between 20:1 and 23:1, associated with an abrupt transition between the upper and lower limits on the number of engines. Propellant mass fraction and throttle setting are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (38%) and engine-out liftoff acceleration at its lower limit (1.1g) over the range of variation (Appendix B-214 through B-217).

3.1.1.11 Subcooled Propane/H_2 (Configuration 2.K)

Configuration Description. Figure 3.1.1.11-1 is a three-view drawing of configuration 2.K. A summary of configuration features is shown in figure 3.1.1.11-2. Detailed performance and weight numbers are tabulated in the appendix A-42 through A-45.

Optimization Sensitivities. The optimization constraints on the selected independent variables are identical to those given in section 3.1.1.10. Detailed sensitivity analyses are presented in the Appendix B-218 through B-241 and are discussed below.

Body Diameter. Total dry weight minimizes along a monotonic function at 29 ft, but is relatively insensitive over the range of variation. There are no significant breakpoints. Vehicle initial weight, propellant mass fraction, weight of hydrogen coolant, mixture ratio, throttle setting, and staging velocity are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (38%) over the range of variation (Appendix B-218 through B-221).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.15g, but is relatively insensitive over the range of variation. A breakpoint occurs at approximately 1.165g, associated with breaking free from the upper limit on body diameter. Propellant mass fraction and throttle setting are relatively insensitive. Body diameter optimized at its upper limit (29.5 ft) and orbiter propellant at its upper limit (38%) over the range of variation (Appendix B-222 through B-225).

Orbiter Propellant at Staging. Total dry weight minimizes at 38%, but is only moderately sensitive over the range of variation. No constraint-related breakpoints occur. Vehicle initial weight, propellant mass fraction, mixture ratio, and throttle

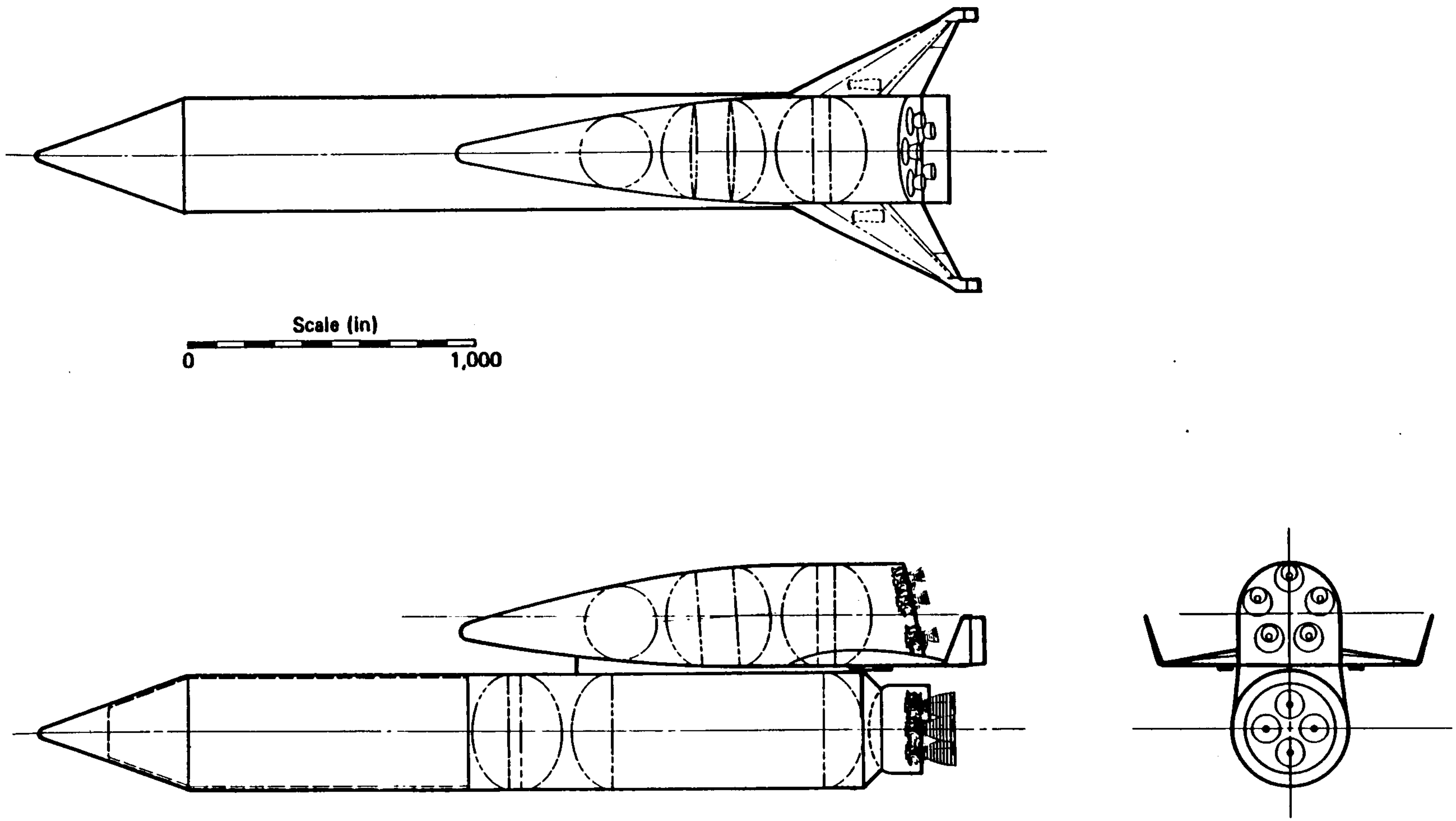

Figure 3.1.1.11-1. Three-View Drawing of Configuration 2.K

Configuration: 2.K

Booster:

Weights:	
Dry Weight (lb) =	165,280
Propellant Weight (lb) =	1,300,000
- LO_2 (lb) =	1,006,000
- SC Propane (lb) =	277,000
- LH_2 Coolant (lb) =	17,600
Inert Weight (lb) =	194,000
λ' =	0.865

Engines:	
Type:	SC Propane/LH_2
Number =	5
Thrust (vacuum, each) (lb) =	654,000
MR:	3.63
P_C (psia) =	4,000
I_{sp} =	330
ε =	24.88
$d_{powerhead}$ (in) =	99
D_{nozzle} (in) =	50.3

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	29.1
$S_{body\ flap}$ (ft^2) =	233

Fins:	
S_F (ft^2) (ea) =	128
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	38.5

Wing:	
S_{ref} (ft^2) =	2,639
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	528

Flyback Engines:	2

Orbiter:

Weights:	
Dry Weight (lb) =	163,000
Propellant Weight (lb) =	1,510,000
- LO_2 (lb) =	1,294,000
- LH_2 (lb) =	216,000
Inert Weight (lb) =	191,000
λ' =	0.888

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,354,000
$V_{staging}$ (ft/s) =	4,518
P/L to Space Station (lb) =	150,000

Figure 3.1.1.11-2. Summary of Configuration Features for Configuration 2.K

setting are relatively insensitive. Body diameter optimized at its upper limit (29.0 ft) over the range of variation (Appendix B-230 through B-239).

Number of Booster Engines. Total dry weight minimizes at four or five booster engines, but is relatively insensitive over the range of variation. A minor breakpoint occurs at 5.4 engines (fractional engines are artifacts of the continuous-function algorithm used in the optimization program), associated with breaking free from the upper limit on orbiter propellant at staging. Propellant mass fraction, body diameter, and throttle setting are relatively insensitive (Appendix B-234 through B-237).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of approximately 21:1, but is relatively insensitive over the range of variation. No breakpoints occur. Propellant mass fraction, mixture ratio, throttle setting, and nominal liftoff acceleration are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (35%) and body diameter at its upper limit (29.0 ft) over the range of variation (Appendix B-238 through B-241).

3.1.1.12 SC Propane/SC Propane (Configuration 2.L)

Configuration Description. Figure 3.1.1.12-1 is a three-view drawing of configuration 2.L. A summary of configuration features is shown in figure 3.1.1.12-2. Detailed performance and weight numbers are tabulated in the appendix A-46 through A-49.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	23 to 27 ft
b.	Engine-out liftoff acceleration	1.1 to 1.3g
c.	Mixture ratio (booster):	2.0 to 4.0
d.	Orbiter propellant at staging:	29 to 39%
e.	Number of booster engines:	4 to 8

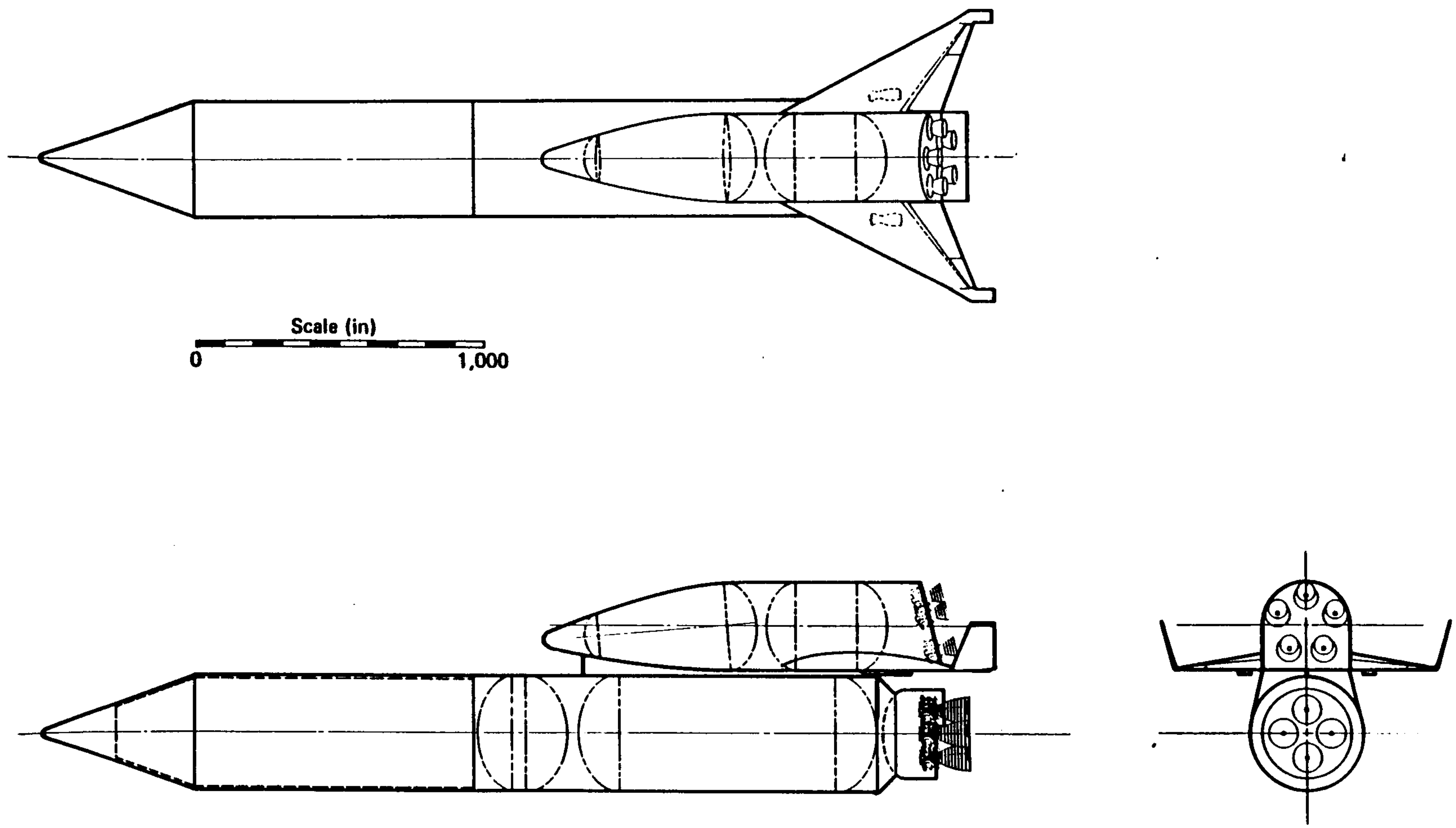

Figure 3.1.1.12-1. Three-View Drawing of Configuration 2.L

Configuration: 2.L

Booster:

Weights:

Dry Weight (lb) =	171,980
Propellant Weight (lb) =	1,455,000
- LO_2 (lb) =	1.120,000
- SC Propane (lb) =	334,000
Inert Weight (lb) =	203,000
λ' =	0.873

Body:

$\frac{\ell}{D}$ =	4.53
D (ft) =	25.3
$S_{body\ flap}$ (ft^2) =	202

Wing:

S_{ref} (ft^2) =	2,738
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	548

Engines:

Type:	Propane/Propane
Number =	5
Thrust (vacuum, each) (lb) =	766,000
MR:	3.35
P_C (psia) =	3,300
I_{sp} =	318
ε =	28.20
$d_{powerhead}$ (in) =	116
D_{nozzle} (in) =	63.7

Fins:

S_F (ft^2) (ea) =	132
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	39.5

Flyback Engines: 2

Orbiter:

Weights:

Dry Weight (lb) =	164,000
Propellant Weight (lb) =	1,533,000
- LO_2 (lb) =	1,314,000
- LH_2 (lb) =	219,000
Inert Weight (lb) =	191,000
λ' =	0.889

P/A Module (4 SSMEs):

Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,541,000
$V_{staging}$ (ft/s) =	4,624
P/L to Space Station (lb) =	150,000

Figure 3.1.1.12-2. Summary of Configuration Features for Configuration 2.L

f. Expansion ratio: 15 to 50

Detailed sensitivity analyses are presented in the appendix B-242 through B-265 and are discussed below.

Body Diameter. Total dry weight is a classic "bucket" function, minimizing in the range of 25.2 to 25.7 ft diameter, being only moderately sensitive over the range of variation. No significant breakpoints occur. Throttle setting is relatively insensitive. The number of booster engines optimized at its lower limit (four) over the range of variation (Appendix B-242 through B-245).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.1g, with only moderate sensitivity over the range of variation. A breakpoint appears to exist at approximately 1.25g, associated with reaching the upper limit on orbiter propellant at staging. Propellant mixture ratio is relatively insensitive. The number of booster engines optimized at its lower limit (four) over the range of variation (Appendix B-246 through B-249).

Mixture Ratio. Total dry weight minimizes in the range of 3.0 to 3.5, with moderate sensitivity over the range of variation. A breakpoint occurs at approximately 2.2 but is difficult to explain. Propellant mass fraction and throttle setting are relatively insensitive. The number of booster engines optimized at its lower limit (four) over the range of variation (Appendix B-250 through B-253).

Orbiter Propellant at Staging. Total dry weight minimizes at approximately 36.5%, but is relatively insensitive over the range of variation. A minor breakpoint occurs at 30%, associated with breaking free from the lower limit on engine-out liftoff acceleration. Propellant mass fraction, mixture ratio, and throttle setting are relatively insensitive. The number of booster engines optimized at its lower limit (four) over the range of variation (Appendix B-254 through B-257).

Number of Booster Engines. Total dry weight minimizes at four engines, but is relatively insensitive over the range of variation. Aside from a minor discontinuity in engine-out liftoff acceleration over the range of seven to eight engines, no breakpoints occur. Propellant mass fraction, body diameter, propellant mixture ratio, throttle setting, orbiter propellant at staging, engine-out liftoff acceleration, and nozzle expansion ratio are relatively insensitive (Appendix B-258 through B-261).

Expansion Ratio. Total dry weight minimizes near an expansion ratio of 26:1, but is relatively insensitive over the range of variation. No significant breakpoints occur. Propellant mass fraction, mixture ratio, and throttle setting are relatively insensitive. The number of booster engines optimizes at its lower limit (four) over the range of variation (Appendix B-262 through B-265).

3.1.1.13 SC Propane/SC Propane Far-Term Performance (Configuration 2.M)

Configuration Description. Figure 3.1.1.13-1 is a three-view drawing of configuration 2.M. A summary of configuration features is shown in figure 3.1.1.13-2. Detailed performance and weight numbers are tabulated in the appendix A-50 through A-53.

Optimization Sensitivities. The optimization constraints on the selected independent variables are as follows:

a.	Body diameter:	23 to 27 ft
b.	Engine-out liftoff acceleration:	1.1 to 1.3g
c.	Mixture ratio (booster):	2.0 to 4.0
d.	Orbiter propellant at staging:	30 to 40%
e.	Number of booster engines:	4 to 8
f.	Expansion ratio:	15 to 50

Detailed sensitivity analyses are presented in the appendix B-266 through B-289 and are discussed below.

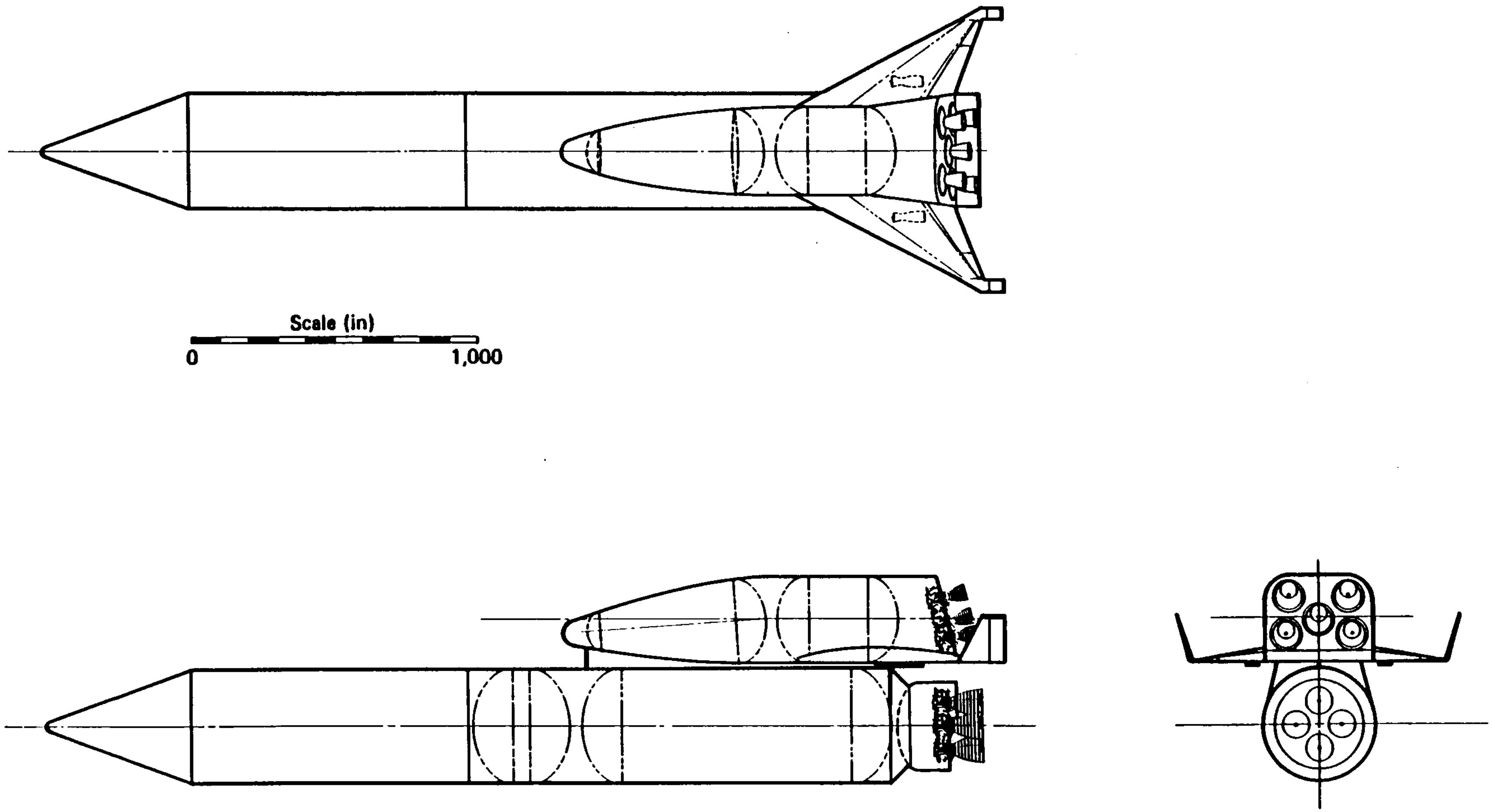

Figure 3.1.1.13-1. Three-View Drawing of Configuration 2.M

Configuration: 2.M

Booster:

Weights:	
Dry Weight (lb) =	167,000
Propellant Weight (lb) =	1,407,000
- LO_2 (lb) =	1,090,000
- SC Propane (lb) =	317,000
Inert Weight (lb) =	195,000
λ' =	0.873

Body:	
$\frac{\ell}{D}$ =	4.53
D (ft) =	24.8
$S_{body\ flap}$ (ft^2) =	198

Wing:	
S_{ref} (ft^2) =	2,653
AR =	2.06
λ =	0.11
t/c =	11%
$S_{flaperons}$ (ft^2) =	531

Engines:	
Type:	SC Propane/Propane
Number =	5
Thrust (vacuum, each) (lb) =	735,000
MR:	5.00
P_C (psia) =	3,900
I_{sp} =	325
ε =	29.88
$d_{powerhead}$ (in) =	105
D_{nozzle} (in) =	59

Fins:	
S_F (ft^2) (ea) =	130
AR =	1.38
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	38.9

Flyback Engines:	2

Orbiter:

Weights:	
Dry Weight (lb) =	165,000
Propellant Weight (lb) =	1,640,000
- LO_2 (lb) =	1,405,000
- LH_2 (lb) =	234,000
Inert Weight (lb) =	193,000
λ' =	0.895

P/A Module (4 SSMEs):	
Weight (lb) =	122,000
Circularization OMS Propellant (lb) =	9,470
Total OMS Propellant (lb) =	18,600

GLOW (lb) =	3,594,000
$V_{staging}$ (ft/s) =	4,181
P/L to Space Station (lb) =	150,000

Figure 3.1.1.13-2. Summary of Configuration Features for Configuration 2.M

C-2

Body Diameter. Total weight is a monotonic function minimizing at approximately 24.75-ft diameter, with moderate sensitivity over the range of variation. A breakpoint occurs at 25.2 ft, associated with reaching the lower limit on engine-out liftoff acceleration. Propellant mass fraction and throttle setting are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (40%) over the range of variation (Appendix B-266 through B-269).

Engine-out Liftoff Acceleration. Total dry weight minimizes at 1.15g, but is relatively insensitive over the range of variation. No breakpoints are apparent. Propellant mass fraction, engine rated vacuum thrust, throttle setting, and booster engine weight are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (40%) over the range of variation (Appendix B-270 through B-273).

Mixture Ratio. Total dry weight minimizes in the range of 3.0 to 3.5, with moderate sensitivity over the range of variation. No constraint-related breakpoints occur. Propellant mass fraction is relatively insensitive. Orbiter propellant at staging optimized at its upper limit (40%) over the range of variation (Appendix B-274 through B-277).

Orbiter Propellant at Staging. Total dry weight minimizes in the range of 37 to 38%, but is relatively insensitive over the range of variation. No breakpoints are apparent. Gross liftoff weight, propellant mass fraction, throttle setting, and nominal liftoff acceleration are relatively insensitive over the range of variation (Appendix B-278 through B-281.

Number of Booster Engines. Total dry weight minimizes at four engines, with moderate sensitivity over the range of variation. No significant breakpoints occur. Propellant mass fraction, body diameter, mixture ratio, throttle setting, engine-out liftoff acceleration, and nozzle expansion ratio are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (40%) over the range of variation (Appendix B-282 through B-288).

Expansion Ratio. Total dry weight minimizes at an expansion ratio of approximately 26:1, but is relatively insensitive over the range of variation. No significant breakpoints occur. Propellant mass fraction, number of booster engines, throttle setting, engine-out liftoff acceleration, nominal liftoff acceleration, and body diameter are relatively insensitive. Orbiter propellant at staging optimized at its upper limit (40%) over the range of variation (Appendix B-286 through B-289).

3.1.1.14 Sensitivity Studies

Apart from the system-level impact of variations in propellant thermochemistry discussed in previous sections, it is of interest to determine the potential performance benefits resulting from advances in generic propulsion technology. Two such sensitivities will be addressed in this section:

a. The application of a step increase in booster engine expansion ratio during the launch ascent (as might be obtained by a translating nozzle extension).

b. Recourse to high chamber pressure in the booster engines.

For illustrative purposes, the following three vehicles were employed as reference concepts to which the sensitivities were applied:

a.	LOX/hydrogen.	section 3.1.1.2
b.	LOX/RP-1 (hydrogen-cooled).	section 3.1.1.3
c.	LOX/methane (hydrogen-cooled).	section 3.1.1.7

(RP-1 and methane were chosen to represent the more attractive hydrocarbon fuel candidates from the standpoint of design experience or maximum performance).

3.1.1.14.1 **Expansion Ratio Change Sensitivities.**

Included in this study was an evaluation of changing the booster engine nozzle to a higher expansion ratio at some point in the boost phase. Four configurations were evaluated, LOX/LH_2, LOX/RP-1 (H_2 cooled), LOX/methane (H_2 cooled), and LOX (RP-1 cooled). The liftoff nozzle positions were set at 30, 15, and 15:1 expansion ratios respectively. Later in the trajectory expansion ratios of 40, 60, 80, or 100:1 at altitudes from 10,000 to 70,000 ft were examined. It was found that dry weights increased with an expansion ratio change no matter where the altitude change takes place, as summarized on figure 3.1.1.14-1. Total dry weight was minimized with the booster engines at constant expansion ratio during boost, set at a low ratio

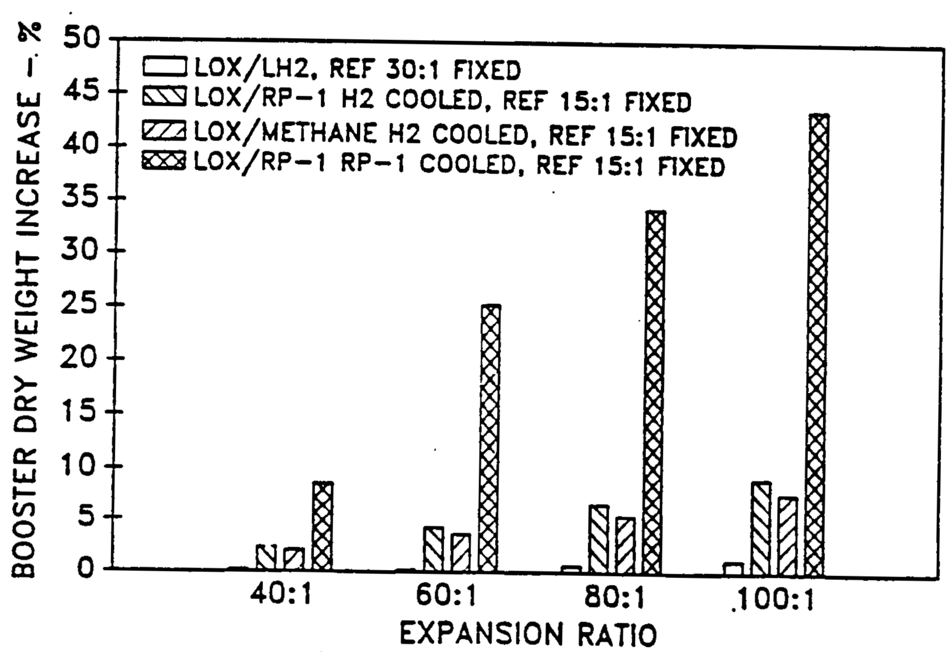

Figure 3.1.1.14-1 Extended Nozzle Expansion Ratio Impact on Two-Stage Booster Dry Weight

3.1.1.14.1.1 **LOX/Hydrogen.**

These sensitivities are presented in figure 3.1.1.14-2. The basic (starting) expansion ratio for this system was 30:1. Because this starting value was so high, sensitivity to changes was minimal.

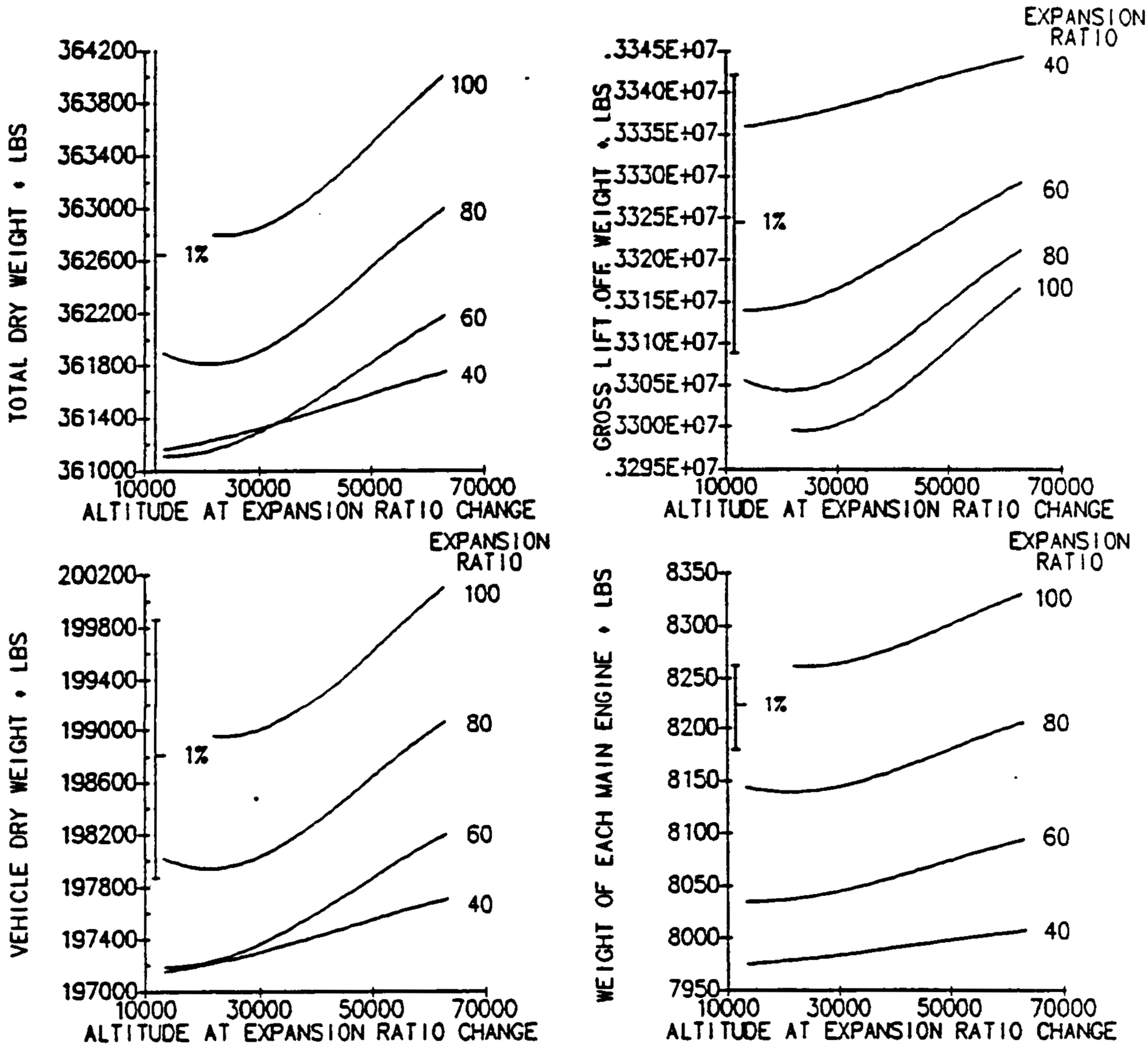

Figure 3.1.1.14-2 Expansion Ratio Change Sensitivities (LOX/LH_2 Vehicle)

3.1.1.14.1.2 LOX/RP-1 (Hydrogen-Cooled)

These sensitivities are presented in figure 3.1.1.14-3. The starting expansion ratio for this system was 15:1. Sensitivity to increase was adverse.

3.1.1.14.1.3 LOX/Methane (Hydrogen-Cooled)

These sensitivities are presented in figure 3.1.1.14-4. The starting expansion ratio for this system was 15:1. The results are nearly indistinguishable from the RP-1 (H_2) case.

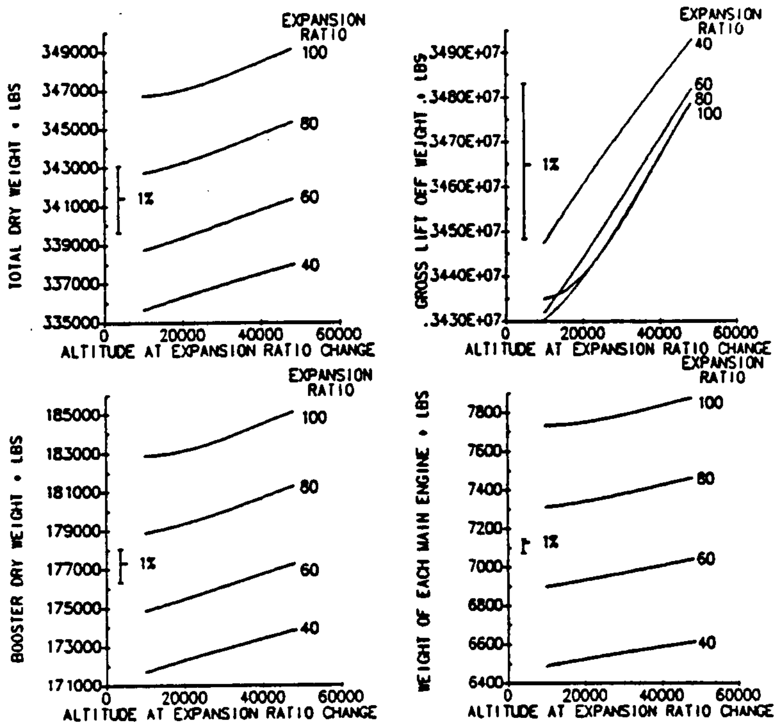

Figure 3.1.1.14-3 *Expansion Ratio Change Sensitivities (LOX/RP-1/H_2 Vehicle)*

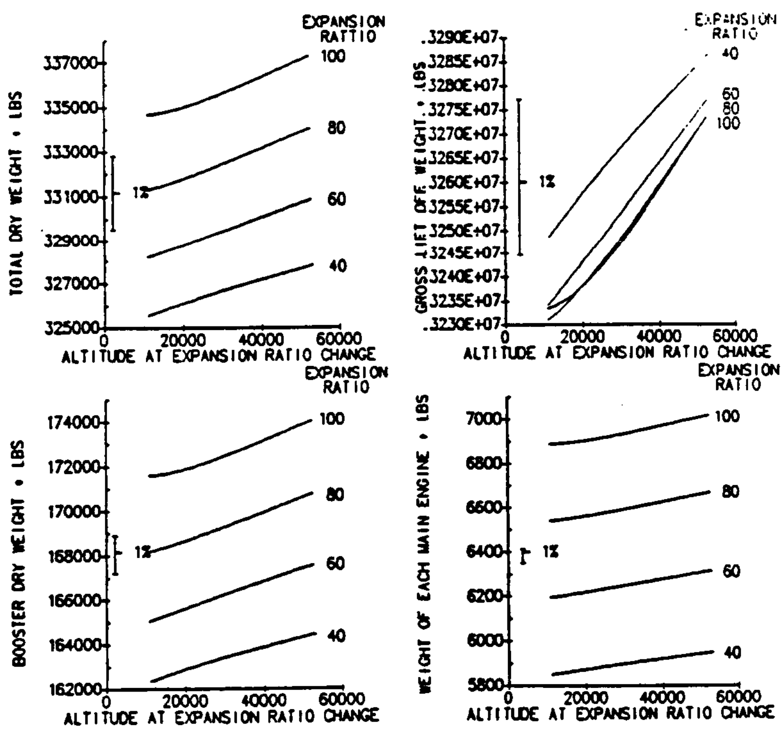

Figure 3.1.1.14-4 *Expansion Ratio Change Sensitivities (LOX/Methane/H_2 Vehicle)*

3.1.1.14.2 **Chamber Pressure Sensitivities.**

For the three illustrative vehicles, booster engine rated chamber pressure ranged from 1000 to 4000 lb/in^2. The dependent variables chosen were:

a. Total dry weight.

b. Gross liftoff weight.

c. Vehicle dry weight (booster).

d. Ascent propellant weight.

e. Propellant mass fraction.

f. Individual main engine weight.

g. Engine rated vacuum thrust (booster).

h. Engine throttle setting (booster).

The general conclusion is that most benefits are realized by P_c = 2500 to 3000 lb/in^2 and improvements are marginal out to P_c = 4000 lb/in^2. This conclusion, however, must be tempered by the recognition that the major figures of merit (i.e., dry weight) are curves with inflections that result in low sensitivity between 2500 to 3000 lb/in^2; indications of increasing sensitivity beyond 3500 lb/in^2 may imply benefits from chamber pressures much higher than examined in this study. Detailed results are presented in the following paragraphs.

3.1.1.14.2.1 LOX/Hydrogen.

These sensitivities are presented in figure 3.1.1.14-5. The reference concept for this study (sec. 3.1.1.2) was optimized for a booster engine chamber pressure of 4000 lb/in^2. Significant reductions in all dependent variables were obtained, with the exception of propellant mass fraction and first stage throttle setting, which were essentially unaffected.

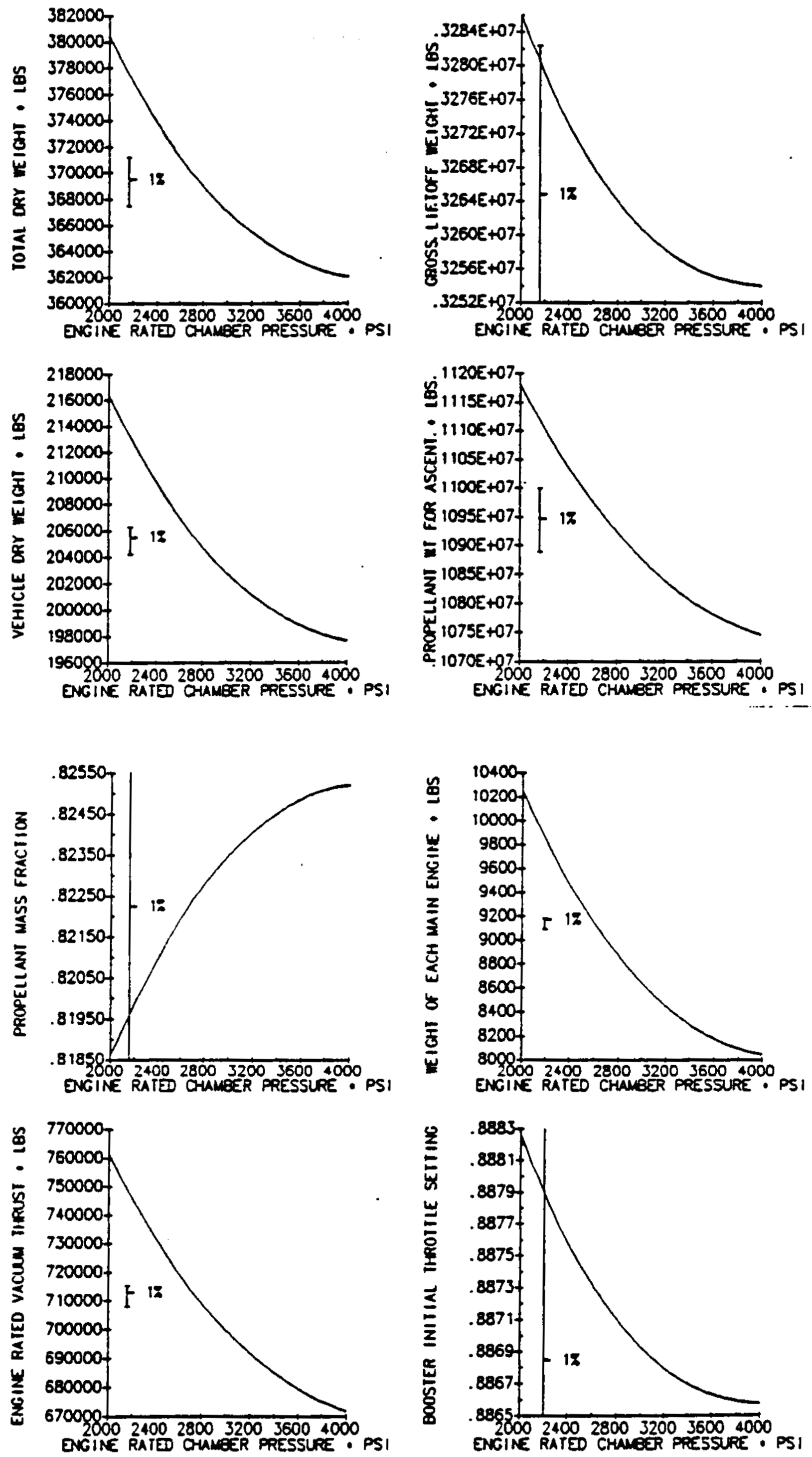

Figure 3.1.1.14-5 *Chamber Pressure Sensitivities (LOX/H_2 Vehicle)*

3.1.1.14.2.2 LOX/RP-1 (Hydrogen-Cooled)

These sensitivities are presented in figure 3.1.1.14-6. The reference concept for this study (sec. 3.1.1.3) was also optimized at 4000 lb/in^2, with a complete alternate design (sec. 3.1.1.4) optimized at 2500 lb/in^2. Results are similar to the LOX/hydrogen case.

3.1.1.14.2.3 LOX/Methane (Hydrogen-Cooled)

These sensitivities are presented in figure 3.1.1.14-7. The reference concept for this study (sec. 3.1.1.7) was optimized at 4300 lb/in^2. Results are similar to the preceding cases.

3.1.1.15 Two-Stage Crossfeed Evaluation

The optimized LOX/LH_2 configuration was used for evaluating crossfeeding propellant from the first-stage propellant tanks to the second stage engines during the boost phase. The propellant, normally carried by the second-stage during the boost phase, would be carried in the first stage or booster. This concept would potentially reduce the inert mass of the second stage and provide a higher mass fraction for the first stage, thus providing a more efficient launch vehicle.

The HAVCD computer program can place all or part of the propellant required for the boost phase in the tanks of the first stage. The line sizes on the first stage were calculated to accommodate the propellant flow rates for both the first- and second-stage engines. Additional hardware is required for the propellant system if crossfeeding propellant across the stage interface is required. The hardware components shown in figure 3.1.1.15-1 are added when any crossfeed occurs.

Figure 3.1.1.15-2 summarizes the effect of crossfeed on launch vehicle design by comparing the weight of configuration 2.B with crossfeed to configuration 2.B without crossfeed.

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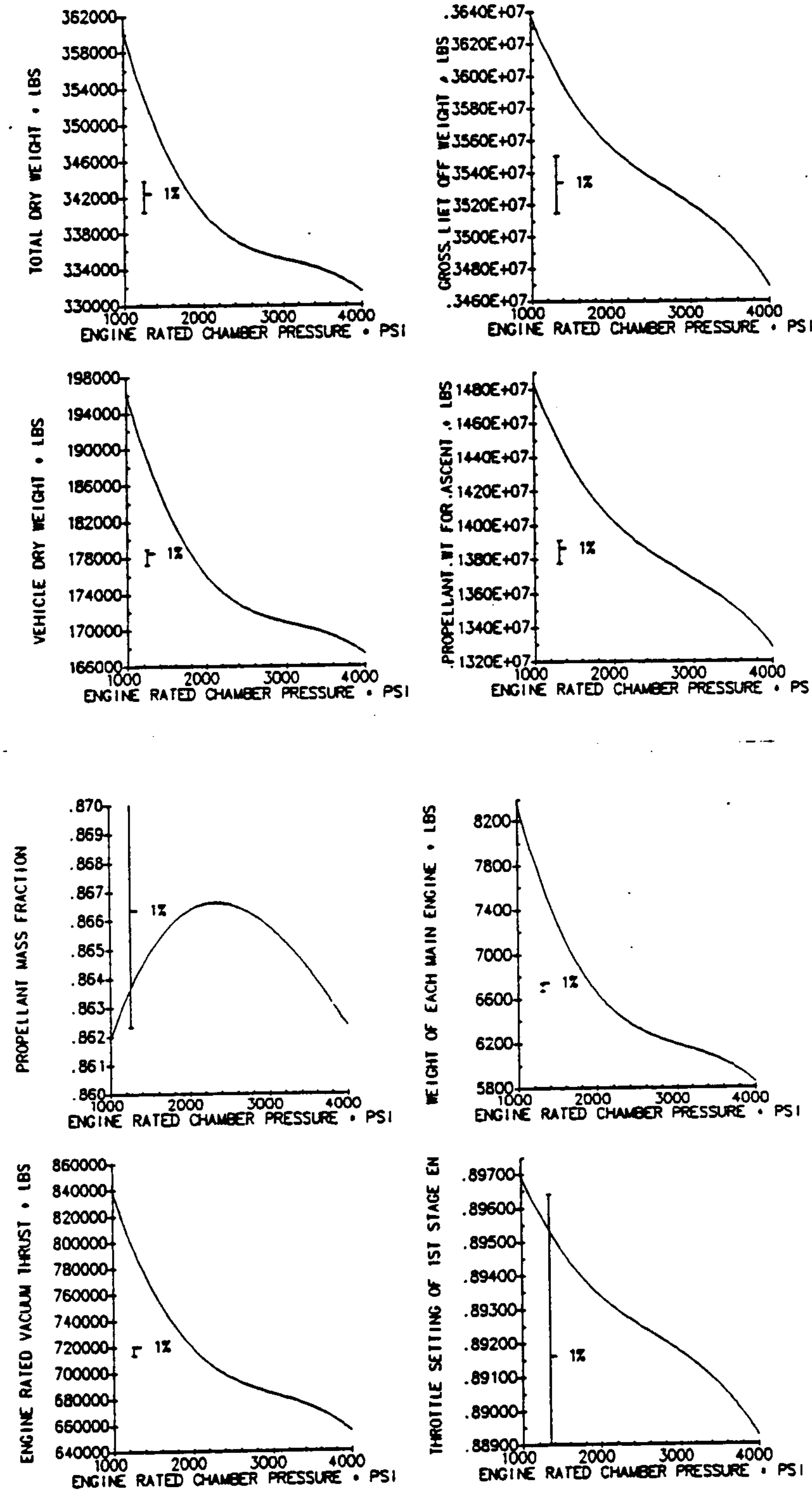

Figure 3.1.1.14-6 *Chamber Pressure Sensitivities (LOX/RP-1/H₂ Vehicle)*

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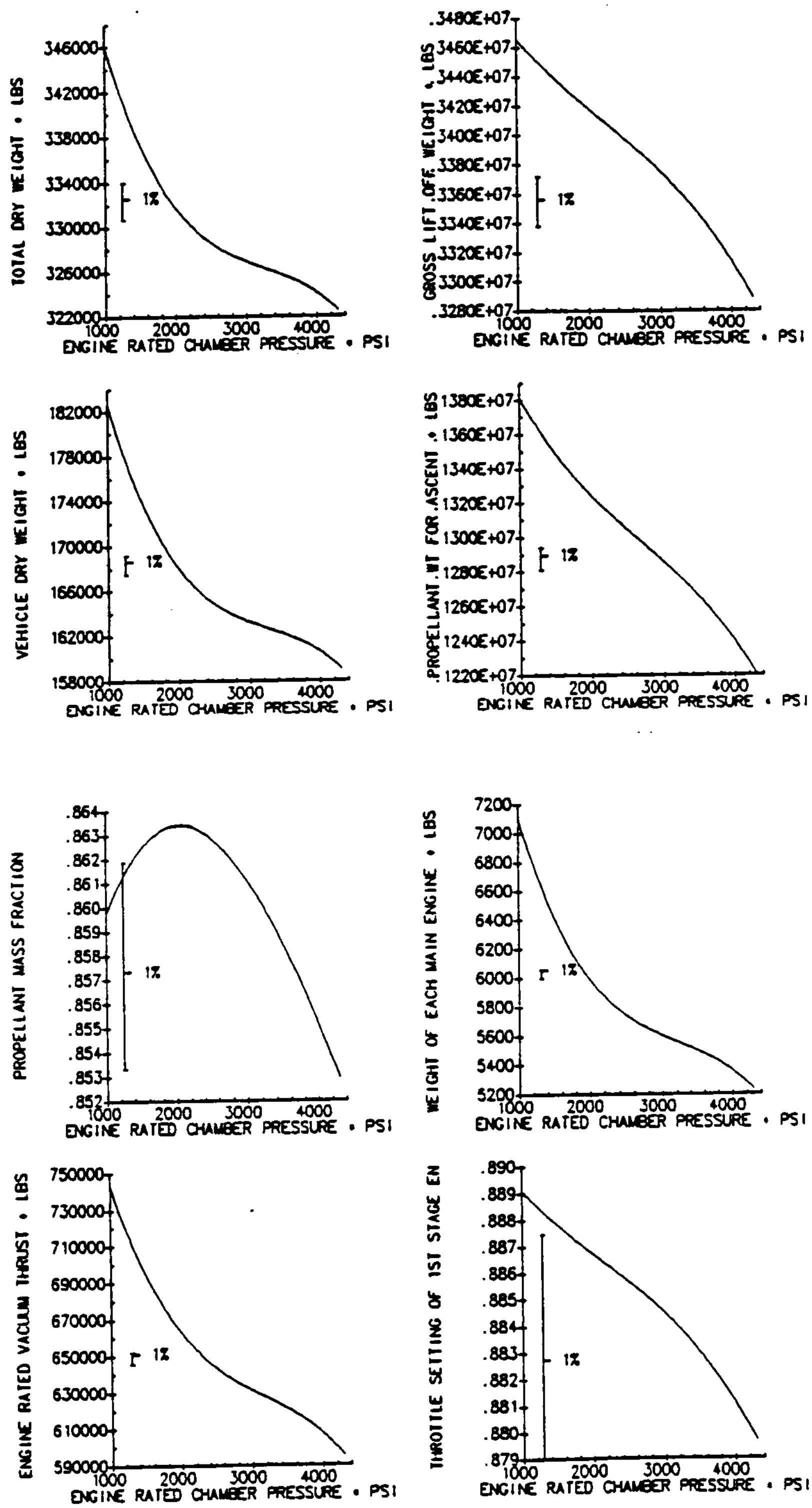

Figure 3.1.1.14-7 *Chamber Pressure Sensitivities (LOX/Methane/H_2 Vehicle)*

Stage	Component	Quantity	Weight (each)	Description
Booster	Disconnect	2	150 lb	
	LH_2 prevalve	1	586 lb	Isolates disconnect
	LOX prevalve	1	548 lb	Same as LH_2 prevalve.
	Line and shroud	2	150 lb	
	1st stage total	-	1907 lb	(Includes 10% weight addition for mounting hardware)
Orbiter	Disconnect	2	150 lb	
	LH_2 prevalve	2	586 lb	One isolates disconnect; the second is redundant for existing tank prevalve.
	LOX prevalve	2	548 lb	Same as LH_2 prevalve.
	LH_2 check valve	1	293 lb	Prevents flow from second-stage tank to first-stage tank during flow switching.
	LOX check valve	1	274 lb	Same as LH_2 check valve.
	2nd stage total	-	3449 lb	(Includes 10% weight addition for mounting hardware)
Total			5356 lb	

Figure 3.1.1.15-1 Crossfeed System Weight

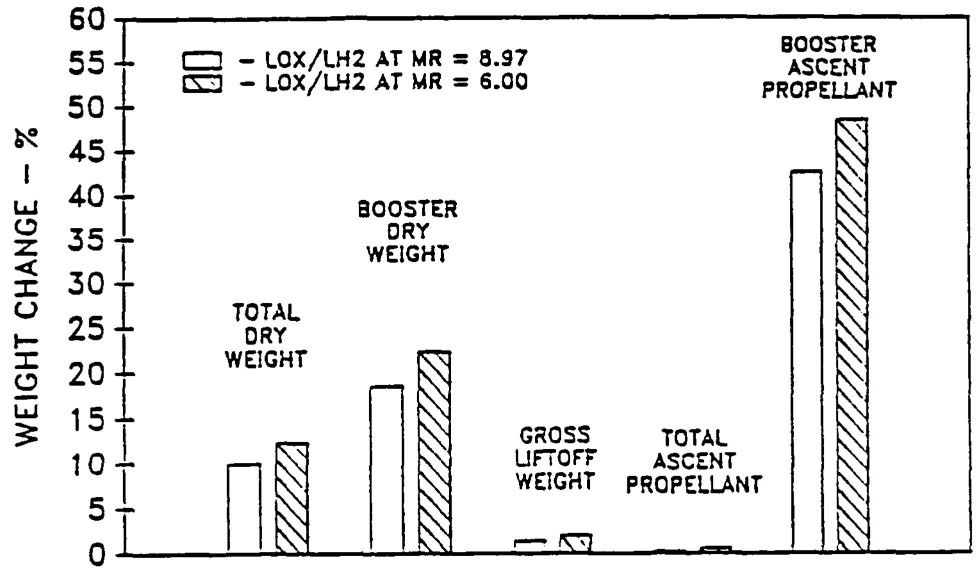

Figure 3.1.1.15-2 Effect of Crossfeed on Vehicle Design

The crossfeed system weight requires a minimum of 5356 lb of dry weight that needs to be added to the system. The crossfeed option was conducted on the LOX/LH_2 optimized configuration. This crossfeed system was not optimized because of time limitation. The results show that using a crossfeed system will not provide any reduction in system dry weight. Very little change occurred in the total propellant weight required and the gross liftoff weight. Notice that in this evaluation 41% more propellant is carried in the first stage. The orbiter liftoff weight is reduced by about 25%. For the low staging velocity, partially reusable stage concept reducing system weight by using crossfeed is not effective. Further, system reliability would be reduced, due to the increase in system complexity. Other study results, however, indicate the potential for system weight decrease for a two-stage, fully reusable vehicle having a higher staging velocity.

3.1.1.16 Variable Mixture Ratio LOX/LH_2 Evaluation

Changing the LOX/LH_2 variable mixture ratio range during the boost phase from a high (8-18:1) range to a lower range (6-12:1) was investigated to improve propellant bulk density and system efficiency. It was assumed that mixture ratio would be changed by changing the oxidizer flow rate while maintaining a constant hydrogen flow rate. Consequently, chamber pressure and engine thrust are reduced by the mixture ratio reduction. It was found that specific impulse improvement during the flight had little effect on minimizing the booster dry weight. Rather, the bulk density improvement had a more significant effect. For example, increasing mixture ratio from 6:1 (for maximum specific impulse) to about 9:1 produced a lower dry vehicle weight.

A single booster mixture ratio was also evaluated. The LOX/LH_2 configuration was optimized to a single mixture ratio of 8.97. The dry weight increased by only 1.5% when a single mixture ratio is used compared to the use of a more complex variable mixture ratio of 6.86 and 12.0. It was therefore concluded that variable mixture ratio LOX/LH_2 main engines do not provide a significant payoff for the booster element of a two-stage partially reusable launch vehicle compared to a new LOX/LH_2 engine operating at a mixture ratio of 9:1.

Figure 3.1.1.16-1 summarizes the sensitivity of engine performance to a change in mixture ratio from 12 to 6, a mixture ratio that has been suggested in other studies. When this set of mixture ratios was used in a version of configuration 2.B optimized to use these mixture ratios, the result showed a 1.3% increase in total dry weight compared to that of configuration 2.B, which had a fixed mixture ratio of about 9:1. A representative design of such an engine was conceptually defined by Acurex Corporation under subcontract. The engine was tailored for the booster element of a two-stage heavy lift system to have a vacuum thrust of 671,110 lb and a chamber pressure of 3000 psia. It is a full-flow cycle design having a skirt area ratio of 20.

Parameter	Initial	Final	%Charge
Mixture ratio	12.00	6.00	-50
Flow rate LH_2	158.3	158.3	0.0
Flow rate LOX	1,900.0	949.8	-50
Chamber pressure	4,000	2,594	-35.2
Thrust	750,000	486,300	-35.2
C*	6,182	7,625	+23.3
I_{SP} (vac)	364.4	438.9	+20.4
Expansion ratio	30:1	30:1	0
Throat area	98.86	98.86	0

Figure 3.1.1.16-1. Effect of LOX/LH2 Mixture Ratio Change on Engine Perfomance

In addition, the feasibility of common engine capability using an upper stage engine having the same dimensions/components as this booster engine was assessed. This engine operates at a mixture ratio of 6 and has a chamber pressure about 2000 psia. The nozzle skirt has an area ratio of 64 and a nozzle skirt insert provides an area ratio of 20.

The booster and upper stage engines operate in the parallel burn mode at lift-off. A drawing of the booster/upper stage engine is shown in figure 3.1.1.16-2. Data tables for the booster and upper stage engine are given in figures 3.1.1.16-3 and 3.1.1.16-4. The engine has a single integrated high pressure-low pressure fuel turbopump and dual integrated high pressure-low pressure oxygen turbopumps. The main fuel turbopump uses a three-stage pump for 3000 psia chamber pressure and a two-stage pump for 2000 psia chamber pressure. The turbine inlet temperatures for all turbines is modest, for example, 428°F for main oxygen turbopump and 809°F for the main fuel pumps in the booster engine and at lower temperature in the lower chamber pressure upper stage engine.

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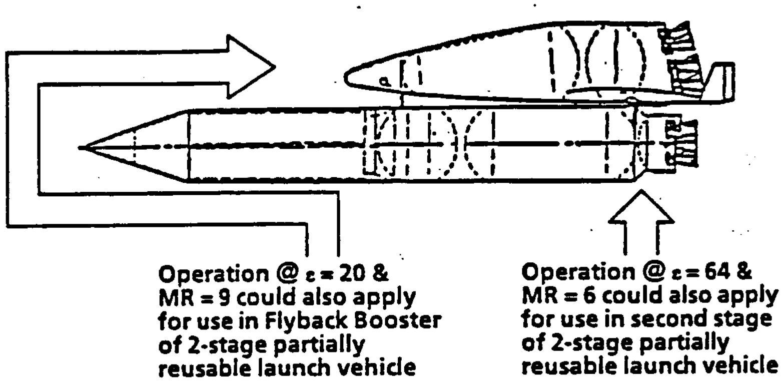

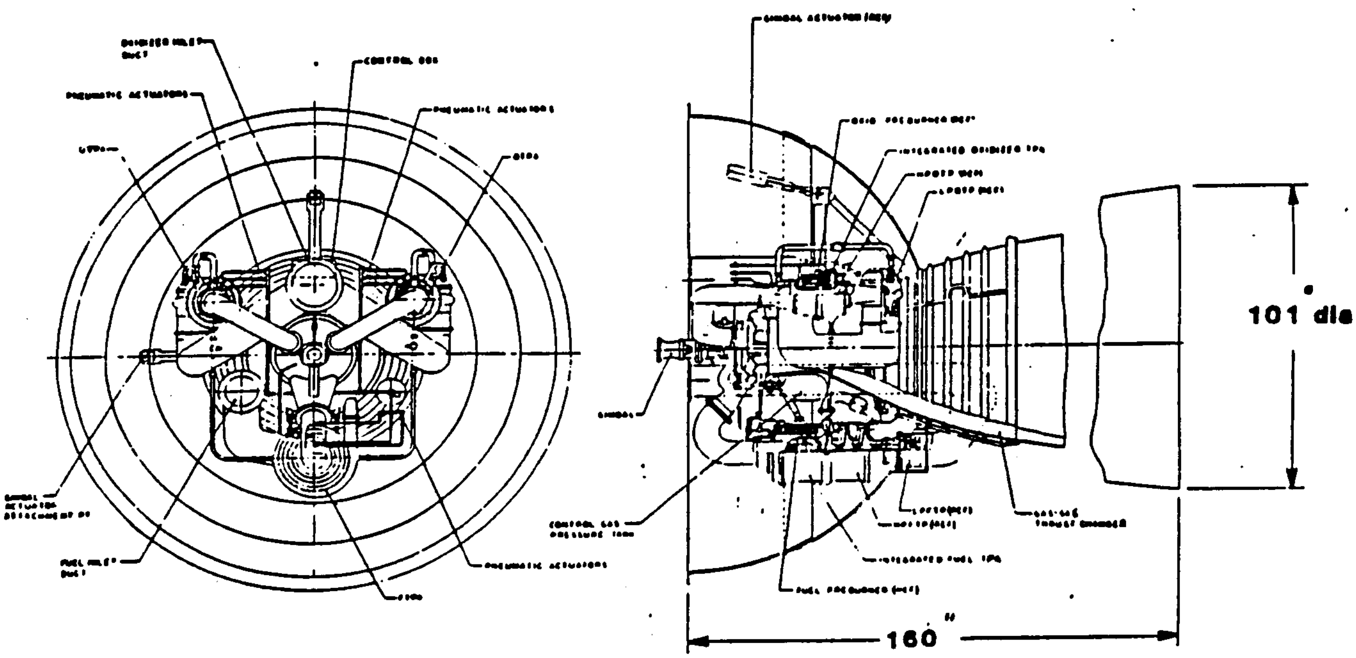

Figure 3.1.1.16-2 Acurex LOX/LH_2 Engine Assembly

Thrust (VAC), lbs	671,110
Mixture ratio, o/f	9:1
Chamber pressure, psia	3000
Area ratio	20:1
Area throat, sq. in.	120.4
Diameter throat, in.	12.38
Diameter exit, in.	55.4
Weight flow rate, oxidizer, lb/sec	1467
Weight flow rate, fuel, lb/sec	163
Total weight flow, lb/sec	1630
Specific impulse (VAC), sec	412
Engine dry weight	5915
Engine thrust-to-weight ratio	113
Mixture ratio, oxidizer TPA-PB	190
Oxidizer turbine temperature, °F	428
Mixture ratio, fuel, TPA-PB	0.65
Fuel turbine temperature, °F	809
Engine length, in.	81.10

Figure 3.1.1.16-3. Acurex Booster Engine Data

Area ratio	20	64
Thrust (VAC), lbs	501,522	516,889
Mixture ratio, o/f	6	6
Chamber pressure, psia	2250	2250
Area throat, sq. in.	120.4	120.4
Diameter throat, in.	12.38	12.38
Diameter exit, in.	55.4	99.0
Weight flow rate, oxidizer, lb/sec	978	978
Weight flow rate, fuel, lb/sec	163	163
Total weight flow, lb/sec	1141	1141
Specific impulse (VAC), sec	440	453
Thrust (VAC), lbs	501,522	516,889
Engine dry weight with NSI, lbs	6037	—
Engine dry weight without NSI, lbs	—	5575
VAC. thrust-to-weight ratio	83	92.7
Mixture ratio, oxidizer TPA-PB	248	248
Oxidizer turbine temperature, °F	215	215
Mixture ratio, fuel, TPA-PB	0.45	0.45
Fuel turbine temperature, °F	426	426
Engine length, in.	160	160

Figure 3.1.1.16-4. Acurex Booster Engine Data

3.1.2 Single-Stage-to-Orbit Vehicle Analysis

The selected configuration design for a rocket powered, manned single-stage-to-orbit system is a fully reusable vertical takeoff, horizontal landing concept. A reference mission of 10,000 lb. payload delivery to a 100-nmi circular polar orbit from WTR launch was also selected and the payload bay was sized to accommodate a 15-ft diameter by 30-ft long payload. A crew size of two was also assumed.

A typical mission for the single-stage-to-orbit vehicle is depicted on figure 3.1.2-1. The vehicle is first towed horizontally to a facility where the payload is lowered into the payload bay. The vehicle is then towed to the launch pad, erected to a vertical position, and checked out for launch. Propellant loading occurs shortly before launch followed by crew member boarding. After liftoff and insertion into the proper orbit, the payload is deployed. Upon completion of the orbital mission the vehicle is deorbited and glides (unpowered) to a runway landing near the launch site for refurbishment prior to a later flight.

The single-stage-to-orbit vehicle has a forward, tapered fuel tank and an aft LOX tank (see fig. 3.1.2-1). The area forward of the fuel tank houses the crew compartment, a deployable canard (for low-speed stability and control), and the nose landing gear. The payload bay is located above the LOX tank and near the vehicle center of gravity. The aft fuselage of the vehicle contains the thrust structure and engine feedlines.

A dry weight factor of 0.75 (25% reduction in across-the-board component weight technology availability compared to the corresponding component weight technology availability level for the two-stage, partially reusable concept discussed previously) was selected for the SSTO vehicle optimizations. This percentage was conservatively selected to insure the capability of all options considered to reach orbit using reasonable, perhaps by year 2000, component weights. The dry weight factor includes engine weight reductions.

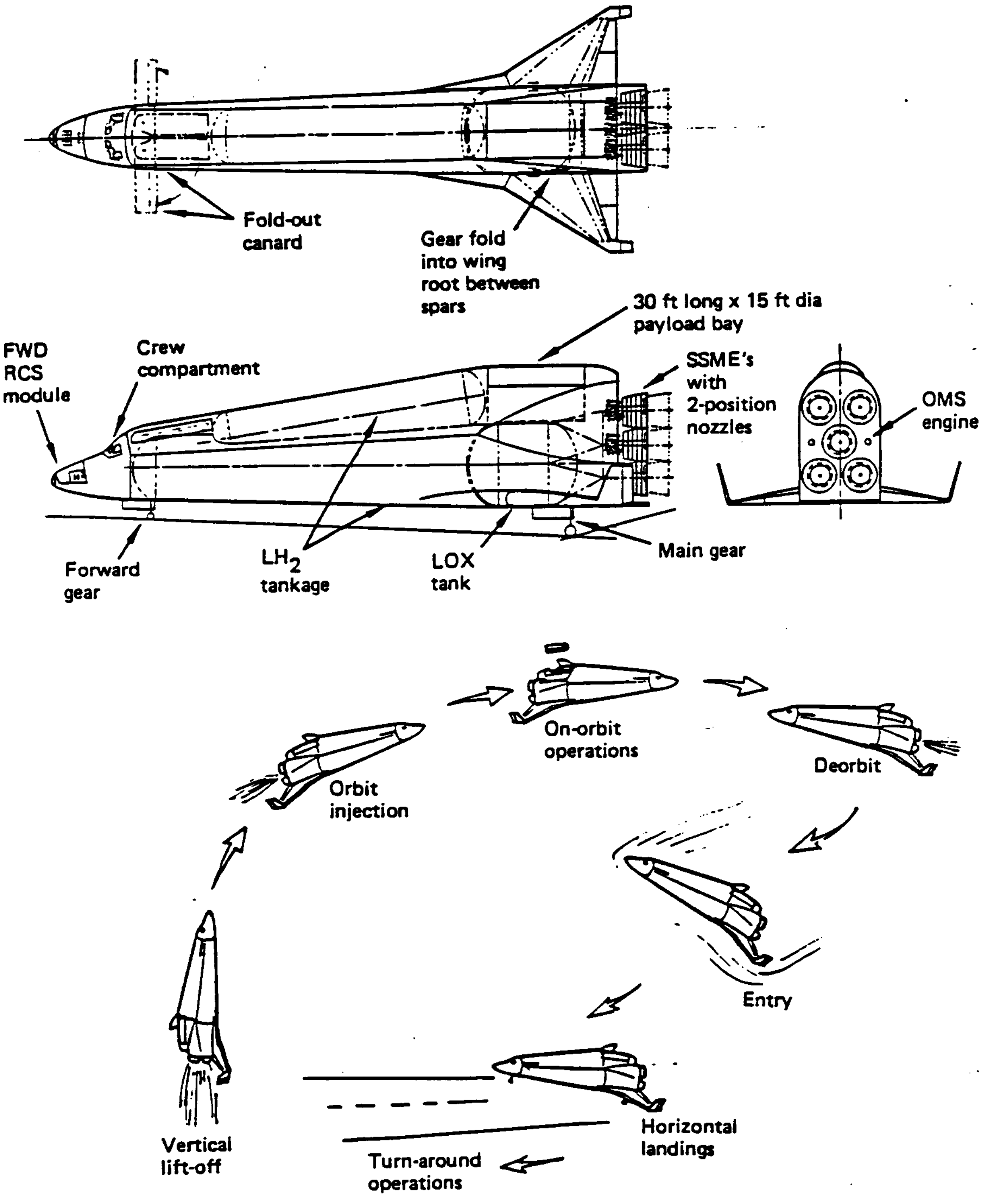

Figure 3.1.2-1. Typical Features of a Single-Stage Fully Reusable Launch Vehicle

The vehicle sensitivity analysis comprises a spectrum of vehicle design conditions optimized to produce minimum total dry weight for selected values of any of the following independent variables:

a. Body diameter.

b. Engine-out liftoff acceleration.

c. Propellant mixture ratio (booster engine).

d. Number of booster engines.

e. Engine expansion ratio (booster engine).

The dependent variables chosen were:

a. Total dry weight.

b. Gross liftoff weight.

c. Vehicle dry weight.

d. Ascent propellant weight.

e. Propellant mixture ratio (booster engine).

f. Throttle setting.

g. Propellant mass fraction.

h. Landing weight.

i. Number of booster engines.

j. Engine vacuum thrust.

k. Engine-out liftoff acceleration.

l. Nominal liftoff acceleration.

m. Booster engine weight.

n. Body diameter.

Note that the list of independent variables is a subset of the list of dependent variables. This area arises because a given variable (e.g., body diameter) may be held as an independent variable for the development of a sensitivity in which all other variables are dependent and allowed to "float" to find their optimum value. In addition, other variables are chosen to be independent, and the given variable then becomes a floating dependent variable.

3.1.2.1 Baseline Vehicle (Configuration 1.A)

Configuration Description. Figure 3.1.2.1-1 presents a three-view drawing of configuration 1.A. A summary of configuration features is shown in figure 3.1.2.1-2. Detailed performance and weight numbers are tabulated in Appendix A-54 through A-55.

Optimization Sensitivities. Because the vehicle was configured only to establish a point-design solution, using SSMEs for the performance requirement, a detailed optimization sensitivity analysis was reserved for the design of the reference vehicle described in section 3.1.2.2.

3.1.2.2 H_2/H_2 (Configuration 1.B)

Configuration Description. Figure 3.1.2.2-1 presents a three-view drawing of configuration 1.B. A summary of configuration features is shown in figure 3.1.2.2-2. Detailed performance and weight numbers are tabulated in the Appendix A-56 through A-57.

Optimization Sensitivities. The optimization constraints on the selected independent variables were as follows:

a.	Body diameter:	24 to 32 ft
b.	Engine-out liftoff acceleration:	1.2 to 1.5g
c.	Mixture ratio (booster):	6 to 10
d.	Initial expansion ratio (booster):	30 to 70
e.	Propellant remaining:	40 to 80%
f.	Number of booster engines:	4 to 8
g.	Second expansion ratio (booster):	70 to 150

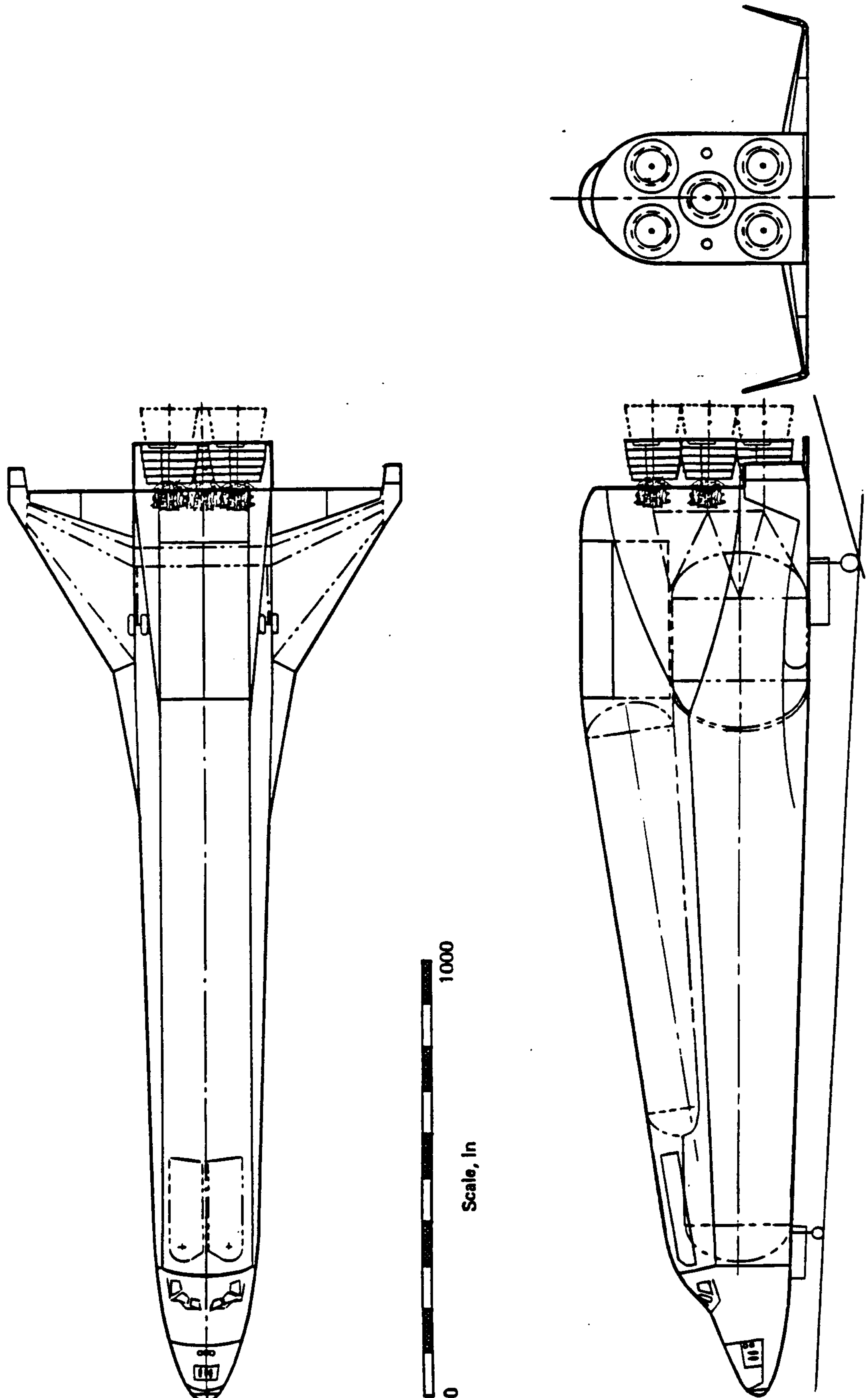

Figure 3.1.2.1-1. Three-View Drawing of Configuration 1.A

Vehicle Features			
• **Weights**		• **Body**	
GLOW (lb) =	1,408,600	$\frac{\ell}{D}$ =	6.93
P/L to Space Station (lb) =	10,000	D (ft) =	25.0
Dry Weight (lb) =	138,650	$S_{body\ flap}$ (ft^2) =	200
Propellant Weight (lb) =	1,235,000	• **Wing**	
- LO_2 (lb) =	1,058,400	S_{ref} (ft^2) =	2,367
- LH_2 (lb) =	176,390	AR =	1.91
Inert Weight (lb) =	162,270	λ =	0.12
λ' =	0.883	t/c =	11%
• **Engines**		$S_{flaperons}$ (ft^2) =	473
Type =	LOX/LH_2	• **Fins**	
Number =	5	S_F (ft^2) (ea) =	114
Thrust (vacuum, each) (lb) =	504,120	AR =	1.39
MR =	6.00	λ =	0.55
P_C (psia) =	3,270	t/c =	11%
I_{sp} =	448	S_{rudder} (ft^2) (ea) =	34.3
$d_{powerhead}$ (in) =	90	• **Cannards**	
$D_{nozzle\ exit}$, (1st Position) (in) =	75.6	S_H (ft^2) =	103
ε (1st Position) =	55	AR =	4.00
$D_{nozzle\ exit}$, (2nd Position) (in) =	125.0	λ =	1.00
ε (2nd Position) =	150	t/c =	15%
• **Crew Accomdations**		$S_{elevons}$ (ft^2) (ea) =	30.9
Crew =	2		
ECS =	Shirt Sleeve		

	LBS VALUE
TOTAL DRY WEIGHT	141020.00
GROSS LIFT OFF WEIGHT	1460000.00
BODY WEIGHT	83074.00
GROWTH WEIGHT	7278.70
INERT WEIGHT	165410.00
EQUIPMENT WEIGHT	12339.00
TANK MOUNT WEIGHT	846.34
STRUCTURAL WALL WEIGHT	61537.00
APU PROPELLANT WEIGHT	2913.20
LANDING WEIGHT	144810.00
LANDING GEAR WEIGHT	4407.70
CANARD WEIGHT	1966.50
WING WEIGHT	24193.00
WEIGHT OF REENTRY INSULATION TILES	9702.30
PAYLOAD WEIGHT	10000.00
PAYLOAD BAY WEIGHT	6704.40

Figure 3.1.2.1-2. Summary of Configuration Features for Configuration 1.A

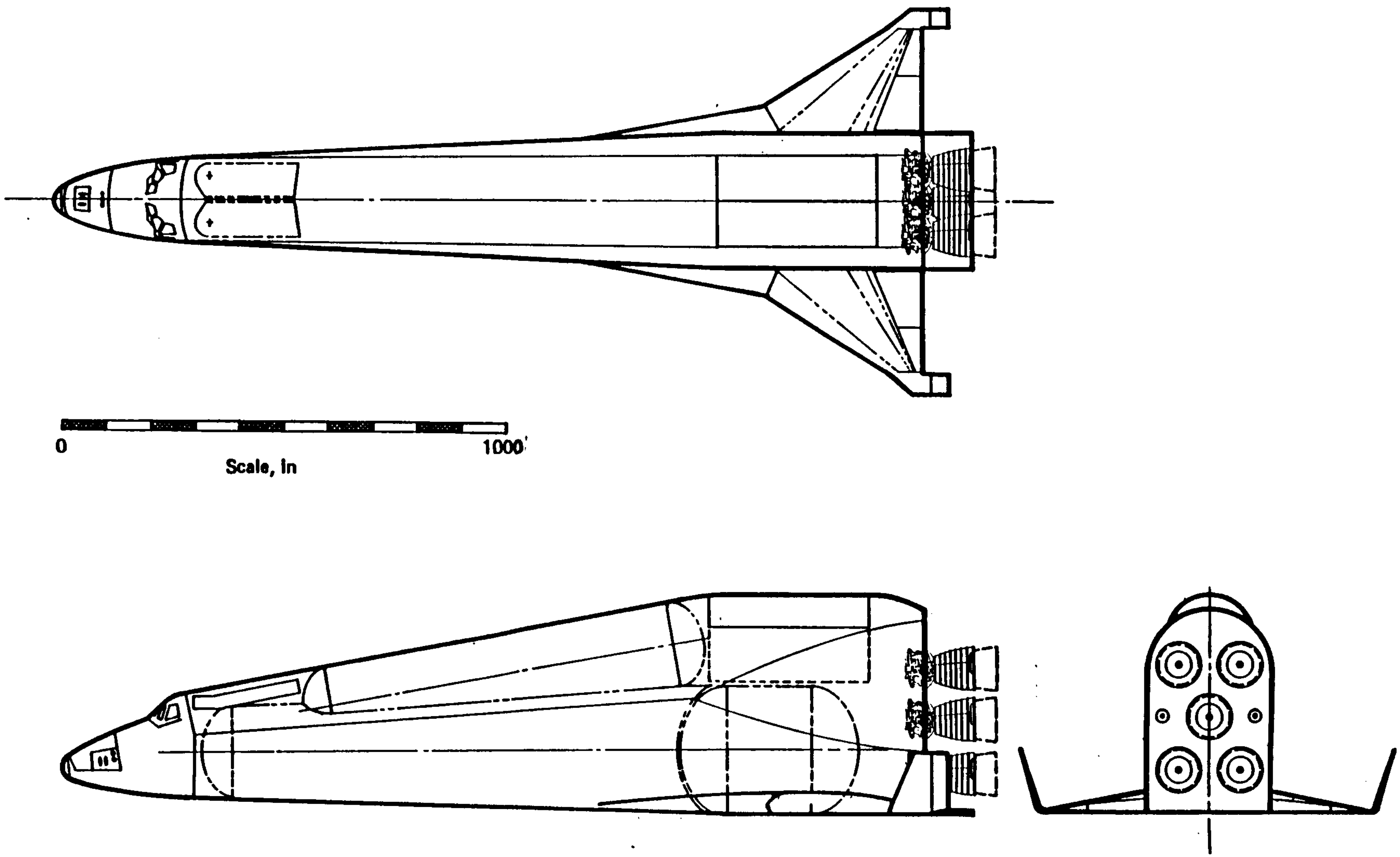

Figure 3.1.2.2-1. Three-View Drawing of Configuration 1.B

Vehicle Features	
• Weights	
GLOW (lb) =	1,277,100
P/L to Space Station (lb) =	10,000
Dry Weight (lb) =	112,470
Propellant Weight (lb) =	1,133,000
- LO_2 (lb) =	1,001,000
- LH_2 (lb) =	131,710
Inert Weight (lb) =	133,070
λ' =	0.894
• Engines	
Type =	LOX/LH_2
Number =	5
Thrust (vacuum, each) (lb) =	415,290
MR =	7.60
P_C (psia) =	4,000
I_{sp} =	425
$d_{powerhead}$ (in) =	86
$D_{nozzle\ exit}$, (1st Position) (in) =	52.6
ε (1st Position) =	30
$D_{nozzle\ exit}$, (2nd Position) (in) =	96.2
ε (2nd Position) =	100
• Crew Accomdations	
Crew =	2
ECS =	Shirt Sleeve

Vehicle Features	
• Body	
$\frac{\ell}{D}$ =	6.93
D (ft) =	24.0
$S_{body\ flap}$ (ft^2) =	192
• Wing	
S_{ref} (ft^2) =	1,924
AR =	1.91
λ =	0.12
t/c =	11%
$S_{flaperons}$ (ft^2) =	385
• Fins	
S_F (ft^2) (ea) =	101
AR =	1.39
λ =	0.55
t/c =	11%
S_{rudder} (ft^2) (ea) =	30.3
• Cannards	
S_H (ft^2) =	84
AR =	4.00
λ =	1.00
t/c =	15%
$S_{elevons}$ (ft^2) (ea) =	25.1

Figure 3.1.2.2-2 Summary of Configuration Features for Configuration 1.B

Detailed sensitivity analyses for a fixed mixture ratio engine are discussed below based on the curves shown in the Appendix B-290 through B-317.

Body Diameter. Total dry weight is a classic "bucket" function minimizing at 25 ft, with appreciable sensitivity over the range of variation. No breakpoints are evident and most curves show appreciable sensitivity. Propellant mass fraction is relatively insensitive. Throttle setting optimized at approximately 91.45%, second nozzle expansion ratio at its lower limit (70:1), engine-out liftoff acceleration at its lower limit (1.2g), and nominal liftoff acceleration at approximately 1.477g over the range of variation (Appendix B-290 through B-293).

Engine-out Liftoff Acceleration. Total dry weight minimizes in the range 1.26 to 1.30g, with appreciable sensitivity over the range of variation. No breakpoints are apparent. Propellant remaining and propellant mass fraction are relatively insensitive. Throttle setting optimized at approximately 91.43% and second expansion ratio at its lower limit (70:1) over the range of variation (Appendix B-294 through B-297).

Mixture Ratio. Total dry weight minimizes in the range 6.9 to 7.4, with appreciable sensitivity over the range of variation. Two very minor breakpoints occur at approximately 7.8 and 8.7, where the former is associated with breaking free from the lower limit on body diameter and the latter is associated with reaching the lower limit on initial expansion ratio. Throttle setting optimized at approximately 91.4%, engine-out liftoff acceleration at its lower limit (1.2g), nominal liftoff acceleration at approximately 1.477g, and second expansion ratio at its lower limit (70:1) over the range of variation (Appendix B-298 through B-301).

Initial Expansion Ratio. Total dry weight minimizes near an expansion ratio of 43:1, but is relatively insensitive over the range of variation. No breakpoints are evident. Propellant mass fraction is relatively insensitive. Throttle setting optimized at approximately 91.4%, engine-out liftoff acceleration at its lower limit (1.2g), nominal liftoff acceleration at approximately 1.477g, body diameter at its lower limit (24 ft), and second expansion ratio at its lower limit (70:1) over the range of variation (Appendix B-302 through B-305).

Propellant Remaining. Total dry weight minimizes at the upper limit of 80%, with moderate sensitivity over the range of interest. A breakpoint occurs at approximately 75.5%, associated with breaking free from the lower limit on engine-out acceleration and with breaking free from the lower limit on engine-out acceleration and with breaking free from the lower limit on body diameter. Propellant mass fraction is relatively insensitive. Throttle setting optimized at approximately 91.4%, nominal liftoff acceleration at approximately 1.477g, and second expansion ratio at its lower limit (70:1) over the range of variation (Appendix B-306 through B-309).

Number of Booster Engines. Total dry weight minimizes at five engines, with appreciable sensitivity over the range of variation. Two major breakpoints occur, at 4.9 and 5.8 engines (fractional engines are artifacts of the continuous-function algorithm used in the optimization program). The former is associated with breaking free from the lower limit on initial expansion ratio. The second is associated with abruptly breaking free from the lower limit on engine-out liftoff acceleration. Propellant mass fraction is relatively insensitive. Throttle setting optimized at approximately 91.4%, nominal liftoff acceleration at approximately 1.477g, and second expansion ratio at its lower limit (70:1) over the range of variation (Appendix B-310 through B-313).

Second Expansion Ratio. Total dry weight minimizes at an expansion ratio of 140:1, with moderate sensitivity over the range of variation. No breakpoints occur. Initial propellant mixture ratio, propellant remaining, and propellant mass fraction are relatively insensitive. Throttle setting optimized at approximately 91.44%, engine-out liftoff acceleration at its lower limit (1.2g), nominal liftoff acceleration of approximately 1.4765g, and body diameter at its lower limit (24 ft) over the range of variation (Appendix B-314 through B-317).

3.1.2.3 SSTO Dry Weight Optimization

The optimized SSTO configurations for total dry weight are shown in figure 3.1.2.3-1. Figure 3.1.2.3-2 compares the hydrocarbon configurations to an optimized, for minimum dry weight, LOX/LH_2 configuration. The hydrocarbon configurations show up to a 5% reduction in dry weight over the optimized LOX/LH_2 configuration. The improved propellant bulk density of the hydrocarbons improve both the dry weight and GLOW for methane and subcooled propane. All vehicles used LH_2 engine cooling.

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Configuration	1.A	1.B	1.C	1.D	1.E	Acurex
Fuel	LH_2	LH_2	RP-1	Methane	SC Propane	LH_2
Coolant	LH_2	LH_2	LH_2	LH_2	LH_2	LH_2
Mixture Ratio	6.0	7.5	3.03	4.19	3.59	9.6
Number of Main Engines	5	5	2(1)	2(1)	2(1)	3
Main Engines Vac. Thrust (lb)	504,120	381,440	338,240	280,622	279,670	775,570
Vacuum Isp - sec	448	425	312	329	317	424/453
Booster P_C (psia)	3,270	4,000	4,000	4,300	4,000	3,000/2,250
Expansion Ratio	55/150	30/100	15(2)	15(2)	15(2)	20/64
Propellant Remaining @ Main Engine Cutoff	N/A	N/A	30%	37%	42%	N/A
Main Engine Total Thrust Range Ratio	.25	.25	.82	.96	Not Done	Not Done
SSME Engine Total Thrust Range Ratio	N/A	N/A	.41	.39	Not Done	N/A
Inert Weight Factor	.75	.75	.75	.75	.75	.75
Dry Weight	141,020	104,690	102,080	100,040	99,216	103,460
Propellant	1,283,000	1,062,300	1,130,300	1,039,200	1,029,400	1,092,400
Glow	1,460,000	1,119,750	1,263,600	1,168,200	1,157,400	1,226,700

(1) Plus 3 SSME Engines.
(2) Initial Expansion Ratio 55 changed to 150 on SSME Engines.

Figure 3.1.2.3-1 Single-Stage Optimized Results

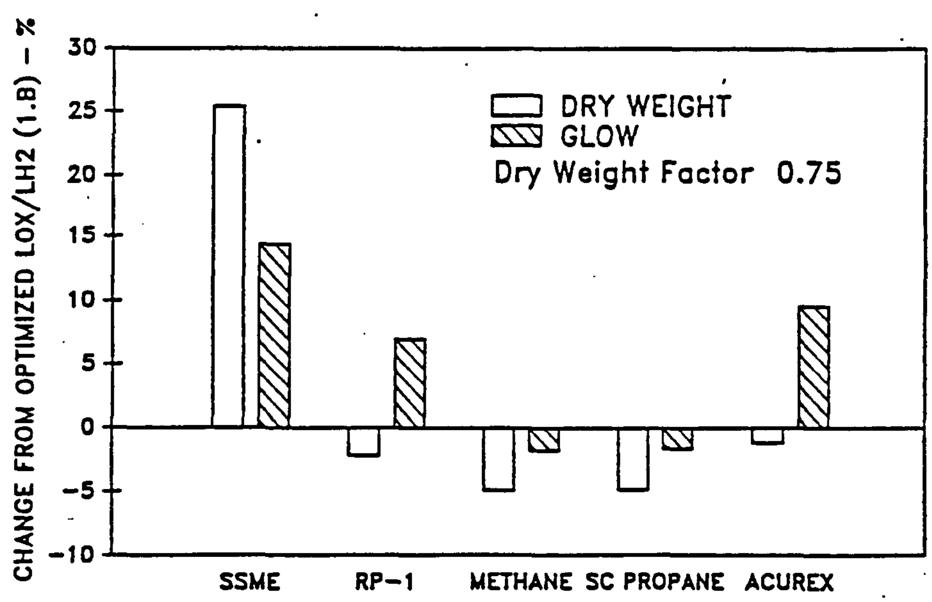

Figure 3.1.2.3-2 Single-Stage Weight Comparisons

3.1.2.4 RP-1/H_2 (Configuration 1.C)

Detailed performance and weight numbers are tabulated in the Appendix A-58 through A-59. The improvement in total dry weight using LOX/RP-1 booster propellant is about 2½ percent less than for the all LOX/LH_2 propellant vehicle.

3.1.2.5 Methane/H_2 (Configuration 1.D)

Detailed performance and weight numbers are tabulated in the Appendix A-60 through A-61. The improvement in total dry weight using LOX/methane booster propellant is about 4.4 percent less than for the all LOX/LH_2 propellant vehicle.

3.1.2.6 SC Propane/H_2 (Configuration 1.E)

Detailed performance and weight numbers are tabulated in the Appendix A-62 through A-63. The improvement in total dry weight using LOX/SC propane booster propellant is about 5.2 percent less than for the all LOX/LH_2 propellant vehicle. The improved bulk density of the SC propane shows some benefit in total dry weight over the other propellant combinations.

3.1.2.7 LOX/LH_2 Using Acurex Engine Data

Detailed performance and weight numbers are tabulated in the Appendix A-64 through A-65. The detailed Acurex engine data is presented and discussed in section 3.3. The improvement in total dry weight using the Acurex engine configuration is about 1 percent less in dry weight than the Aerojet powered (configuration 2.B) vehicle.

3.1.2.8 Single-stage LOX/LH_2 Variable Mixture Ratio Impact

Allowing the mixture ratio to change during the ascent of the LOX/LH_2 SSTO vehicle was found to generate a minimum dry weight system. Liftoff mixture ratio optimized at 8.4:1 and second mixture ratio optimized at about 7.5:1. The optimum mixture ratio change occurred at 52% of the propellant remaining in the vehicle.

However, the optimized variable mixture ratio system is less than 2% lighter in dry weight that a fixed mixture ratio system optimized at 7.6, assuming the gas generator engine performance levels used for this part of the study.

3.1.2.9 Single-stage LOX/LH_2 Variable Expansion Ratio Impact

The all LOX/LH_2 SSTO vehicle optimized at a liftoff expansion ratio of 30:1 and the second expansion ratio in 100:1 (propellant remaining in the SSTO vehicle at expansion ratio changed at 72% of the total vehicle quantity).

The LH_2 plus hydrocarbon fueled SSTO used an expansion ratio on the LOX/LH_2 engines of 55:1 at liftoff, changing to 100:1 later in the trajectory. All the hydrocarbon engines optimized at the lowest expansion ratio (15:1) to minimize system dry weight.

3.1.2.10 SSTO Computer Model Comparison

The Boeing SSTO model results for LOX/LH_2 was compared to Reference 4 study (fig. 3.1.2.10-1). Different payloads, orbit inclination, and other assumptions between the two models required that both results be normalized for direct comparison. A fair agreement exists between the two models with Boeing's model being the more conservative of the two in dry weight determination. This comparison enhanced confidence in the effectiveness of the Boeing developed model for SSTO vehicle optimization analysis and prediction of realistic vehicle characteristics.

3.1.3 Summary of Related Vehicle Analysis Conducted on IR&D Funding

The contract SSTO analysis scope required that the vehicle option optimizations be conducted on the basis of dry weight minimization. The results obtained, as discussed above, thus pertain to highly efficient SSTO vehicle concepts having a polar LEO payload to GLOW ratio of almost 1%. This would be a remarkable achievement for an SSTO vehicle. For example, the current partially expendable, multi-stage (these factors decrease vehicle weight) Space Shuttle has a polar LEO payload to GLOW ratio of only about 1/2% (partly because it uses mostly early 1970's component weight technology levels). To obtain such high effectiveness the above discussed SSTO vehicle require about a 25% across-the-board reduction relative to ALS vintage weights for a partially reusable two-stage vehicle (including engine weights).

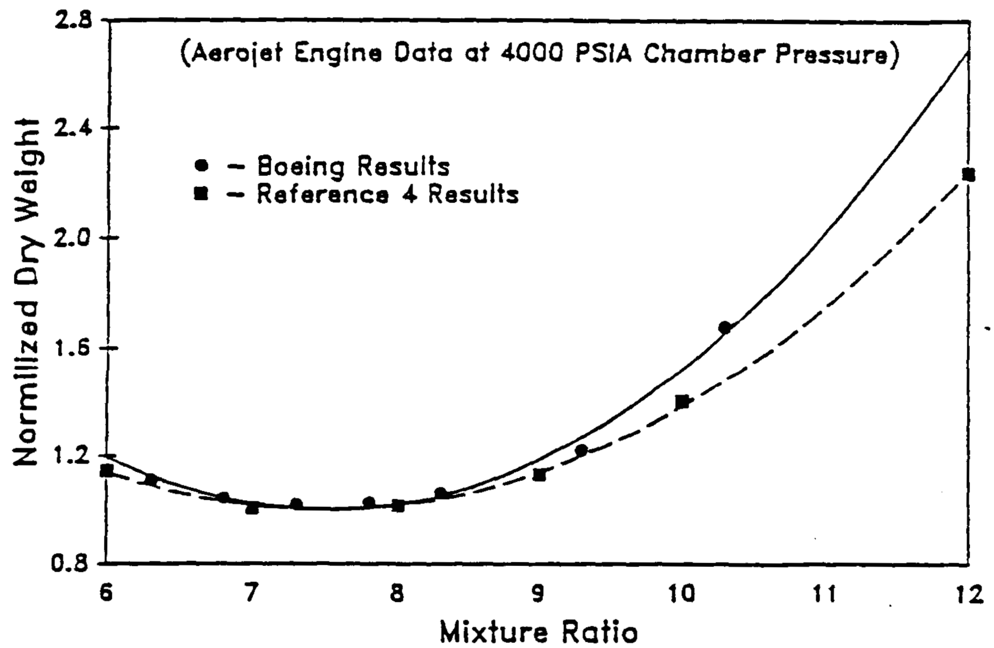

Figure 3.1.2.10-1 Boeing Normalized LOX/LH_2 SSTO Study Results Compared to NASA Normalized Study Results

Since the cost of achieving such considerable weight reductions may not be affordable, and/or may require very lengthy development schedule, Boeing performed on IR&D funding, beyond the above discussed contract scope, an alternative type of SSTO vehicle optimization, namely minimizing the impact on required SSTO vehicle dry weight factor (rather than minimizing dry weight itself). To date, this continuing study has resulted in the following key findings:

a. By increasing allowable weight and propellant weight sufficiently, in conjunction with using several identical two-position nozzle LOX/LH_2 engines having a single moderately high mixture ratio, (about 7.5:1), an across-the-board component dry weight factor of about 1.0 can be obtained for payload delivery to Polar LEO. This dry weight factor is equivalent to currently projected ALS vintage component weight technology level for a two stage partially reusable launch vehicle (mid 1990's availability).

b. For a payload of 10k lb to 100 x 100 nmi polar LEO a vehicle GLOW of about 4 million lb is required to allow a dry weight factor of 1 if LOX/LH_2 propellant is used (slightly lower GLOW allowable for a LOX/methane/LH_2 cooled vehicle).

c. The resulting manned, all-rocket, vertical lift-off SSTO vehicle is relatively simple and small (even at a GLOW OF 4 million lb) compared in a manned, horizontal take-off, airbreather/rocket SSTO vehicle sized for the same payload delivery capability. Further, development risk would be greatly reduced since the required component weight technology levels could be readily achieved by the mid 1990's using reasonable extension of today's levels.

Figure 3.1.3-1 presents a preliminary plot of dry weight factor versus GLOW for LOX/LH_2 and $LOX/CH_4/LH_2$ SSTO vehicle concepts sized for delivery of a 10K lb payload to 100 x 100 nmi polar LEO. Like the SSTO vehicle studies conducted under contract funding, these concepts also have engine-out mission completion capability (one engine-out at any point in the launch trajectory, including at lift-off). These curves indicate about how much the dry weight of the two different types of SSTO vehicles (Figures 3.1.3-2 and 3.1.3-3) could be reduced to allow lower GLOW levels.

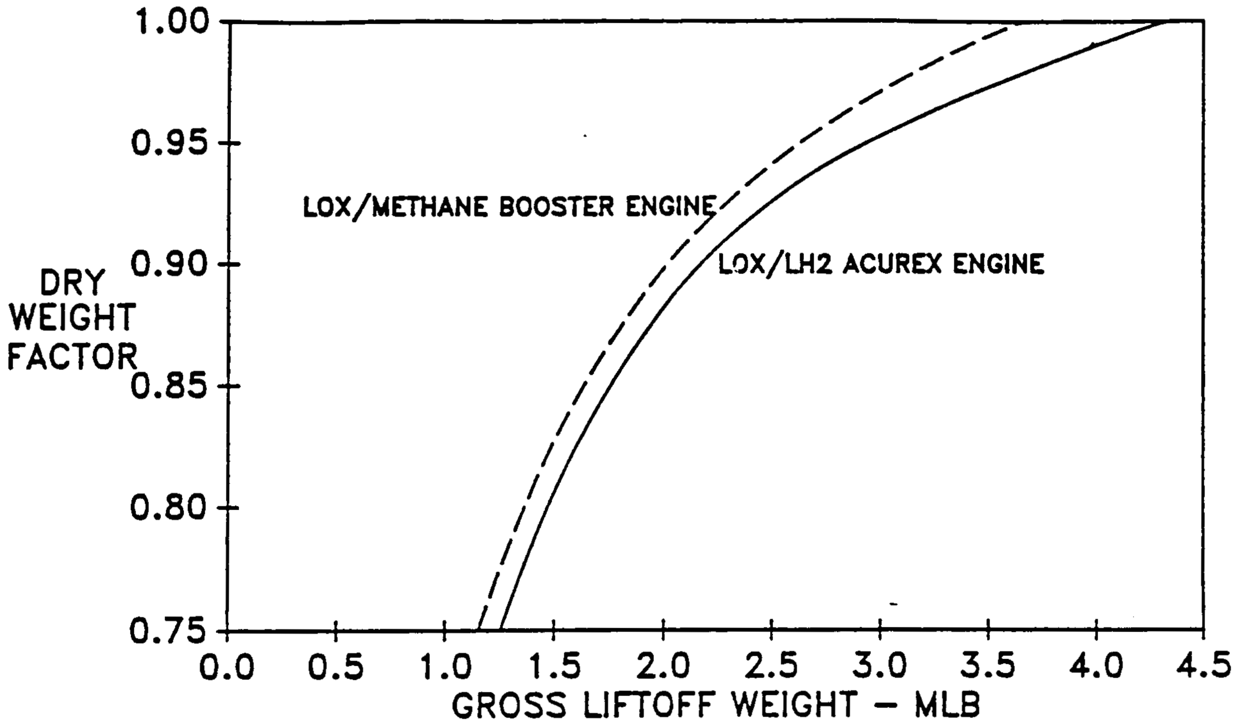

Figure 3.1.3-1 Vehicle Liftoff Weight Optimized for Maximum Dry Weight Factor

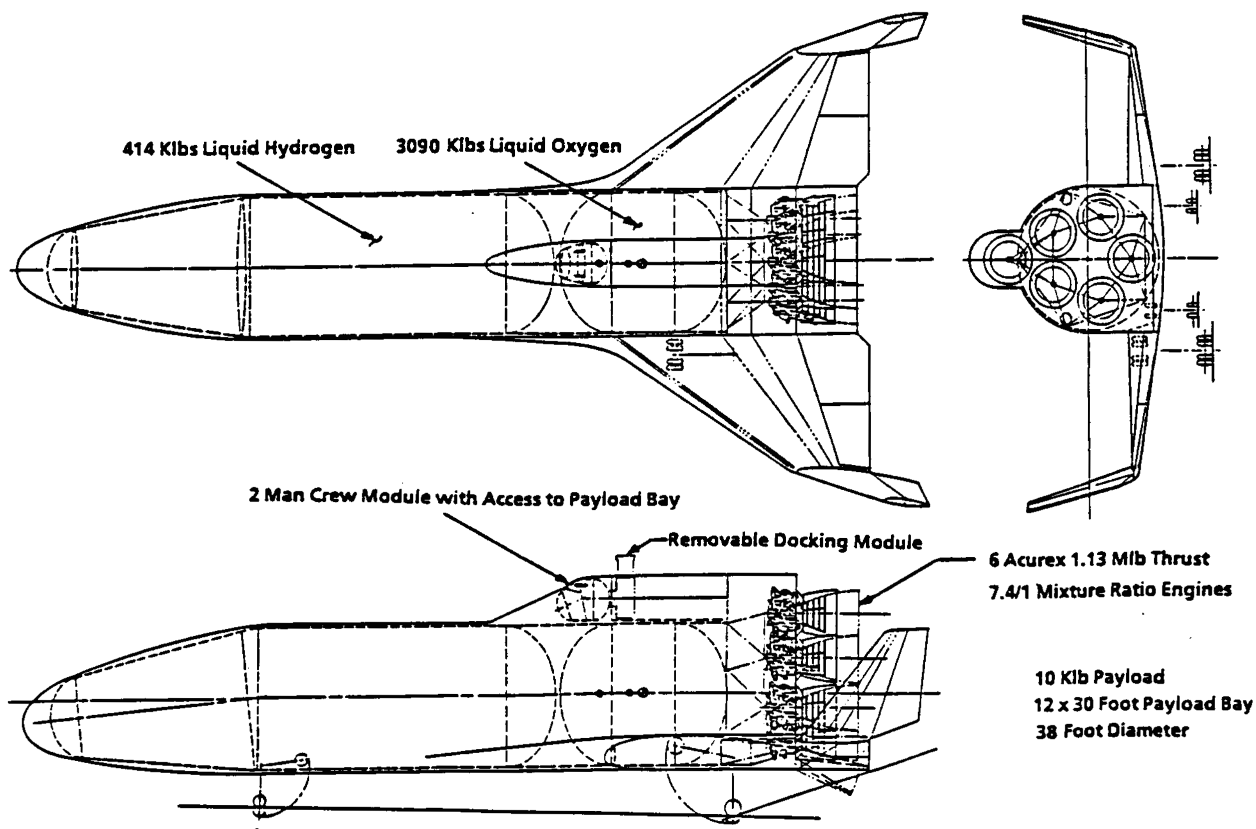

Figure 3.1.3-2 LOX/LH2 SSTO Vehicle Concept with 4M LB Glow for ≈ 0.99 Dry Weight Factor

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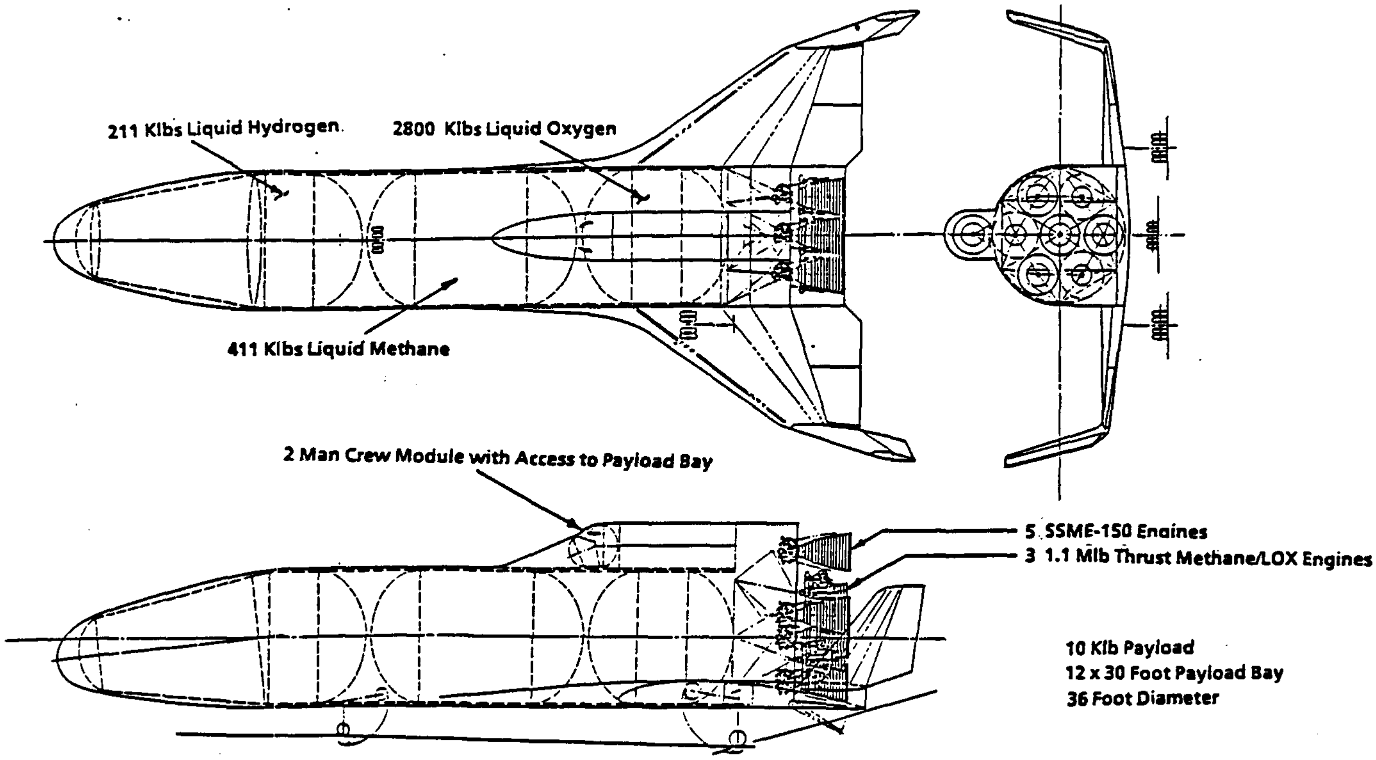

Figure 3.1.3-3 LOX/LH2 + LOX/CH4/LH2 SSTO Vehicle Concept with 3.5M lb Glow for ≈ 0.99 Dry Weight Factor

Another key IR&D finding was that the development of a new high thrust engine such as required for the 4 million lb GLOW SSTO vehicle discussed above (6 engines, of 1 million lb lift-off thrust each required for engine-out capability) might benefit not only a new SSTO manned access to the Space Station vehicle, but also enable modular adaptability to a wide range of launch vehicle requirements (Figure 3.1.3.-4). In this example, multiple redundant pumps are used on each engine for "pump-out" rather than complete engine-out capability. Thus, the required number of vehicle engines is reduced. Multiple use of the main modular component depicted (tankage/engine) permits manufacturing economies, such that even a partially reusable manned access for the Space Station vehicle might be cost effective. This partially reusable, manned vehicle would be much smaller and lighter than an SSTO vehicle having the same payload capability and weights technology levels. Thus it would have a significantly lower development cost. Like all the vehicle adaptations shown on Figure 3.1.3-4, only the center ("core") engine need gimbal. Otherwise the engines could be virtually identical, except for possible reduced cooling provision of those engines on the strap-on tankage (having a shorter burn-time than the core engine). Such studies are on-going to drive-out the required characteristics of the "best-compromise" type of new engine needed to adapt to a broad range of potential mission requirements.

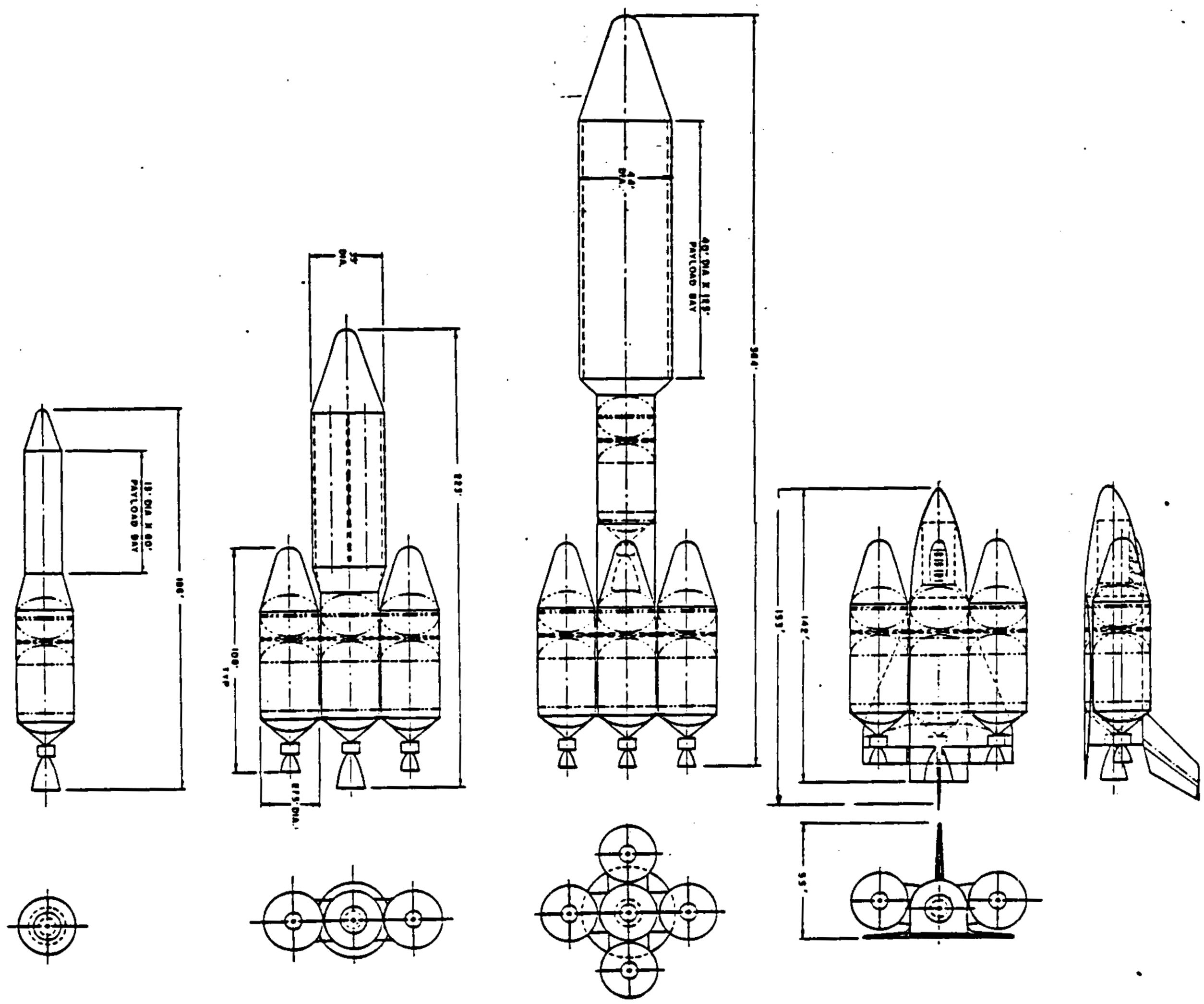

Figure 3.1.3-4 Modular Adaptable LOX/LH_2 Launch Vehicle Concept

3.2 SUBCOOLED PROPANE IMPACT

The use of subcooled (SC) propane fuel propellant has been shown to be potentially advantageous for a single-stage-to-orbit (SSTO) vehicle. Near-boiling-point (NBP) propane is assumed to be available as a stock material from which to obtain SC propane. Liquid oxygen (LOX), to be used as the oxidizer, would be held at 90K in the vehicle. It is therefore reasonable to consider subcooling the propane to about 90K to 91K as well.

This study task examined ways to achieve the subcooled propane state, various methods of maintaining propellant condition on board, and means to transfer, store, and otherwise manage the propane supply at the launch site. The results of this study task include an identification and sizing of the propane-related Government-supplied equipment (GSE) as well as a rough order of magnitude (ROM) cost estimate.

This study task found that an LN_2-refrigerated counterflow heat exchanger will provide a relatively economical, rapid, safe chilldown process to achieve the subcooled propane. Propane viscosity at 91K is close to that of kerosene (or RP-1), so either pump or differential pressure transfer systems can be used. The pump transfer system is recommended because it does not require the generation of large quantities of pressurant gases.

Onboard propellant conditioning, i.e., temperature control and prevention of thermal stratification, is proposed to be accomplished by a ground-based recirculating chiller, using the same LN_2 system as was initially used for refrigeration of the propane.

Subcooling to the proposed temperature of 91K increases propane density by about 33% over NBP propane. It also reduces vapor pressure to a negligible value. Higher density means a smaller propellant tank and low vapor pressure improves the ability to pump propane because cavitation tendency is reduced. The low vapor pressure does require special provisions to maintain tank ullage pressure for tankage not designed to withstand vacuum-induced loads.

The system was sized to accommodate a 48-hr vehicle turnaround time. This scenario permitted a nominal fuel tank loading time of 4 hr (i.e., 100,000 lb/hr).

Rough order of magnitude (ROM) cost for a facility system to provide a propane fuel propellant load of 400,000 lb, prechilled, and to maintain onboard propellant condition is approximately \$5.0 to \$5.5 million (see fig. 3.2-1).

ITEM	ROM COST
Cryogenic tankage	\$640,000
Pressure and purge gas supply	380,000
Propellant chilling system	200,000
Vacuum-jacketed piping	540,000
Buildings and other civil works	270,000
Launch pad plumbing, umbilical, etc.	150,000
Architect fees and construction/installation labor	2,720,000
Miscellaneous unpriced items and contingency	360,000
ROM Total	\$5,260,000

Figure 3.2-1 ROM Cost Estimate Summary

3.2.1 Propane Physical Properties

Commercial propane is a commonly used hydrocarbon for industrial feed stocks as well as for a variety of household uses. A useful feature of propane is that it is liquid at room temperature under moderate pressures (i.e., 40 to 50 psig), and vaporizes by ambient heat to provide a convenient supply of gaseous fuel.

In spite of propane's widespread private and industrial use, relatively little work has been reported with respect to subcooled propane. One reason is that the temperature range over which propane exists as a liquid is very wide, and it is typically stored at ambient temperatures. A large amount of heat has to be removed to bring propane to its freezing point of -306.7°F (85K). A second reason is that propane vapor pressure falls below atmospheric pressure at -43.73°F (231K). At lower temperatures, a tank ullage pressurant is necessary to avoid an ullage vacuum, which could cause in-leakage of contaminants or cause the collapse of the vehicle tank. Figure 3.2.1-1 lists useful characteristics of propane. (See also fig. 3.2.1-2 through 3.2.1-6.) These properties were used in the work reported in the sections to follow.

3.2.2 Subcooling Propellants

Typical processes for subcooling liquid propellants include:

a. Helium bubbling.

b. Hydrogen bubbling.

c. Vacuum-induced boiling.

d. Nitrogen heat exchanger.

e. Turbo expansion.

f. Joule-Thompson effect.

g. Combination.

A specific amount of prior work relates to subcooling and slushing of fuels such as methane and hydrogen. Two approaches predominate. One is self-cooling by vacuum-induced boiling, another is by the bubbling of a cold gas such as helium through the liquid. Of these, the vacuum-induced method is preferred. The gas bubbling method tends to induce gas absorption into the liquid being chilled. Also, as the liquid approaches freezing temperatures, ice shells tend to form around the bubble columns, restricting free contact between the cold gas and the liquid. Solubility of the chill gases in the liquid is a drawback because the amount of foreign gas in solution may vary with

Density of liquid at 86°F, lb/ft^3	30.37
Specific volume of saturated vapor at 5°F, lb/ft^3	2.44
Specific heat of liquid at 86°F, Btu/lb°F	0.65
Specific heat ratio (c_p/c_v) of vapor at 86°F and one atmospheric pressure	1.14
Vapor pressure at triple point, mm Hg	0.0000546
Thermal conductivity, (Btu-ft)/(ft^2.hr.°F)	
Saturated liquid at NBT	0.076
Saturated liquid at 5°F	0.065
Saturated liquid at 86°F	0.056
Vapor at saturation pressure at NBT	0.00625
Vapor at saturation pressure at 5°F	0.0082
Vapor at one atmosphere pressure at 86°F	0.0107
Viscosity, Centipoises:	
Saturated liquid at NBT	0.210
Saturated liquid at 5°F	0.161
Saturated liquid at 86°F	0.101
Vapor at saturation pressure at NBT	0.0062
Vapor at saturation pressure at 5°F	0.00712
Vapor at one atmosphere pressure at 86°F	0.0082
Color	Clear and Water White
Flammability limits (Vol. % in air)	2.3 to 7.3
Toxicity, Underwriters' Laboratories classification	Group 5b

Figure 3.2.1-1 Propane Properties

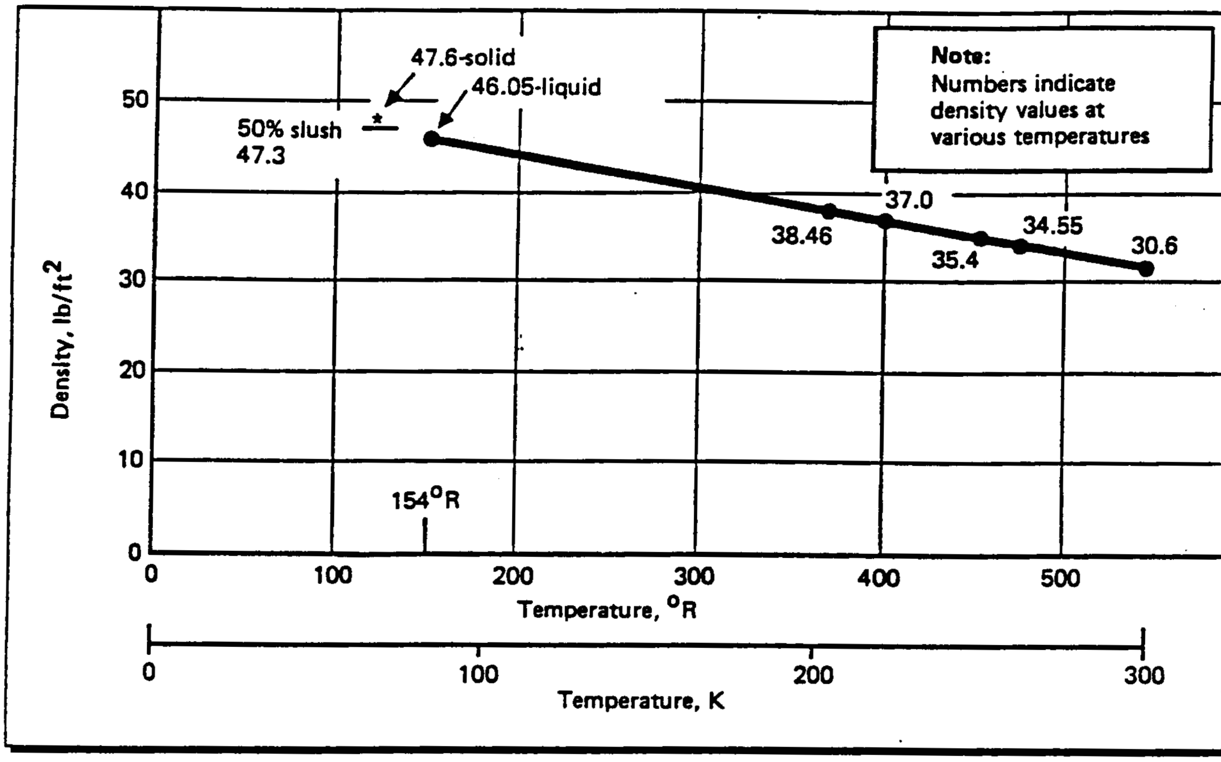

Figure 3.2.1-2. Density of Propane Versus Temperature

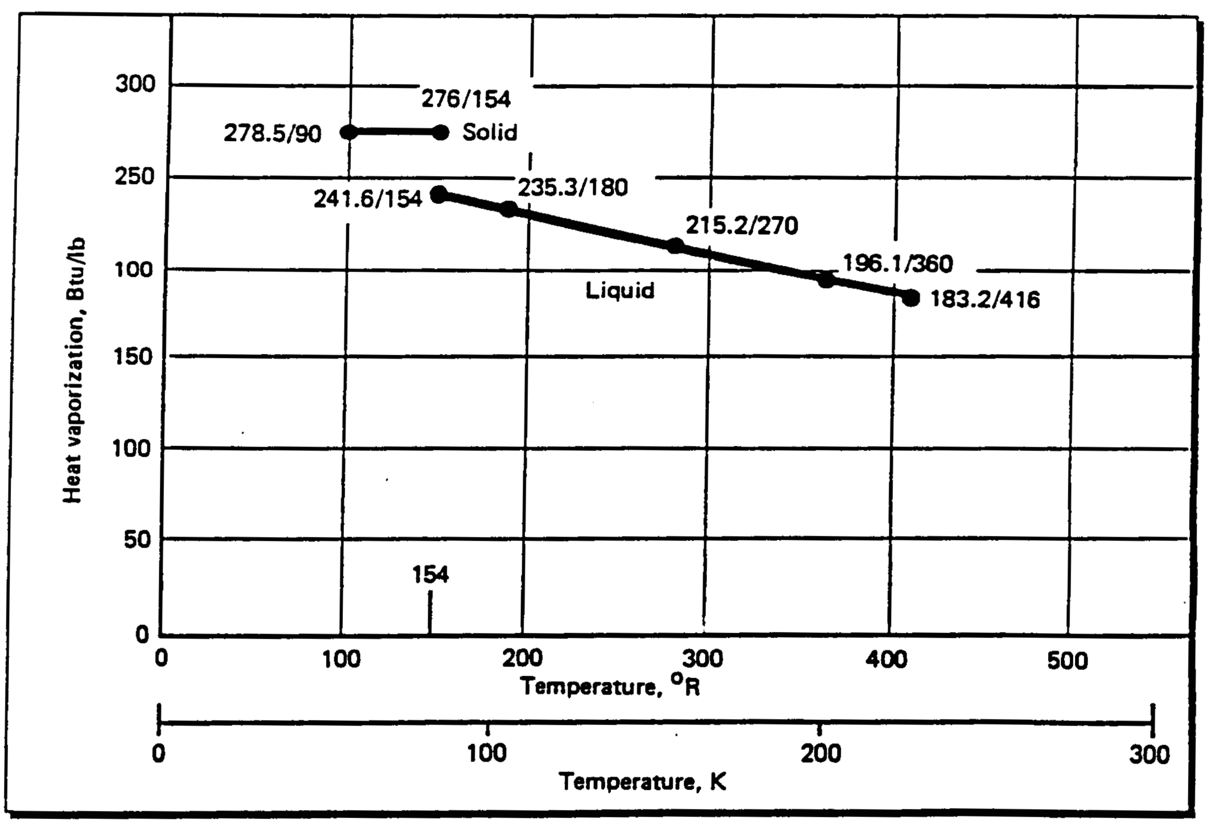

Figure 3.2.1-3. Propane Heat of Vaporization as a Function of Temperature

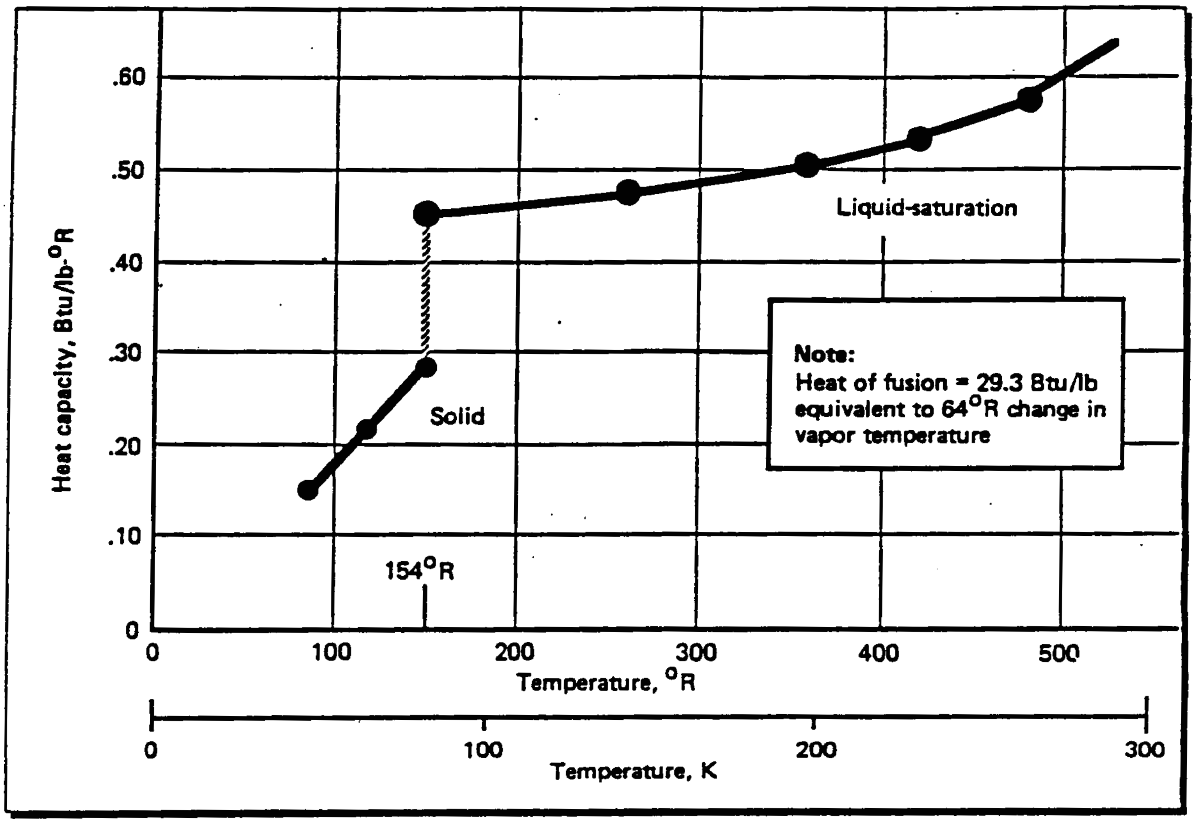

Figure 3.2.1-4. Heat Capacity of Solid/Liquid Propane as a Function of Temperature

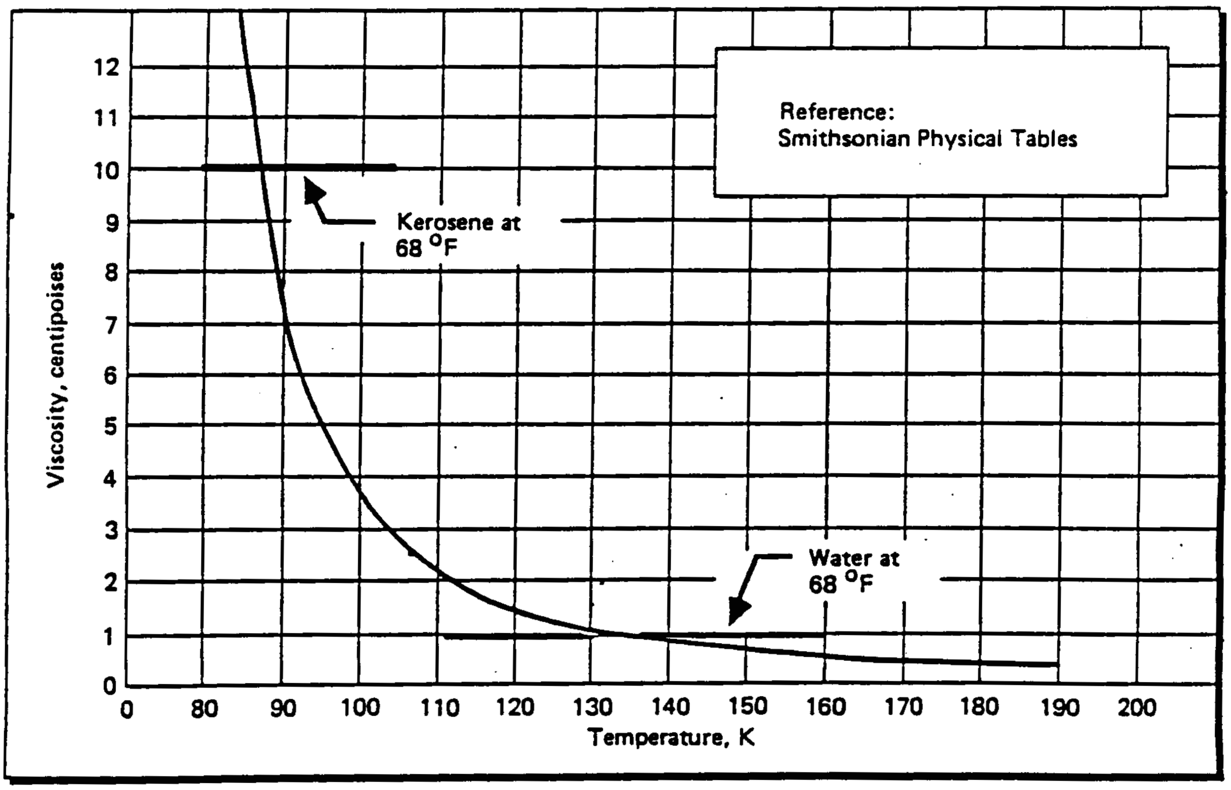

Figure 3.2.1-5. Propane Viscosity Versus Temperature

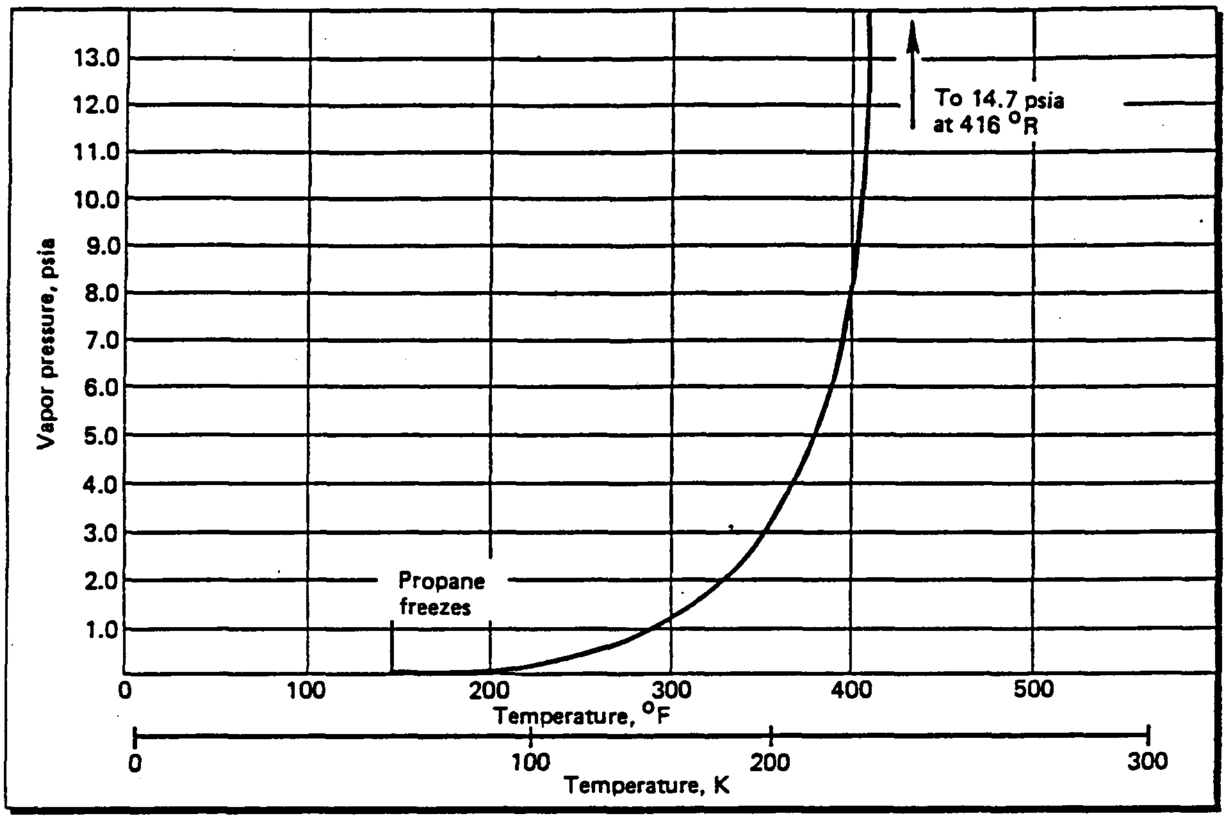

Figure 3.2.1-6 Propane Vapor Versus Temperature

time, pressure, temperature, etc., resulting in a propellant with unknown characteristics. Another drawback is that special equipment is needed to produce the cold gas in the first place. Figures 3.2.2-1, 3.2.2-2, and 3.2.2-3 show solubility characteristics of helium, hydrogen, and nitrogen in subcooled propane.

In prior work, the vacuum-induced boiling was found to produce more uniform chilldown of the liquid and avoided the gas absorption problem altogether. Unfortunately, neither approach is suitable for propane. Vacuum-induced boiling is an ineffective way to subcool propane because of the rapid reduction of propane vapor pressure as its temperature is lowered (fig. 3.2.2-1). At the desired 90 to 91K temperature, propane vapor pressure is only about 0.00005 in Hg. A large unconventional vacuum pumping system would be needed to sustain propane boiling at a rate that could induce phase change of enough propane to achieve rapid temperature reduction. Gas bubbling would require the use of helium, hydrogen, or nitrogen to achieve the desired temperature. Helium is expensive; hydrogen could be used, but is also relatively expensive. Nitrogen may be quite soluble in very cold propane, so it would tend to degrade performance. A further drawback of the gas bubbling method using GHe or GH_2 is that expensive refrigeration is required to chill/liquefy these gases for use in the first place.

Subcooling can be achieved by use of a chilling fluid such as LN_2. When large amounts of heat need to be removed relatively rapidly, the use of LN_2 is well-suited. LN_2 is produced in large quantities by large air liquefaction plants. Central plant production reduces LN_2 refrigeration costs substantially below the cost of onsite refrigeration systems sized for equivalent refrigeration when only intermittent refrigeration is needed, as in this case.

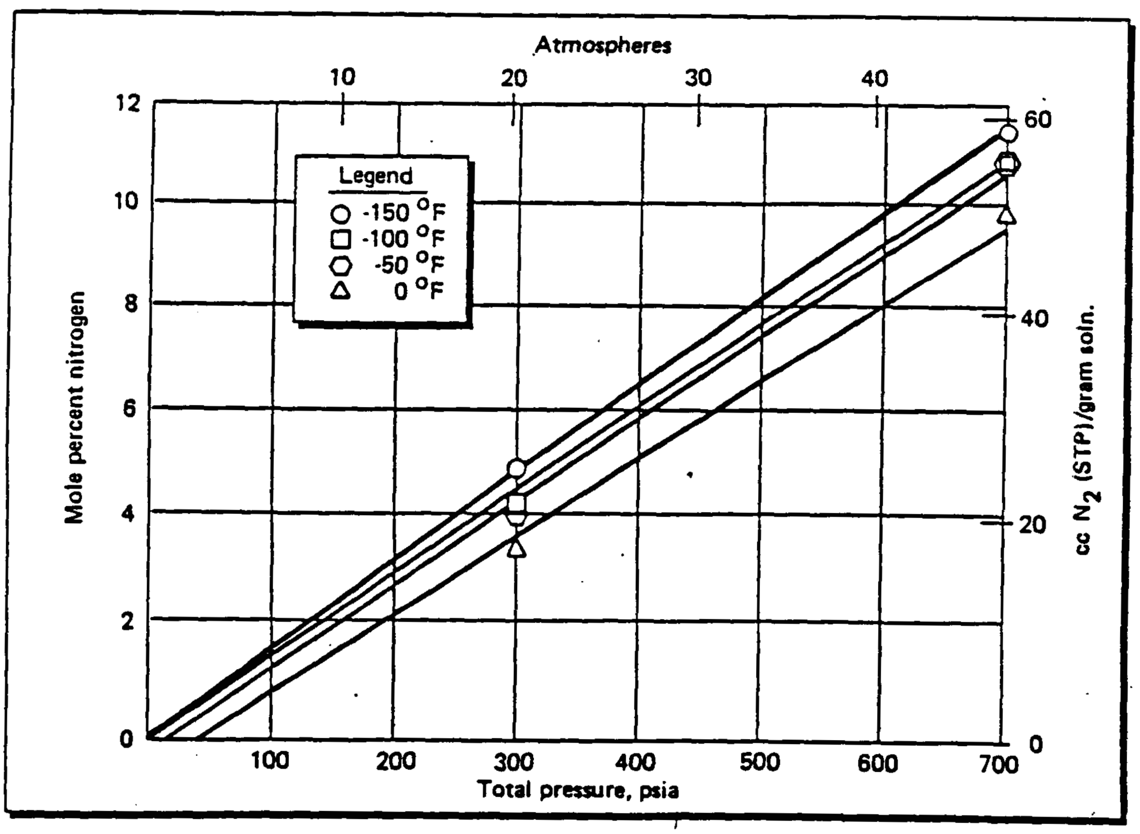

Figure 3.2.2-1 Isothermal Pressure-Composition Diagram for the System Liquid Propane-Nitrogen

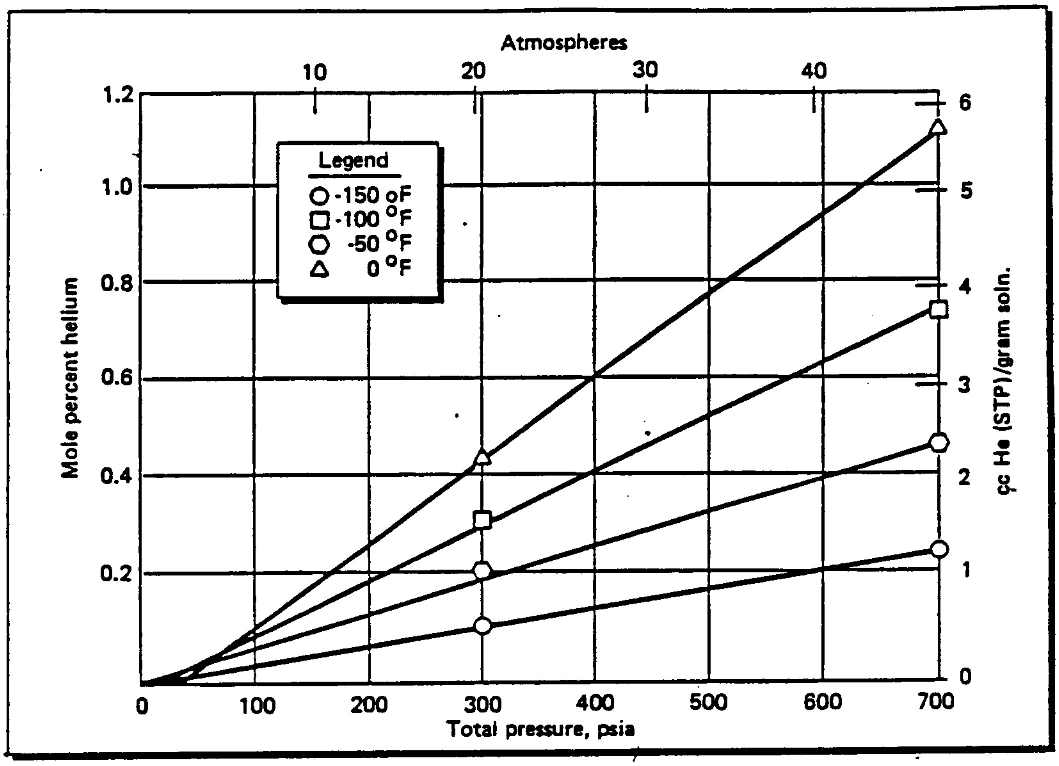

Figure 3.2.2-2. Isothermal Pressure–Composition Diagram for the System Liquid Propane-Helium

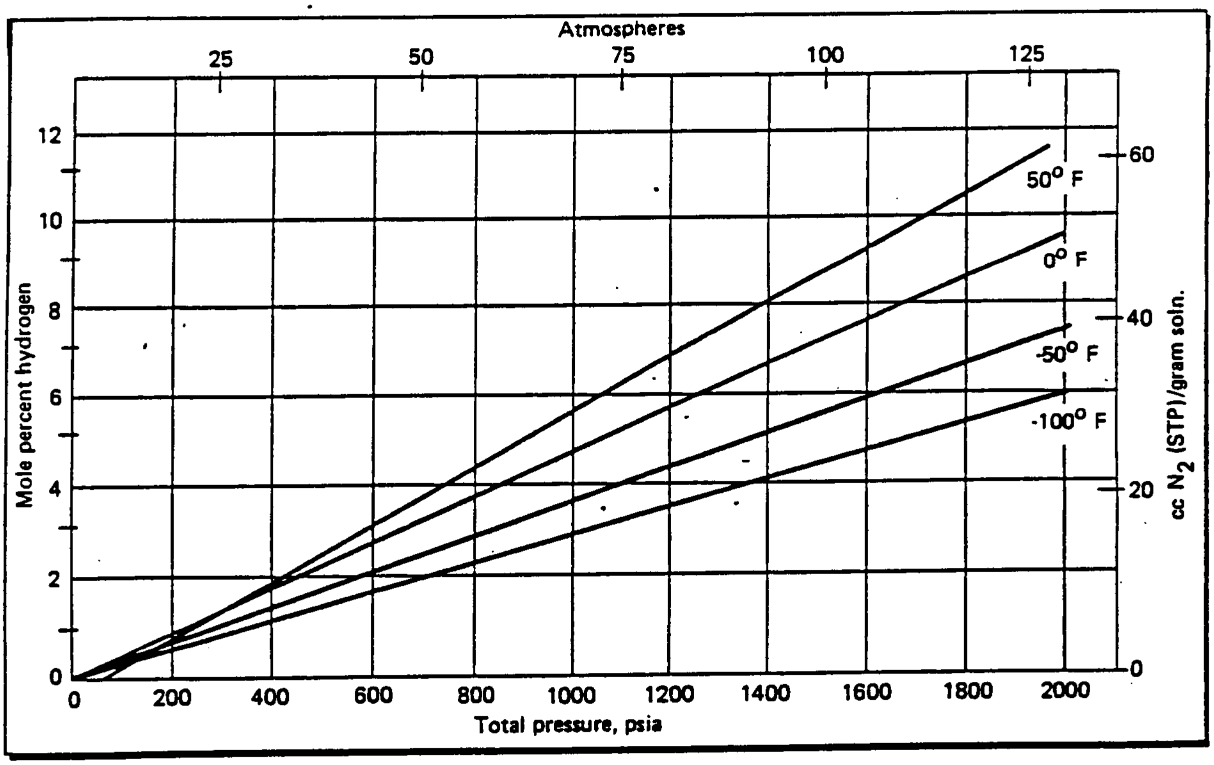

Figure 3.2.2-3. Isothermal Pressure–Composition Diagram for the System Liquid Propane-Hydrogen

3.2.2.1 Subcooling Propane with LN_2

One practical way to subcool propane is with a simple LN_2/GN_2 to propane heat exchanger shown schematically in figure 3.2.2.1-1. Operating in a counterflow mode the LN_2 in the heat exchanger vaporizes at 77K (-321°F) and effectively chills the incoming propane. A heat balance shows that approximately 0.5 to 0.6 lb LN_2 per pound of propane is required to chill the propane to 91K. The nitrogen could be recovered for reuse. However, the cost of a recovery system and reliquefaction facility is not warranted in view of the low initial cost of LN_2. Note that GHe is so costly, that helium recovery systems are often justifiable on a cost basis.

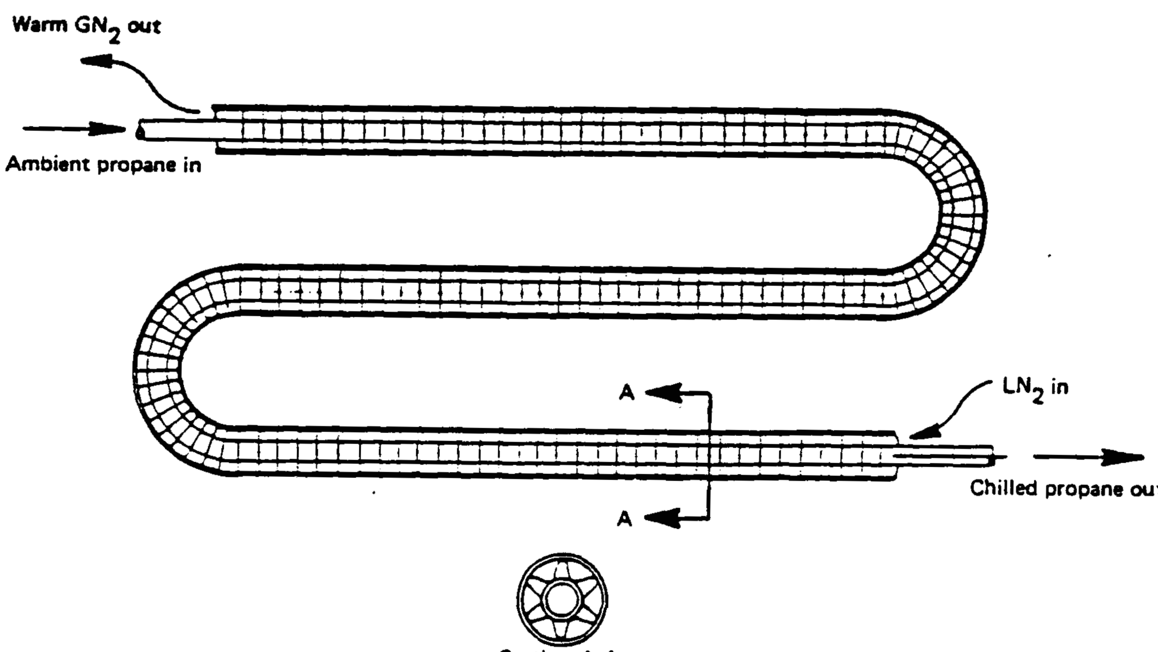

Figure 3.2.2.1-1 Schematic Counterflow Tube-in-Tube Heat Exchanger

3.2.2.1.1 Cost of Chilling the Propane

At Kennedy Space Center, LN_2 is delivered on-site at about \$80.00 per ton, i.e., \$.04/lb. The approximate cost of LN_2 for initially chilling 400,000 lb. of propane would be:

$$400{,}000 \text{ lb } C_3H_8 \times 0.6 \frac{\text{lb } LN_2}{\text{lb } C_3h_8} \times \frac{\$0.04}{\text{lb } LN_2} = \$9600.00$$

The simplicity, reliability, and safety of this approach, combined with modest cost, make it a prime candidate.

3.2.2.1.2 When to Chill the Propane

A further consideration is when to chill the propane. One option is to chill the propane upon its arrival on the site and store the cold propane in an appropriate dewar until time for use. This approach avoids the need for large high pressure tanks used to store ambient temperature propane. The alternative is to chill the propane while it is being loaded onto the vehicle. This second approach avoids the need for extended storage of the propane at cyrogenic temperatures. Figures 3.2.2.1.2-1 and 3.2.2.1.2-2 list the pros and cons of the two options.

Overall, it is concluded that chilling the propane on arrival at the site, and storing it cold in a conventional cryogenic storage dewar provides the most practical system. It requires the least equipment, and represents the least likelihood of interference with launch operations.

3.2.2.1.3 Conditioning Onboard Propellant

The purpose of conditioning onboard propellants is to maintain the planned propellant temperature and avoid temperature stratification. This is to assure that the planned density of propellant has been loaded, and to obtain the desired engine operating conditions. It is also to assure that the right total mass of propellants has been loaded so that minimum propellant residual can be achieved at burnout.

Conventional propellant conditioning is achieved by recirculating a flow of propellant from the vehicle to a GSE chiller and back to the vehicle. For this study other alternatives were considered as well. The propane temperature proposed (91K) is close to the LOX temperature, i.e., 90K. LOX boil-off vapor could be one means of keeping the propane cold. A tankage system having a "common bulkhead" with an inert

PRO	CON
• Keeps chilldown out	• Requires cryogenic storage of launch countdown dewars 2 at 80,000 gal
• Chilldown equipment sizing other) does not set	• Requires LN_2 (or loading rate refrigeration during pre-loading holding period
• Provides dewar capacity to off-load vehicle in the event of launch abort	• Requires GHe or GH_2 dewar • ullage pressurization system
• Avoids the need for large high pressure (100 psig) storage tanks for the ambient temperature propane	

Figure 3.2.2. .2 -1. Pros and cons of Storing Propane Subcooled

PRO	CON
• Propane storage dewar(s) not required	• Does not provide cold propane storage to off-load vehicle in event of an abort
• Propane refrigeration not required during storage	• Larger, higher chill-rate chilling system required
	• Delays in chilling will impact countdown

Figure 3.2.2.1.2-2. Pros and Cons of Storing Propane Warm and Chilling During Loading

heat transfer medium sandwiched to assure positive separation of propellants, may also be considered. The basic problem of using the LOX to keep the propane cold is that the 1K ΔT available is not enough to produce significant heat transfer between the two propellants. Also the need for relatively close proximity of the two propellants raises questions concerning safety assurance.

A second generic approach is to provide onboard nitrogen-cooled heat exchangers. This system could be used to keep both the LOX and the propane cold by plumbing inert LN_2 on board and allowing it to flash off in tank-mounted heat exchangers. One advantage of this approach is that it does not require propellant recirculation. Also, refrigerant leaks are benign, and relatively small flows are adequate since the heat of vaporization of the LN_2 is available to chill the propellants. The limitation of this option is that it does not prevent propellant stratification and may even increase it, unless some type of in-tank stirring devices are installed.

Other investigators considering subcooled propane conditioning have suggested the solution of bubbling cold helium through aspirator-like devices in the bottom of the tank. This would require availability of significant quantities of cold helium which would be expensive. Nitrogen might be substituted, however, its solubility in cold propane could be high enough to impact performance and so would be unacceptable. (Note that GN_2 is not suitable as a tank ullage pressurant for subcooled propane for the same reason.)

It is concluded that the conventional approach of recirculating a flow stream of propellant (approximately 100 to 150 gpm) from the vehicle to a GSE chiller using LN_2, is a practical effective means to provide thermal conditioning of the onboard propellant.

Insulation is a consideration for the vehicle propane tank. Insulation represents a weight penalty for the vehicle. However, it can prevent buildup of frost and ice. It also reduces the rate of recirculation required to maintain the propane at 91K. A tank with insulation similar to the Space Shuttle external tank has a heat leak of approximately

77.2 Btu/ft2/hr compared to a frosted Atlas LOX tank at 200 Btu/ft2/hr. The insulated tank requires the recirculation of approximately 100 gpm. If the tank were left uninsulated the required recirculation rate would be about 450 gpm which approaches the flow rate contemplated for routine loading or off-loading operations.

3.2.3 Storing and Handling Subcooled Propane

3.2.3.1 Storage Options

Subcooled propane is in the temperature range of NBP LOX and LN_2. Storage considerations are therefore largely the same, i.e., vacuum jacketed cryogenic storage tanks with valves, fittings and the like designed for cryogenic service. One notable difference of propane is that, unlike LOX and LN_2, its vapor pressure is extremely low (.00005 in Hg). A tank ullage pressure system would be required for safety unless the inner tank is designed to withstand full vacuum. As previously mentioned, GN_2 is not a suitable ullage pressurant. GHe or GH_2 are both suitable pressurant gases. Since it is likely that LH_2 will be on-site if not actually on the vehicle, GH_2 is a logical pressurant to use. In flight GH_2 any be able to be delivered at elevated temperature by the engine to minimize pressurant mass in the vehicle propane tank at shutdown.

A second difference is that while LOX and LN_2 storage temperatures can be maintained by the simple expedient of venting the storage tanks to atmosphere, the propane will require refrigeration while in storage. An approximation of the refrigeration required can be obtained by noting that well-designed cryogenic storage tanks when full lose approximately 0.5% per day of their liquid to venting. A 80,000 gallon LN_2 dewar would then vent away about 400 gallons to absorb the in-leak of heat. Using an LN_2 chiller to refrigerate a propane tank would be expected to require about the same amount of LN_2, since the heat in-leak to a propane tank at 91K would be virtually identical to the LN_2 tank.

Assuming LN_2 to be available at \$.04/lb, LN_2 would cost on the order of \$95 to \$100 per day to maintain the propane at the desired 91K. This is a very nominal cost compared to other alternatives.

3.2.3.2 Transfer of Propane

3.2.3.2.1 Transfer Alternatives

Transfer methods considered were differential pressure transfer and pumped transfer. The recirculation mode of conditioning the onboard propellants requires a pumped transfer system. Further, the pressure transfer approach uses relatively large quantities of hydrogen or helium gas, and would tend to need larger line sizes than the pumped transfer system. The pumped transfer system design can more easily accommodate extensions in the design length of facility lines, and permits the use of a lower design working pressures for the storage tank. For these reasons the pumped transfer system is preferred.

3.2.3.2.2 Pump Type

Propane viscosity varies significantly with temperature (see fig. 3.2.1-4). At 91K it has a viscosity approximately that of kerosene, which is not high enough to be a major factor in selecting pumping equipment. However, conventional centrifugal pumps for handling distillates, diesel fuels, kerosenes and the like are not directly suitable because many of the normal materials are not suited to the cold temperatures. Instead, conventional centrifugal cryogenic pumps such as for LOX and LN_2 will be more suited to this service. Such pumps are stock items for cryogenic equipment suppliers.

3.2.3.2.3 Prechill of Transfer System and Vehicle Tank

It will be desirable to prechill the pumps, valves, fill lines and vehicle tank with cold GN_2/LN_2 prior to introducing the propane. The nitrogen can be safely vented and will serve to inert the system. The residual GN_2 would then be purged by GH_2, after which the subcooled propane flow would be initiated. By this sequence the fill system thermal transients are reduced, cryogenic flow phenomena such as surging, geysering, and water hammer caused by vapor cavity collapse will be avoided, and the GH_2 will serve as the ullage gas pressure in the vehicle tank while filling.

3.2.3.2.4 Handling Safety

Routine practice for safe handling of other cryogens will apply to subcooled propane as well. There is one area of difference worth noting. A leak or small spill of LOX, LN_2, or LH_2 flashes to vapor quickly, producing a vapor cloud which disperses relatively soon. (Although care must be exercised with respect to local pooling or streaming of cold GOX.) A leak or spill of subcooled propane, however will not vaporize until significant warming has occurred. Leaks may, therefore, be less visible and pooling of quantities of subcooled propane may occur.

A major spill of subcooled propane will also represent a new situation which should be evaluated further. Flowing like kerosene, the subcooled propane could inundate large areas of a facility floor, or containment barrier before evaporating into combustible/explosive vapors that are heavier than air and thus would tend to settle in low places causing a further safety hazard. Once ignited, a large pool of subcooled propane would begin to vaporize at an increasing rate to feed a fire of increasing size and intensity. Probably no other cryogen poses this unique safety issue to the degree presented by subcooled propane.

3.2.4 Ground Support Equipment System Definition

This section uses the foregoing considerations to define and size a system for the requirements listed in section 3.2.4.1.

3.2.4.1 System Requirements

The following requirements were used as a basis for system definition:

Item	Description
Launch site:	Cape Kennedy
Liquid propane:	Available on-site at 233K
Quantity loaded:	400,000 lb
Propane tank size:	12 ft diameter
Tank ends:	Hemispherical
Propane tank elevation:	150 ft above pad
Launch hold durations:	Up to 12 hr
LOX tank:	Located aft at 90°K
General launch scenario:	TBD, assume 48 hr turnaround from an aborted launch
Vehicle dimensional assumptions:	See figure 3.2.4.1-1

On the basis of the above and figure 3.2.4.1-2, Baseline Vehicle Loading Sequence and figure 3.2.4.1-3, Launch Abort Turnaround, scenarios were assumed for purpose of aiding the selection of fill rates for transfer system sizing. Vehicle loading or offloading rates resulting in a 2 to 4 hr period to complete propellant transfer appears reasonable, implying net flow rates of 300-600 gpm. Such time periods are also long enough for approaching thermal equilibrium in the tankage structure and vehicle plumbing. These rates also are close to that required for recirculation to condition the onboard propellant. As a result the same systems would be used. Vacuum-jacketed 4 in

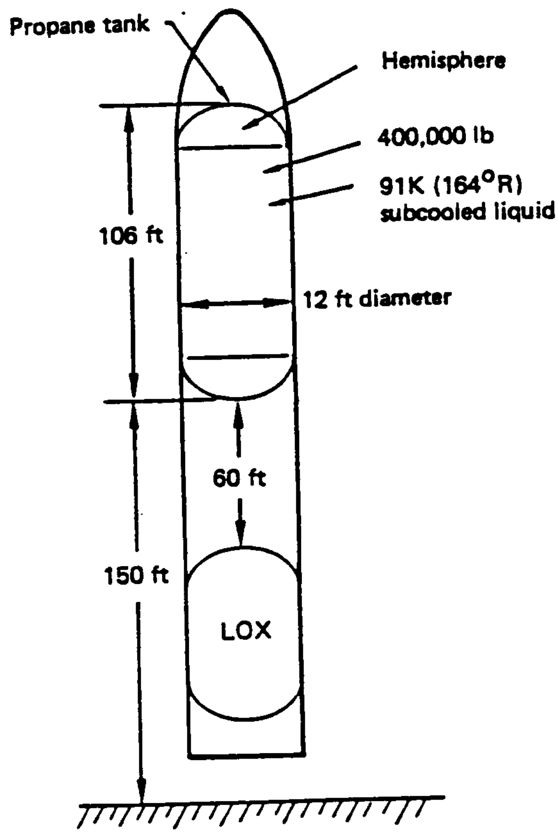

Figure 3.2.4.1-1 Schematic of Vehicle Configuration

Operation	Time (min)	% Load	Loading rate (gpm)	Quantity (gal)
LN_2/GH_2 Prechill of lines and vehicle tankage	15	-0-	NA	-0-
Cover gas purge and recharge, GH_2	10	-0-	NA	-0-
Slow fill, C_3H_8	10	1.5	100	1,000
Fast fill, C_3H_8	105	97.0	600	63,000
Slow fill, C_3H_8	10	1.5	100	1,000
Total	150			65,000
Recycle	as required	-----	100-300	NA

Figure 3.2.4.1-2 Baseline Vehicle Loading Sequence

Item	Description
General launch abort scenario:	48 Hour Turnaround
Abort launch	Start
Secure facility	4 hrs
Offload propellant	4 hrs
Corrective actions	24 hrs
Countdown to propellant load	8 hrs
Load propellant(s)	4 hrs
Complete countdowwn	4 hrs
Launch	End
Turnaround time	48 hrs

Figure 3.2.4.1-3 Launch Abort Turnaround Scenario (Typical)

lines would be the minimum size considered for a 1500 ft run to the vehicle. A 6 in line size appears more suitable, and is recommended for the baseline design, because it allows greater variation in final choices of line length and loading rates.

The abort scenario also requires the local availability of an 80,000 to 100,000 gallon capacity dewar to receive the cold propane from the vehicle following the abort decision. This requirement supports the concept of chilling the propane upon arrival at the site and storing it in the pre-load GSE tankage. This same tankage would then also serve as the off-load receiver in the case of a launch abort.

3.2.4.2 System Concepts, Options, and Selections

3.2.4.2.1 Baseline System

Because of its simplicity, safety and low cost, the use of LN_2 to chill and condition the propane has been selected as the baseline approach. Figure 3.2.4.2.1-1 pictorial presents a sketch of the subcooled propane chill and transfer facility.

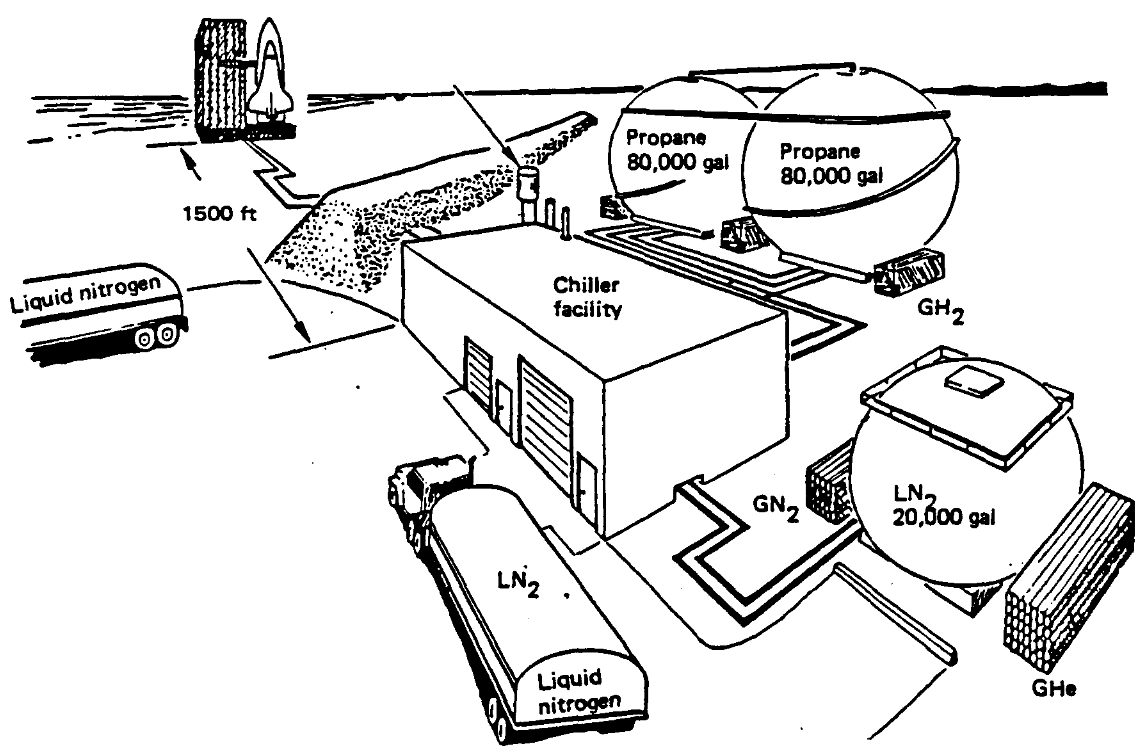

Figure 3.2.4.2.1-1 Subcooled Propane Chill and Transfer

The facility has two 80,000 gallon cryogenic tanks for propane, a 20,000 gallon cryogenic tank for LN_2, and a propane chilldown/transfer building. Vacuum-jacketed transfer lines interconnect to the storage tankage for loading and offloading of the vehicle. All pumping and chilling equipment except for the vehicle off-load pump is located within the building. Bottle banks for high pressure helium gas and high pressure hydrogen gas are provided. GN_2 is assumed to be available from a pipeline, but a small local high pressure bottle supply is also provided as a safety measure. The vehicle off-load pump, which also serves as the recirculating boost pump, is located at the launch pad.

Dual propane tankage is provided to permit the receipt and chilling of fresh propane to proceed uninterrupted in the event of a launch abort which could require the off-loading and temporary storing/conditioning of approximately 70,000 gallons of chilled propane. Storage is also provided for 20,000 gallons (two tanker loads) of LN_2, to provide a degree of flexibility in receiving and use of LN_2. The LN_2 storage permits the off-loading of a tanker in the event of a delay in propane chilling. The LN_2 storage also permits uninterrupted chilling of propane in the event of delays in LN_2 deliveries and provides the LN_2 needed for onboard conditioning of the loaded propellant. However, during all normal operations, LN_2 tankers would be scheduled in accordance with operational needs, because of the low cost and flexibility of delivery quantities.

As mentioned previously an alternative to storing the propane cold, would be to store the incoming propane at ambient temperature in conventional high pressure, ambient temperature propane storage tanks. Initial cost of the tank(s) would be less, and propellant conditioning during storage would not be required. One drawback is that there would not be a tank for cold propane in the event that vehicle off-loading became necessary. A major factor is that a facility operation to chill the propane becomes part of the launch countdown thus increasing complexity and potential for launch delays.

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A third alternative is to not chill the propane for the next launch until the current launch is away. This timing would also provide storage capacity for cold propane in the event of launch abort using only a single dewar instead of two. However, this approach lacks redundancy, and could also cause launch delays in the event of minor facility operational problems. The propane chill and transfer facility is shown schematically in figure 3.2.4.2.1-2. A redundant chilling capability is provided to allow chilling of fresh propane and conditioning of onboard propane to proceed simultaneously if needed. It also allows either system to be used, for either purpose, in the event the other system is out of service (for maintenance or repair). Also, both systems could operate in parallel during the fast fill phase of loading.

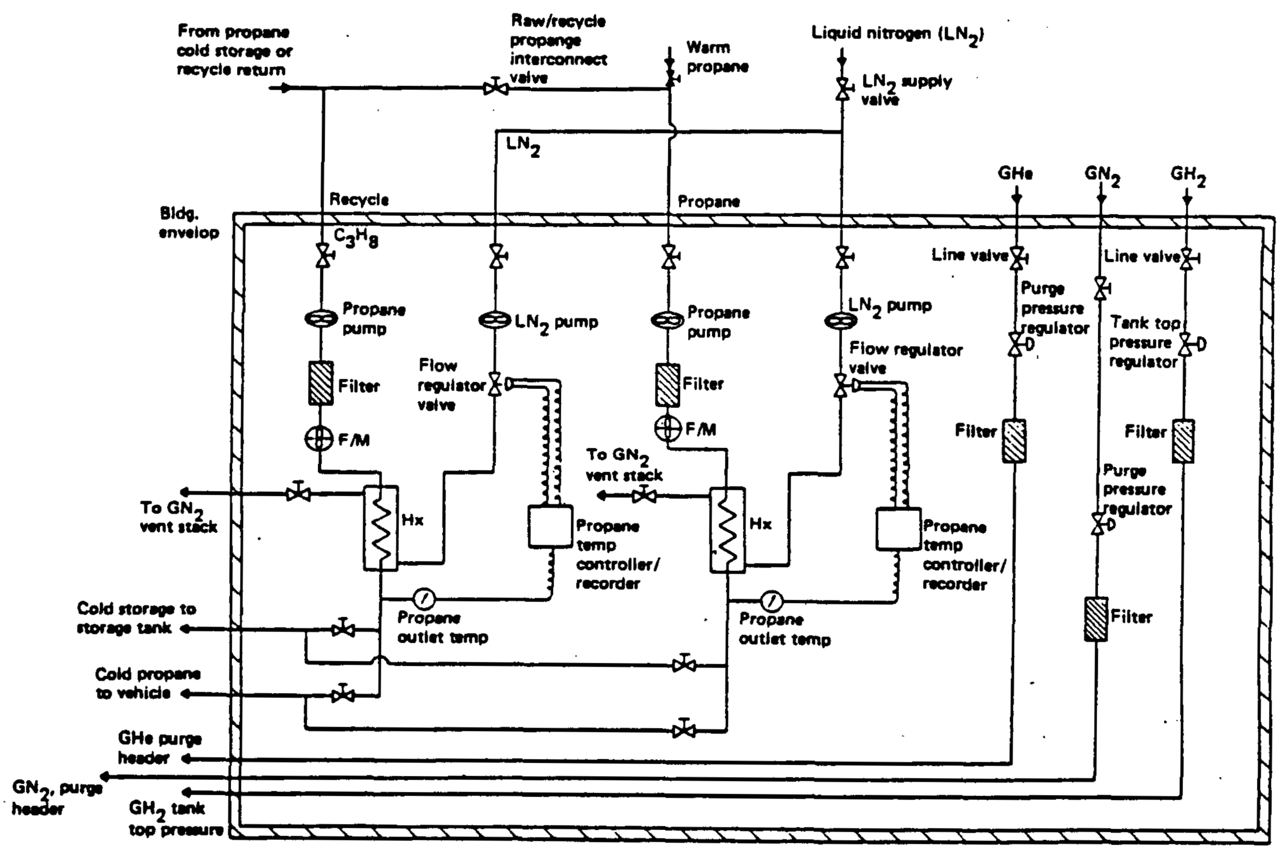

Figure 3.2.4.2.1-2 Propane Chill and Transfer Facility Schematic

Other options for propane chillers do not appear to be viable candidates, especially in view of the desirability of system redundancy. A typical current price for a cryogenic plant capable of 100 ton per day production of LN_2 is on the order of $20M installed. This would be a typical sized alternative system in terms of chiller capacity. Overall, it is believed the use of LN_2 cooled heat exchangers represent the best approach for subcooling propane.

The propane chill and transfer facility is plumbed to provide propellant loading and recirculation flow to the vehicle tankage. Within the same facility are the appropriate headers, manifolds, valving controls and indicators to provide helium and nitrogen gas purges, and hydrogen gas as the tank top pressurant for all fuel tanks.

3.2.4.2.2 Vehicle Fill Rate

The time required to perform the propellant loading operation is considered in this section. Among the considerations are: time period in the countdown available for filling the tanks, allowable hold period after tanks are filled, sizing of propellant transfer lines, pumps, valves, etc., fill system and tankage fluid dynamics and thermodynamics (cryogenic geysering, water hammer, etc.) and loss of propellant due to boiloff.

One guide in addressing all these considerations is the solution already reached for the fill rates and transfer methods used for current systems, such as the Space Shuttle. LOX is pump-transferred while LH_2 is pressure-transferred to the Shuttle ET. Full flow rates are on the order of 8000 gpm for LH_2 and 1500 gpm for LOX. This rate results in about 30-45 min fill time for the ET at maximum fill rate. Adding time for purging, line and tank chilldown and accurate final level setting would typically add another hour, so an hour and a half to two hours is estimated as being a typical time period devoted to the propellant loading operation for the space shuttle.

For a propane-fueled instead of LH_2-fueled vehicle, where loss of fuel to tank venting is not at issue, and where temperature stratification will be prevented by fuel recirculation, other considerations may dominate. Assuming distance from the storage facility to the launch platform is on the order of 1500 ft, line loss and vehicle tank elevation static head result in a pumphead requirement of approximately 550 to 600 ft for 4 in piping, compared to about 200 ft for 6 in pipe assuming flow rates of approximately 750 to 800 gpm (i.e., fill flow plus recirculation flow).

A line size of 6 in represents a reasonable compromise between pumping power demand (friction loss) and low propellant transfer system cost. Note that during propane tank fill, approximately 150 to 200 gpm will be recirculated for maintaining the temperature of the onboard propellant. Net tank fill rate of 600 gpm is, therefore, appropriate for the baseline.

The low vapor pressure of the propane will preclude geysering of the propellant entering the tank. The fill and recirculation lines will be vacuum-jacketed to minimize heat transfer. Heat gain from friction loss in the transfer line is less than 1 Btu/lb, for 4 in pipe, and less than 0.1 Btu/lb for 6 in pipe, so is not a significant consideration; at 800 gpm, the propane will be in transit through the line for less than 4 min so that heat input from the transfer line will be negligible. Current fill piping at Kennedy Space Center for Space Shuttle tankage is 6 in vacuum-jacketed line, about 1800 ft long.

3.2.4.2.3 Preferred System Description

The preferred system is the LN_2-chilled process, using tanker trucks as the primary LN_2 supply. An on-site LN_2 storage tank serves as a backup, and also provides the refrigeration supply for the cold propane tanks during periods of extended hold times. It is recommended that the propane be stored cold to minimize the possibility that the chilling cycle interferes with other launch countdown tasks, and to minimize on-site tankage.

Transfer of the propane would be by conventional cryogenic transfer pumps. Centrifugal pumps of adequate capacity, (800 gpm) are available from several suppliers, including parts and service. Cryogenic pumps are recommended for the subcooled propane to ensure they are made of materials suited to cryogenic temperatures, and because they can be obtained with containment housings which collect any leakage for safe routing to a facility vent stack.

Conditioning of the onboard propellant is proposed to be accomplished by recirculation to the refrigeration facility via the loading/off-loading interconnect lines. This method provides ample chilling capacity and the flow through the tank assures that stratification in the tank is prevented. For this study is is assumed that the propane tank would have insulation equivalent to that used on the external tank of the Space Shuttle.

3.2.4.3 System Operations

This section outlines a typical sequence of operations to support further definition of system characteristics. It is assumed that an ample supply of propane is available on-site, provided as an available flow stream to the propane subcooling facility. For the operations scenario it is also assumed that the LN_2 storage tank is filled, and all gas bottle tanks are fully charged.

Operations

Step No. Step description

1.0 Prechill cold propane receiver

- 1.1 Dry GN_2 purge at ambient pressure
- 1.2 Stop purge, fog nozzle spray LN_2 into tank top vent at ambient pressure. Chill to -100°F
- 1.3 Stop LN_2 spray, purge GN_2 with GH_2 at ambient pressure. Set GH_2 pressure regulator at atmospheric pressures plus 1 to 2 psig for propane cover gas pressure

2.0 Propane chill process

- 2.1 Initiate LN_2 flow to heat exchanger, until facility is chilled
- 2.2 Initiate propane flow to heat exchanger #1
- 2.3 Open propane fill line to cold propane tank
- 2.4 Open propane recycle line from cold propane tank to heat exchanger #2 and recycle
- 2.5 Operate in fill/recycle modes at design rate to fill tank in 4 hr, i.e., approximately 100,000 lb/hr
- 2.6 Condition propane in full tank via recycle loop until temperature of 91K is achieved.

2.7 Switch to holding mode using secondary refrigeration loop at the storage tank for extended hold

3.0 Fill vehicle tank

3.1 Prechill vehicle tank and fill lines with cold GN_2

3.2 Purge GN_2 with cold GH_2, pressurize GH_2 to atmospheric plus 1 to 2 psig and set GH_2 pressure regulator

3.3 Draw cold propane from storage tank and transfer to vehicle tank

3.4 Initiate recycle flow from vehicle tank to recycle propane to chill heat exchanger

3.5 Continue propane fill and recycle flows until tank full level is reached

3.6 Adjust flow rates to maintain recycle flow to achieve/maintain propane temperature

3.7 Set GH_2 pressure regulator to final ullage pressure setting

3.8 Stabilize facility operation until launch countdown calls for facility shutoff

4.0 Vehicle launch abort - offload propane

4.1 Vehicle assumed to be in prelaunch mode, with recirculation system operating to maintain propellant temperature. Cold propane ground storage tank level assumed low enough to accommodate fuel offload

4.2 Vehicle launch abort command results in changes to valve position selector switches. Valve to cold storage tank is opened, valve to vehicle tank closed, recycle interconnect valve opened, both chiller systems operate, GH_2 tank top pressure regulator switched to "High Rate" setting

4.3 Propane off-loading proceeds under pumped flow conditions until GH_2 is sensed at a propane pump inlet

4.4 All pumps are shutdown and the pressure, purge, and vent (PP&V) system is activated to purge propellant residuals from all lines and valves

4.5 System valves are repositioned for prefill readiness and the system placed on hold until fill command is received.

3.2.5 ROM Cost Estimate

This section summarizes cost estimates for the subcooled propane GSE installation.

3.2.5.1 GSE Procurement and Installation

Equipment cost estimates are based upon supplier advance quotes for the majority (approximately 80%) of the material costs. Supplier advance quotes are typically 15-20% high as an uncertainty allowance. However, they have been used as stated, but only a small (15%) contingency applied to the overall material cost estimate so as to provide an offsetting effect.

Costs are stated in FY87 dollars since the exact timing of the construction of such a facility is not yet known. Architect fees are assumed to apply to construction materials and site preparation, not to facility construction labor. Figure 3.2.5.1-1 shows the preliminary cost estimate for the facility.

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Material and Labor

Item no.	Description	Estimate Basis Q = Quote E = Engineering Estimate	Unit Cost	No. units	Total
1.	Propane tank, 80,000 gal vacuum insulated or equivalent	Q (LOX Equip.Inc)	$235,000	2	$470,000
2.	LN_2, 20,000 gal vacuum insulated or equivalent	Q (MVE)	$140,000	1	$140,000
3.	GN_2 bottle bank, 100,000 3000 psig working pressure	Q US Steel	$150,000	1 set	$150,000
4.	GH_2 bottle bank, 50,000 2000 psig working pressure	Q US Steel	$ 66,000	1 set	$ 66,000
5.	GH_2 bottle bank, 50,000 2000 psig working pressure	Q US Steel	$ 66,000	1 set	$ 66,000
6.	Centrifugal cryogenic pump electric-driven, 800 gpm, 400 ft head, 25 shp	Q ACD	$ 15,000	4	$ 60,000
7.	Heat exchanger, 15x10^6 BTU/hr LN_2/Propane, tube-in-tube counterflow	Q HEX Products	$ 40,000	2	$ 80,000
8.	Liquid filter 10 micron abs 3000 gpm propane service	Q AMC	$ 8,000	2	$ 16,000
9.	Valve, 6-in cryogenic remote actuation, on-off	Q CVI	$ 8,000	4	$ 32,000
10.	Valve, 6-in cryogenic remote actuation, modulating	Q CVI	$ 9,000	2	$ 18,000
11.	Valve, 6-in cryogenic manual shutoff	Q CVI	$ 6,000	2	$ 24,000
12.	Controller-recorder, temp proportional/reset adjustment ±0.5%	Q Foxboro Co	$ 2,000	2	$ 4,000
13.	Vacuum jacketed LN_2 piping 200 ft, 6 elbows, 150 psig, 1"x2-1/2" bayonet connections plus 3 valves	Q CVI	$ 32,000	1 set	$ 32,000
14.	Vacuum jacketed propane piping 3000 ft, 10 elbows, 20 ft sections, 250 psig, 6 in.x 8 in., $260.00/ft	E Based on Q by CVI	$780,000	1 set	$780,000
15.	LN_2 chiller for storage tank hold time recirc. 300 gpd size	E	$ 25,000	1	$ 25,000
16.	Nitrogen pressure, purge vent system	E	$ 15,000	1 sys	$ 15,000
17.	GN_2/GH_2 pressure, purge vent system	E	$ 15,000	1 sys	$ 15,000
18.	Power, propane service and umbilical, remote disconnect and swing-away arm	E	$150,000	1 sys	$150,000
19.	Chiller facility bldg. 40x80 ft concrete construction, Halon fire control, office and emergency survival system @ $40.00/ft^2	E	$128,000	1	$128,000
20.	Instrumentation and control panels and wiring to remote stations, including launch tower	E	$ 50,000	1 set	$ 50,000
21.	Electric power supply 100 kw electric service	E	$ 40,000	1 sys	$ 40,000
22.	Grading and paving 80,000 ft^2 @ $1.50/ft^2	E	$120,000	--	$120,000
Subtotal					$2,481,000
23.	Architect fee @ 10%	E			$248,000
24.	Miscellaneous unpriced equipment @ 15%	E			$372,000
25.	Facility construction/ installation prime contract, direct labor 25 manyears @ $100K/MY	E			$2,500.000
Grand Total					$5,601,000

Figure 3.2.5.1-1 Subcooled Propane Supply System Cost Estimate

3.3 VARIABLE MIXTURE RATIO ENGINE STUDY

A subcontract was awarded to the Aerotherm division of Acurex Corporation to provide LOX/LH2 engine specific impulse (vac), engine weight and nozzle exit diameters using the variable mixture ratio, full-flow cycle engine with a nominal thrust of 700K lbs at a mixture ratio of 10. Parameters are mixture ratio (5, 6, 8 on the low end and 10, 12, 14 on the high end), nozzle area ratio (20:1, 64:1, and 100:1). Use two chamber pressures, one with a 2-stage hydrogen pump and one with a 3-stage hydrogen pump. The subcontract also included the definition of an engine with a high mixture ratio of 9, tailored for the booster element of a 2 stage heavy lift launch vehicle, which could also be adapted for a mixture ratio of 6, for a second stage of this launch vehicle concept.

3.3.1 Technical Discussion

Figure 3.3.1-1 shows a plot of vacuum specific impulse as a function of mixture ratio and nozzle exit-to-throat area ratio. The curve is for chamber pressures in the 2000-3000 psia range. The specific impulse peaks at mixture ratio 6 for all area ratios. The specific impulse stays high over the mixture ratio range from 4 to 8 and decreases approximately linearly at mixture ratios greater than 8.

The specific impulse is sharply affected by changes in nozzle exit-to-throat area ratio. For example, the difference in specific impulse between the 64:1 and 20:1 area ratio is greater than the specific impulse difference between mixture ratio of 6 and mixture ratios of 4 or 8.

In figure 3.3.1-2 nozzle exit diameters are shown as a function of mixture ratio for 3000 and 2000 psia chamber pressure engines for area ratios of 20 and 64. The higher chamber pressure allows smaller nozzle exit diameters. It will be noted that a 700K thrust engine requires a 100 inch diameter for area ratio of 64 at a chamber pressure of 3000 psia. Changing mixture ratio from 10 to 14 has a neglible effect on the nozzle exit diameter at constant area ratio.

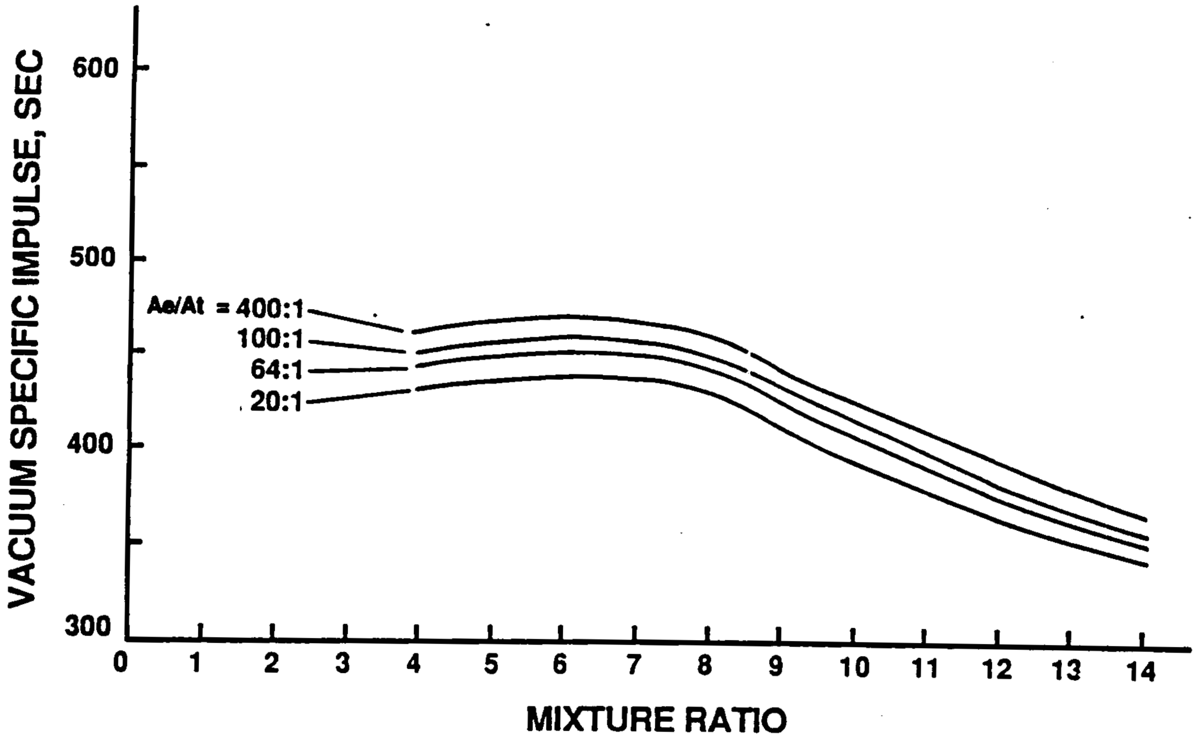

Figure 3.3.1-1 O_2/H_2 Vacuum Specific Impulse as a Function of Mixture Ratio and Area Ratio

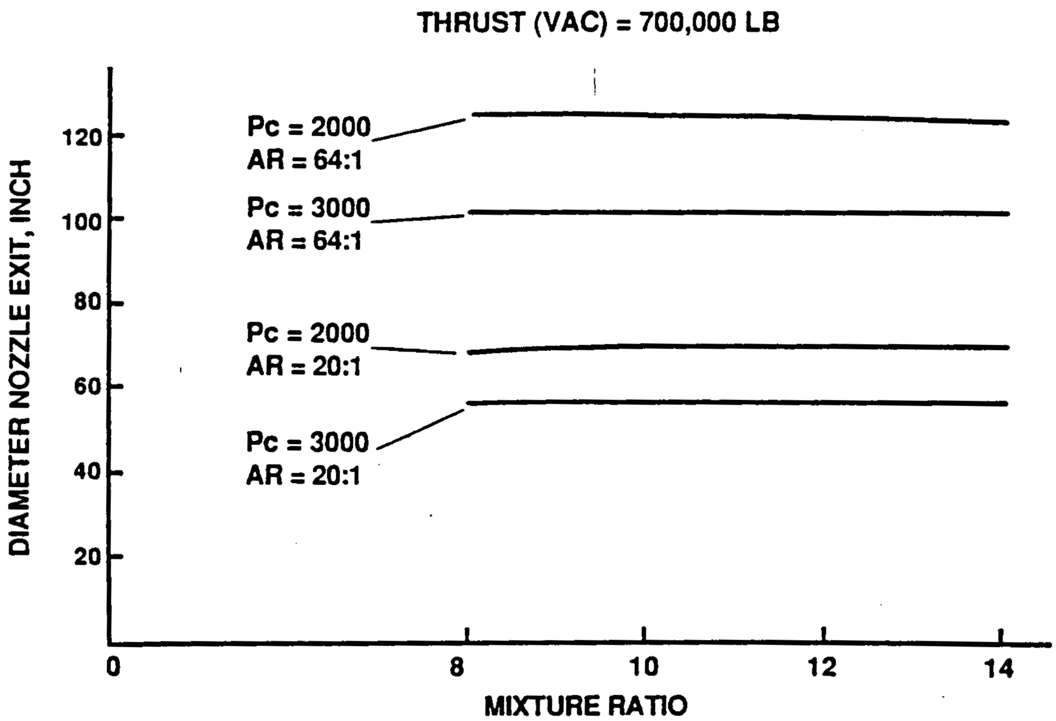

Figure 3.3.1-2 Nozzle Exit Diameter as a Function of Mixture Ratio, Area Ratio, With/Without Nozzle Skirt Insert

The effect of chamber pressure on vacuum specific impulse for various nozzle exit diameters and mixture ratios is shown in Figure 3.3.1-3. This curve shows that the higher chamber pressure (3000 vs 2000) provides a clear margin increase in specific impulse at all mixture ratios for given nozzle exit diameters. The difference in specific impulse is 4-5 second for nozzle exit diameters of 100 inches. At very large nozzle exit diameters (large area ratios) the difference is specific impulse is reduced to about 2.

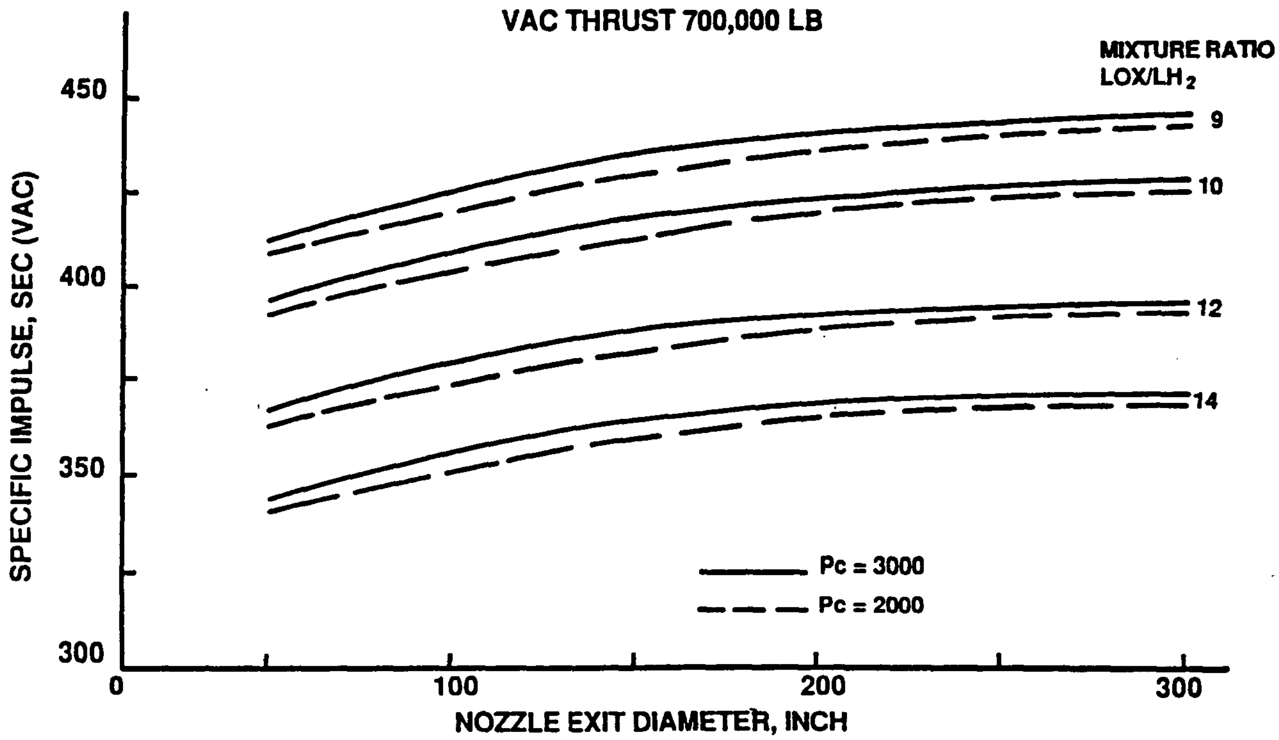

Figure 3.3.1-3 LOX/LH_2 Specific Impulse Versus Nozzle Exit Diameter, Mixture Ratio and Chamber Pressure

Engine weights for chamber pressures of 3000 psia and 2000 psia are given as a function of mixture ratio and area ratio in Figures 3.3.1-4 and 3.3.1-5 respectively. The effect of mixture ratio in the range 10-14 has neglible effect on engine weight at both chamber pressures.

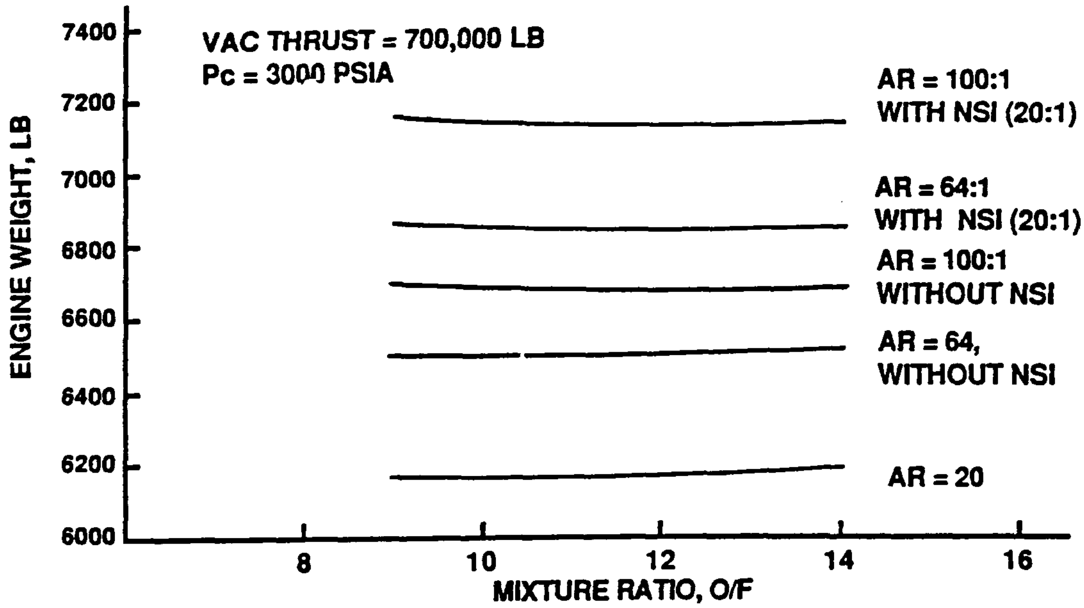

Figure 3.3.1-4 Engine Weight as a Function of Mixture Ratio and Area Ratio, With/Without Nozzle Skirt Insert

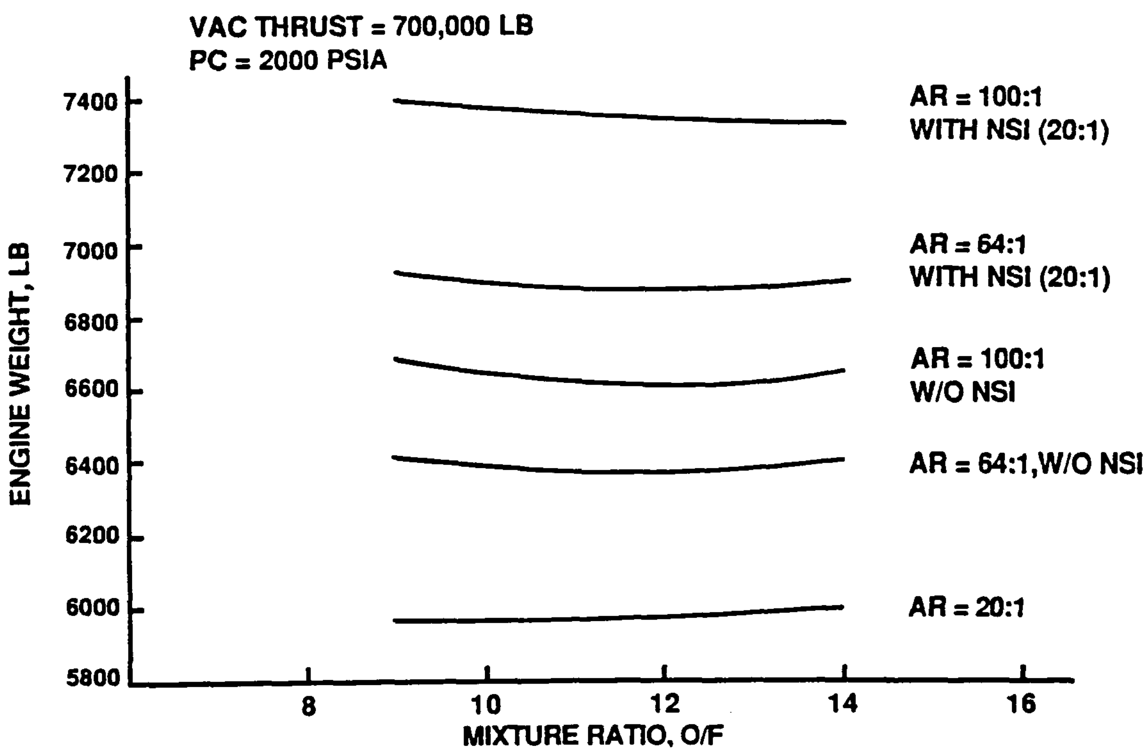

Figure 3.3.1-5 Engine Weight as a Function of Mixture Ratio and Area Ratio, With/Without Nozzle Skirt Insert

The variation of major subsystem weights as a function of mixture ratio for 3000 psia and 2000 psia chamber pressures is shown in Figure 3.3.1-6. It will be noted that the thrust chamber subsystem weights decrease with mixture ratio while the turbomachinery subsystem weights increase with mixture ratio.

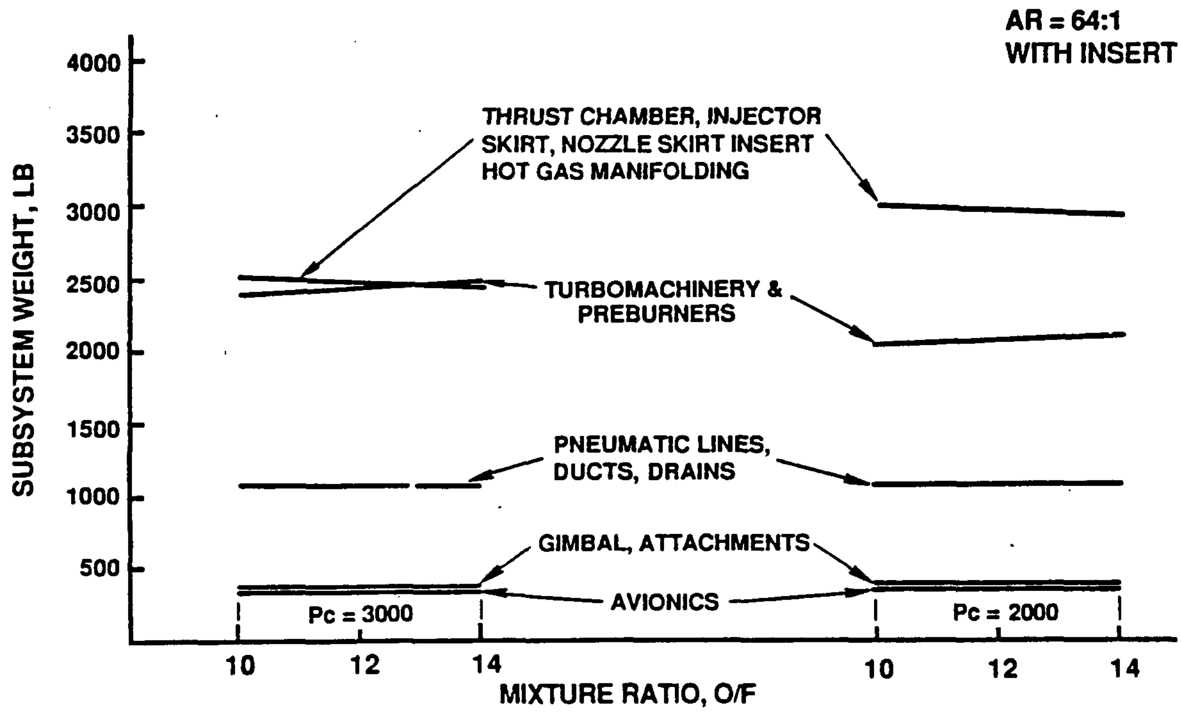

Figure 3.3.1-6 Variation of Major Subsystem Weights as a Function of Mixture Ratio for 700,000 lb Thrust LOX/LH_2 Engines

In figure 3.3.1-7 the weights of the various components of the thrust chamber subsystem are shown as a function of mixture ratio. Weights of thrust chamber components are relatively insensitive to variation in mixture ratio in the range 10-14. At the lower chamber pressure of 2000 psia the nozzle skirt is larger than the skirt for 3000 psia chamber and therefore somewhat heavier. The lower weight of the 2000 psia hot gas manifolds reflects the low gas temperature which they constrain.

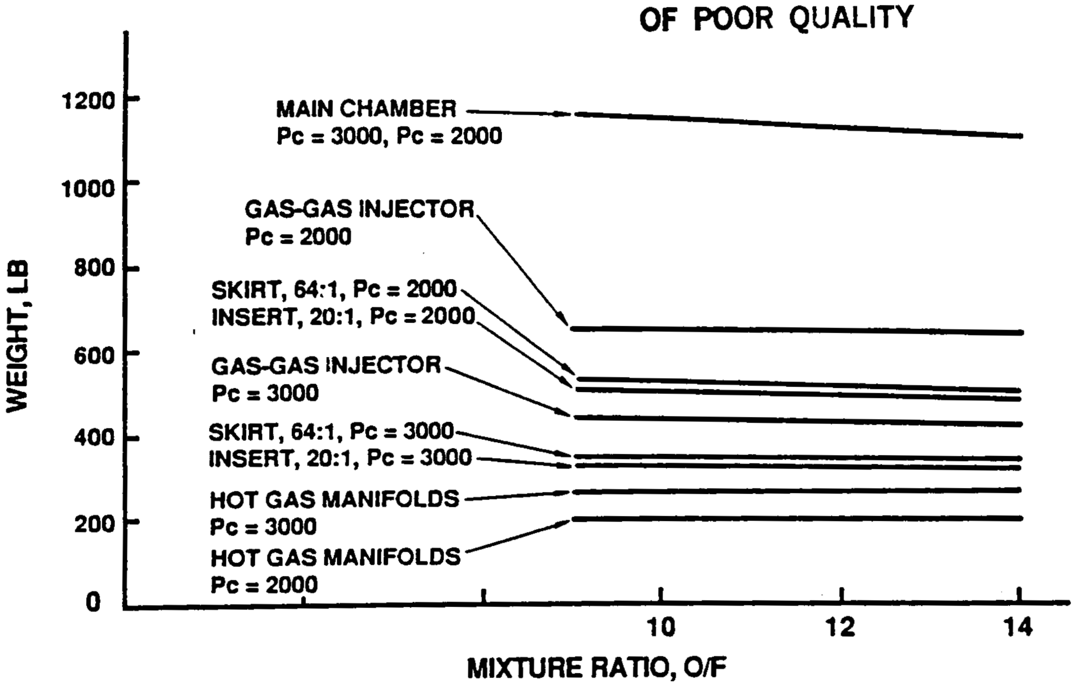

Figure 3.3.1-7 Weights of Thrust Chamber Components Versus Mixture Ratio for 700,000 Thrust LOX/LH_2 Engines

Figure 3.3.1-8 shows a drawing of a gas-gas injector. This injector has dual oxidizer-rich inlets which direct gases to a common plenum for feeding the oxidizer injection segments.

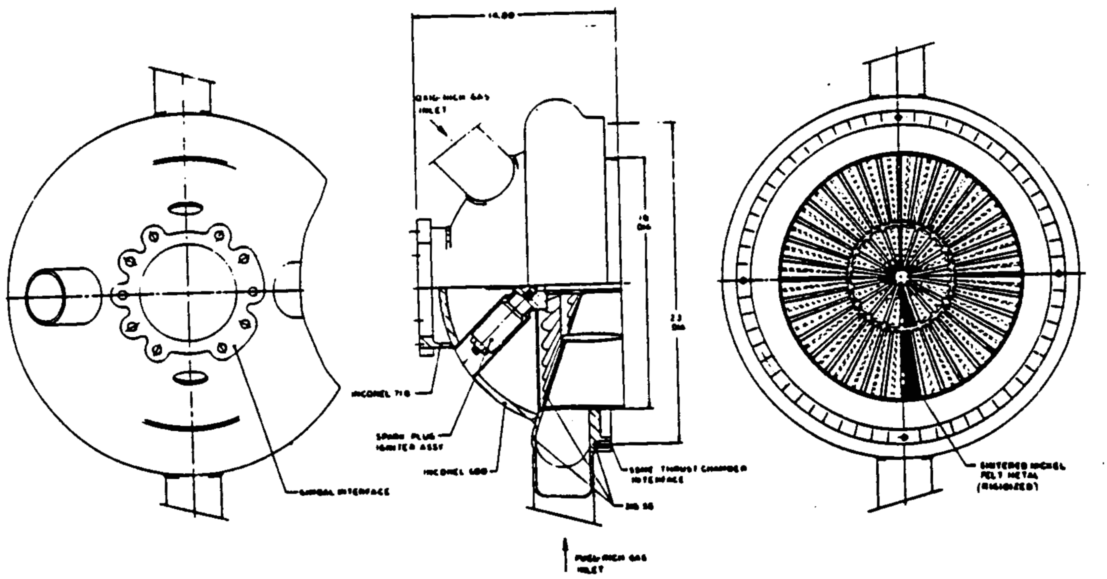

Figure 3.3.1-8 Injector Assembly Diagonal Plate (Gas-Gas)

As shown in Figure 3.3.1-9, the reduction of hydrogen turbopump-preburner weight largely offsets the increase in weight of the oxygen turbopump-preburners as the mixture ratio increases from 10 to 14. A high mixture ratio (10-14) dual oxygen boost pump and main turbopump units were used. Figure 3.3.1-10 shows a drawing of an oxygen turbopump with integrated preburner. Figure 3.3.1-11 shows a drawing of a fuel turbopump-preburner assembly with integrated boost turbopump.

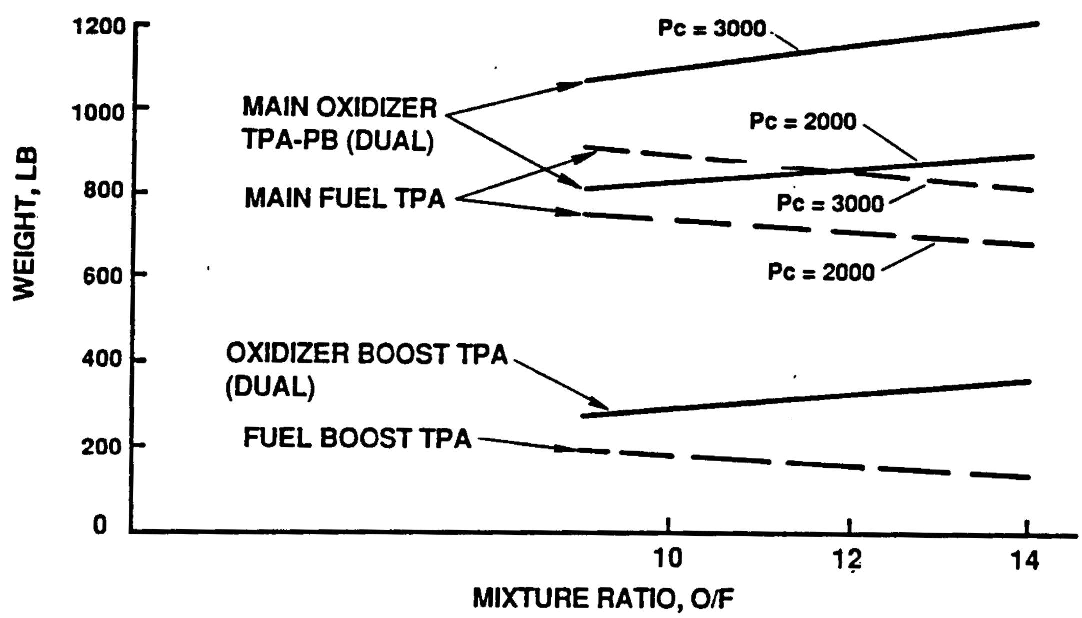

Figure 3.3.1-9 Weights of Turbo Machinery Components Versus Mixture Ratio for 700,000 Thrust LOX/LH_2 Engines

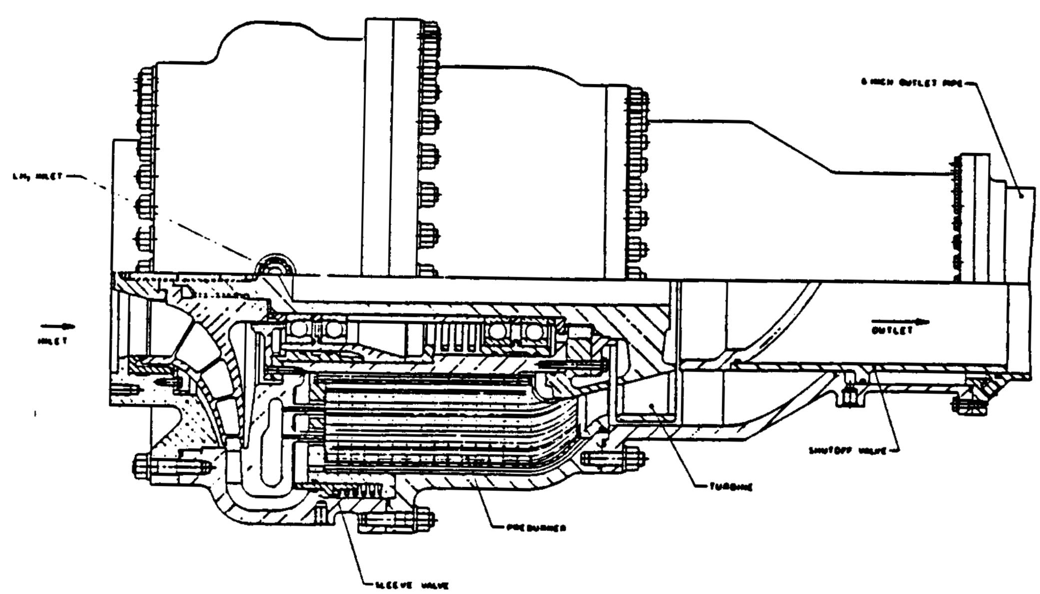

Figure 3.3.1-10 High Pressure Oxidizer Turbopump

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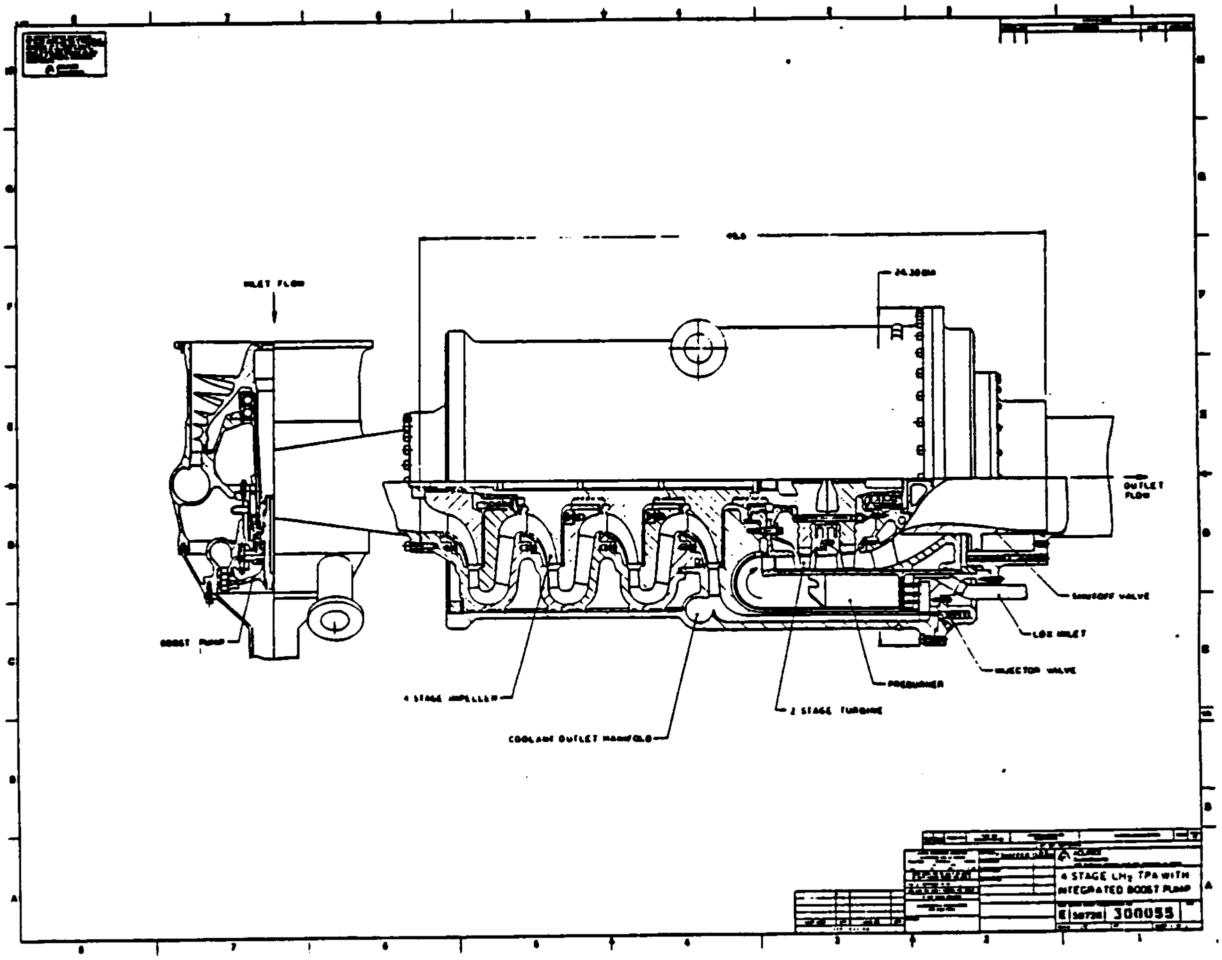

Figure 3.3.1-11 4 Stage LH_2 TPA With Integrated Boost Pump

A possibly feasible nozzle skirt is shown in Figure 3.3.1-12. The example shown is for an SSME size chamber. The advantage of the NSI is the optimum area ratio at liftoff gives excellent sea level thrust.

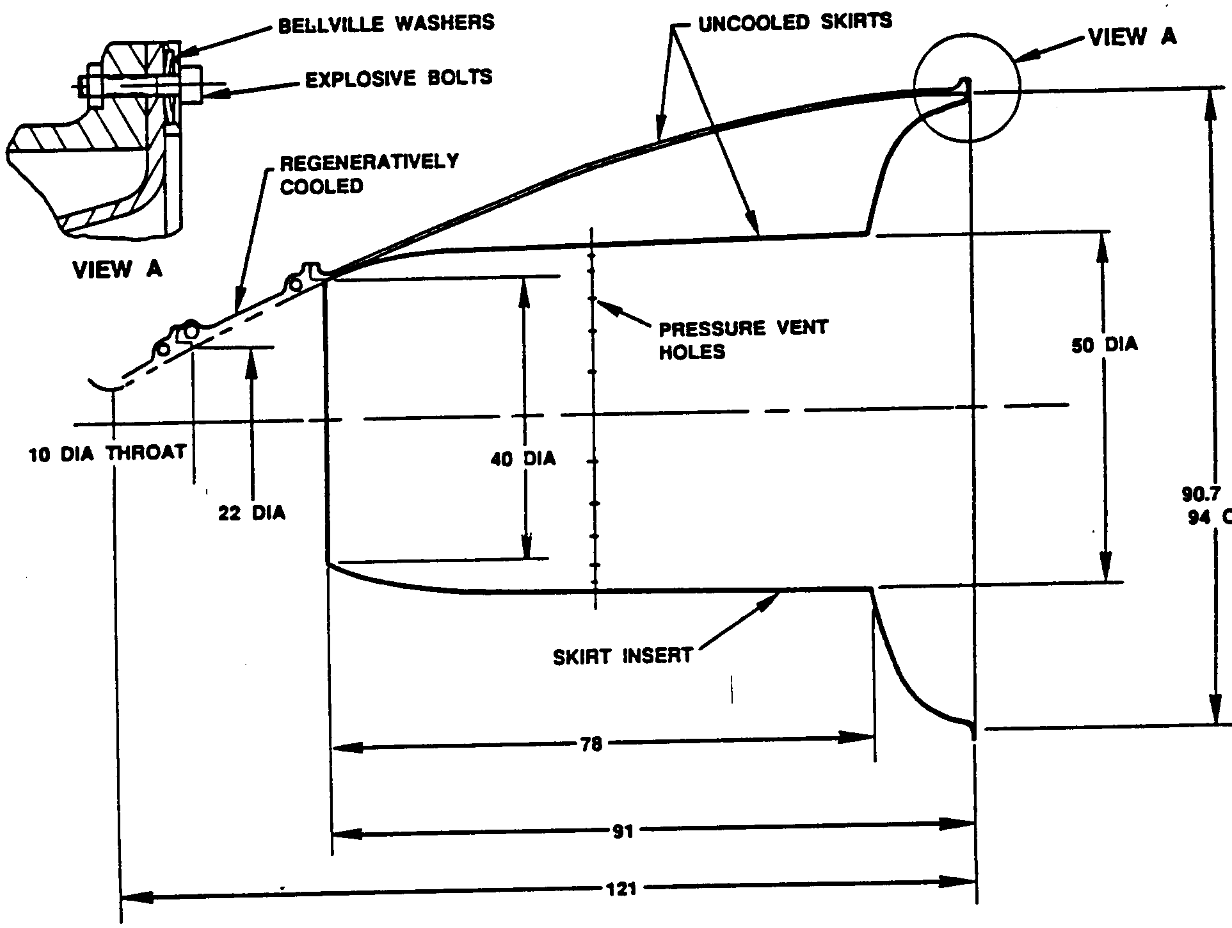

Figure 3.3.1-12 Typical Nozzle Skirt Insert

The relationship between the nozzle thrust coefficient and altitude for 3000 and 2000 psia chamber pressure is shown in Figures 13 and 14. The flight trajectory program will determine the optimum altitudes for nozzle skirt ejection. However, the altitudes shown in Figures 3.3.1-13 and 3.3.1-14 should be close to optimum.

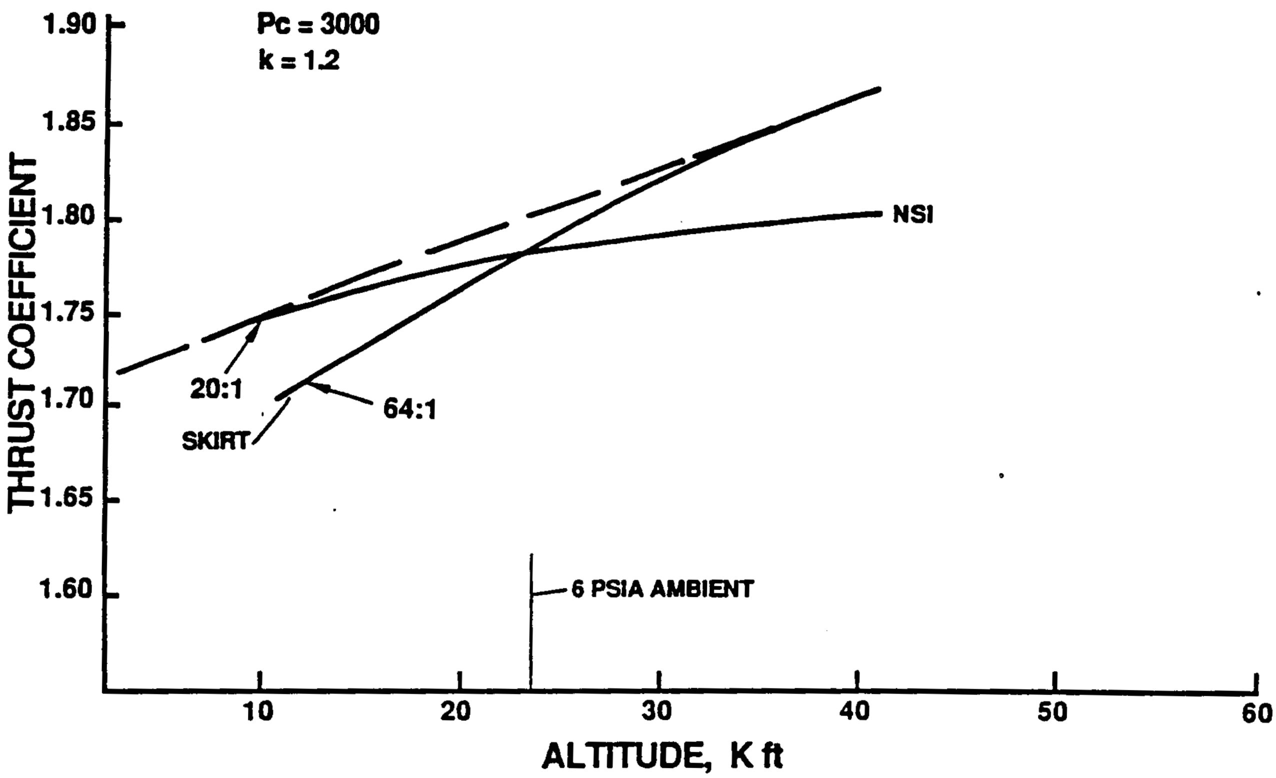

Figure 3.3.1-13 Transition Altitude For 20:1 to 64:1 Area Ratio Skirts

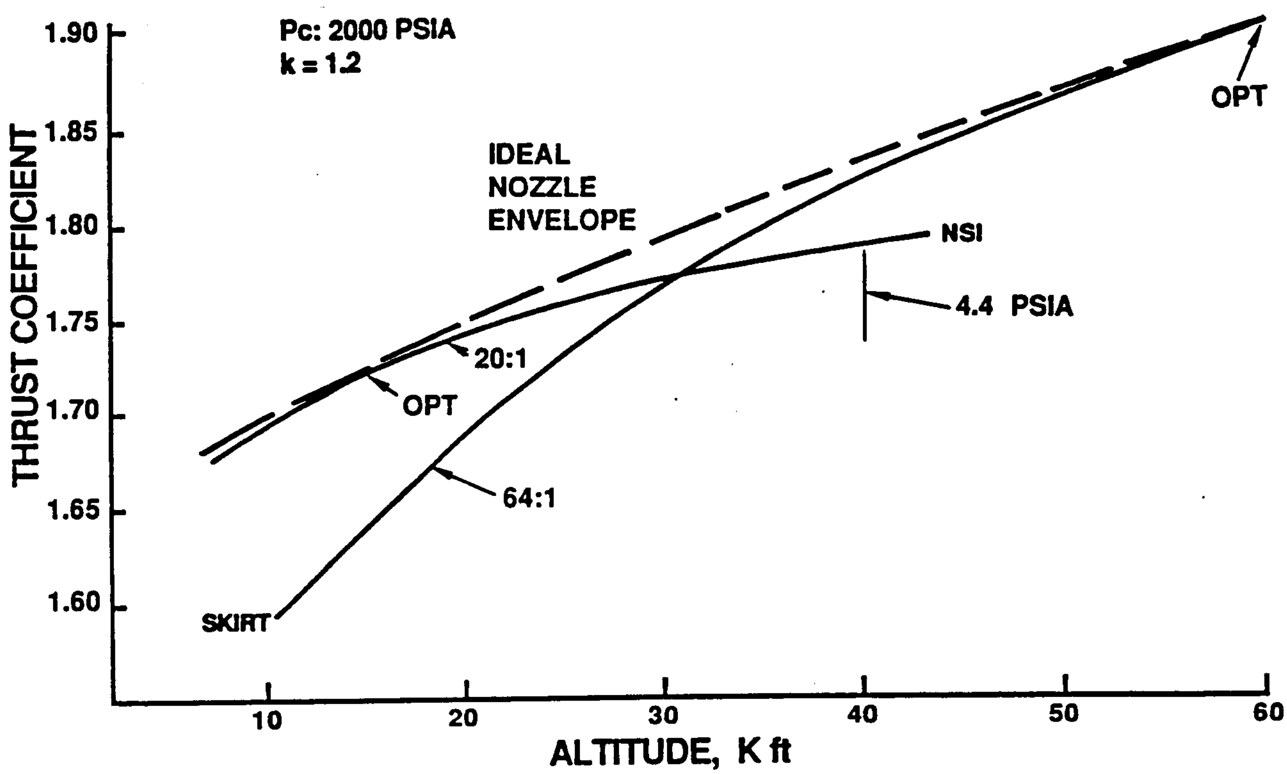

Figure 3.3.1-14 Transition Altitude For 20:1 to 64:1 Area Ratio Skirts

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The lengths of the engines for 3000 and 2000 psia chamber pressures and nozzle exit area ratio of 20, 64, and 100 are shown in Figure 3.3.1-15. The high chamber pressure provides a significant reduction of engine length. The engine length is not a significant function of mixture ratio, only chamber pressure and area ratio for the constant thrust of 700,000 lbs (vac).

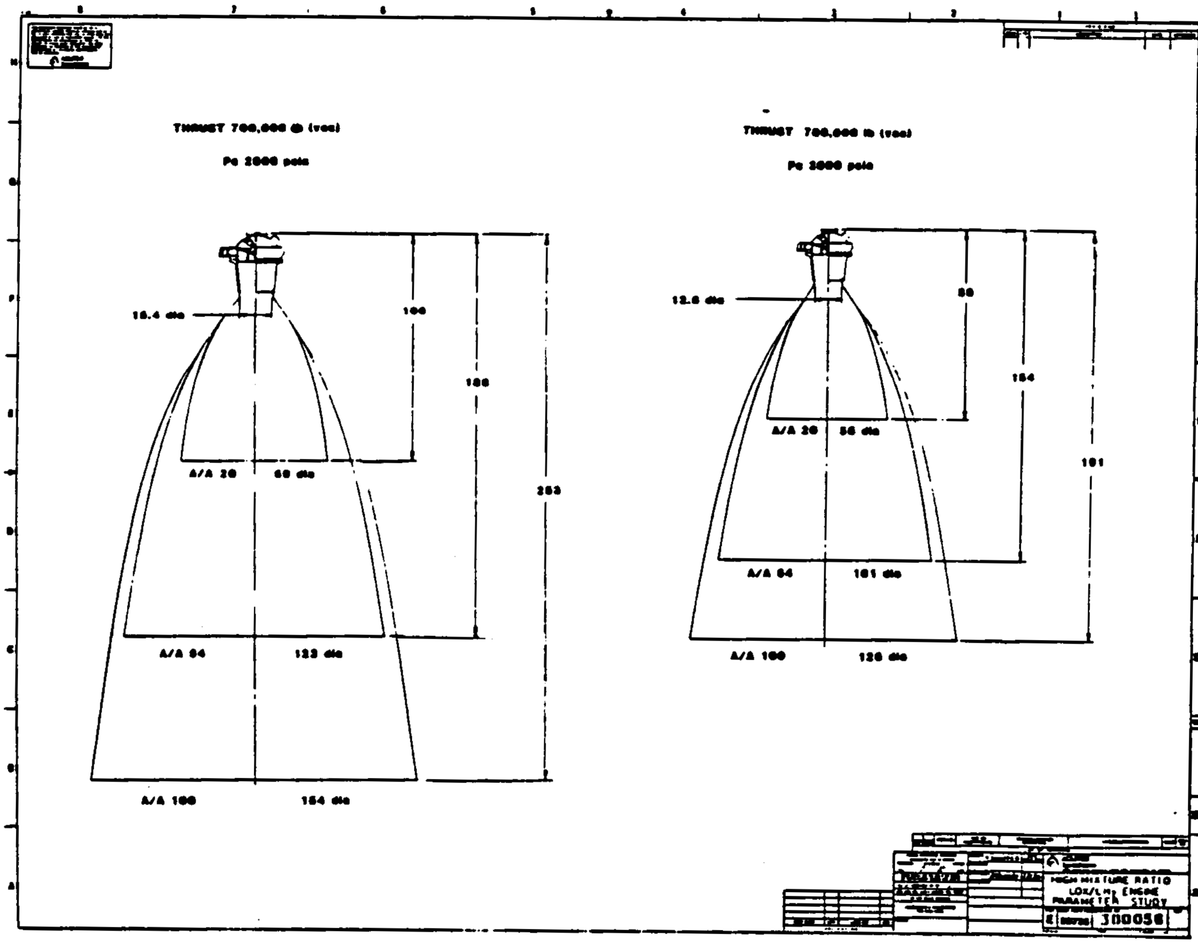

Figure 3.3.1-15 High Mixture Ratio LOX/LH $_2$ Engine Parameter Study

The variable mixture ratio engine characteristics for 3000 psia and 2000 psia chamber pressure engines with skirt area ratios of 64 are given in Figures 3.3.1-16 and 3.3.1-17. Three engines A, B, and C having initial mixture ratios of 10, 12, and 14 respectively are shown. Each engine transitions to low mixture ratio, i.e., 5, 6, 7, or 8 for higher specific impulse and reduced thrust. For the data shown, the fuel flow rate of each engine is maintained constant at the lower mixture ratios.

An engine with a high mixture ratio of 9, tailored for the booster element of a 2-stage heavy lift system was also defined. This engine has a vacuum thrust of 671,110 lbs, a chamber pressure of 3000 psia and is a full-flow cycle design having a skirt area ratio of 20. Further, this engine can be adapted to operate at a mixture ratio of 6 and have a chamber pressure about 2000 psia to serve as the engine of the second stage of the launch vehicle. It's nozzle skirt has an area ratio of 64 and includes a skirt insert having an area ratio of 20.

The booster and upper stage engines operate in the parallel burn mode at lift-off. A drawing of the booster/upper stage engine is shown in Figure 3.3.1-18. Data tables for the booster and upper stage engine are given in Figures 3.1.1.16-3 and 3.1.1.16-4 (previously shown). The engine has a single integrated high pressure-low pressure fuel turbopump and dual integrated high pressure-low pressure oxygen turbopumps. The main fuel turbopump uses a 3-stage pump for 3000 psia chamber pressure and a 2-stage pump for 2000 psia chamber pressure. Figure 3.3.1-19 shows the variation of pump discharge pressure an turbine inlet pressure with chamber pressure. Figure 3.3.1-20 shows the corresponding oxidizer and fuel main turbine inlet temperature for 3000 and 2000 psia versus high mixture ratio. The turbine inlet temperatures for all turbines are modest, for example, 428°F for main oxygen turbopump and 809°F for the main fuel pumps in the booster engine and at lower temperature in the lower chamber pressure upper stage engine.

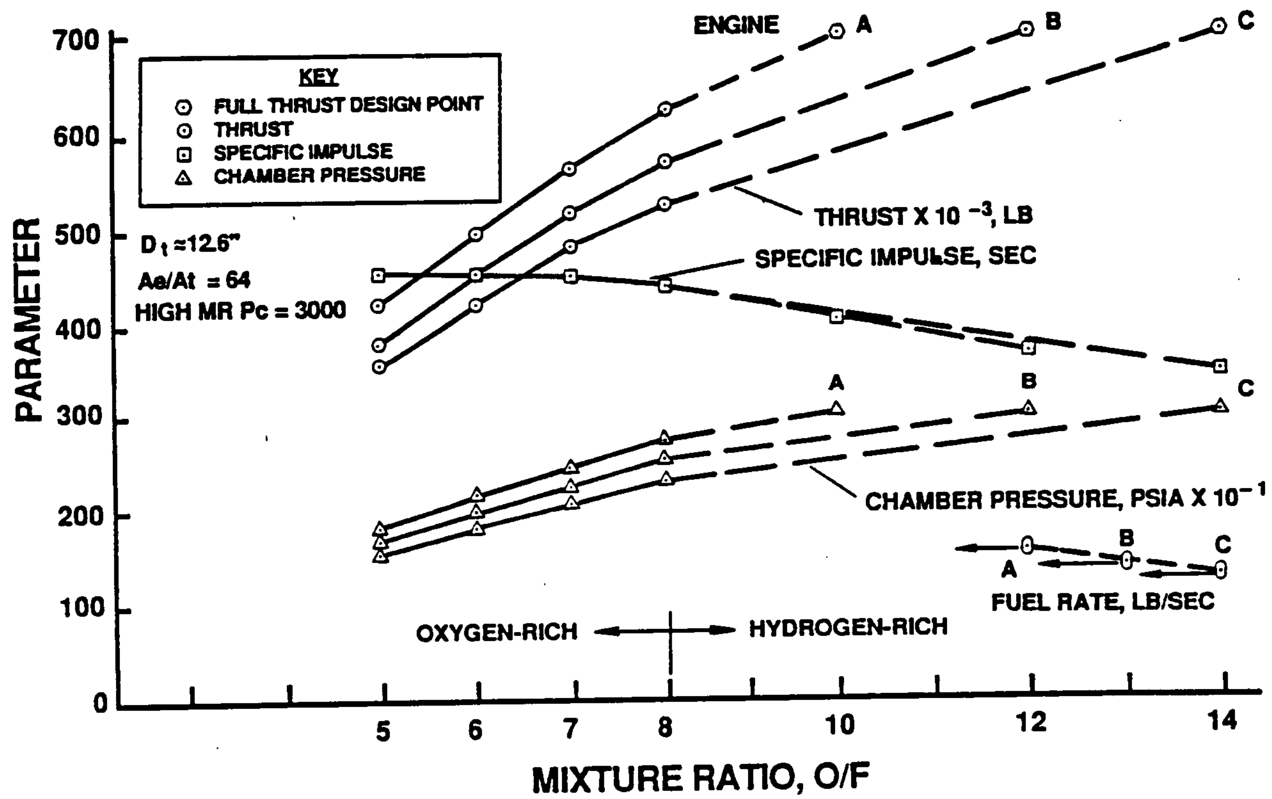

Figure 3.3.1-16 Variable Mixture Ratio Engine Characteristics

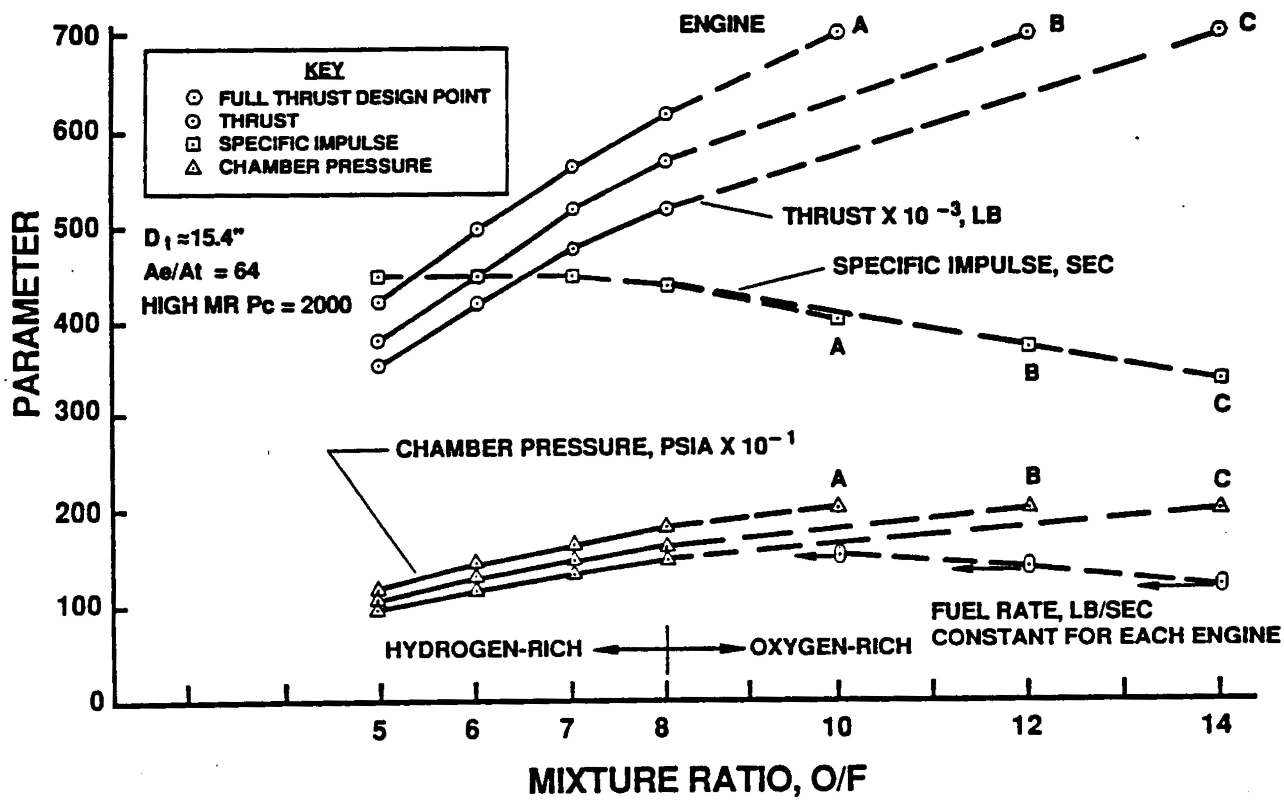

Figure 3.3.1-17 Variable Mixture Ratio Engine Characteristics

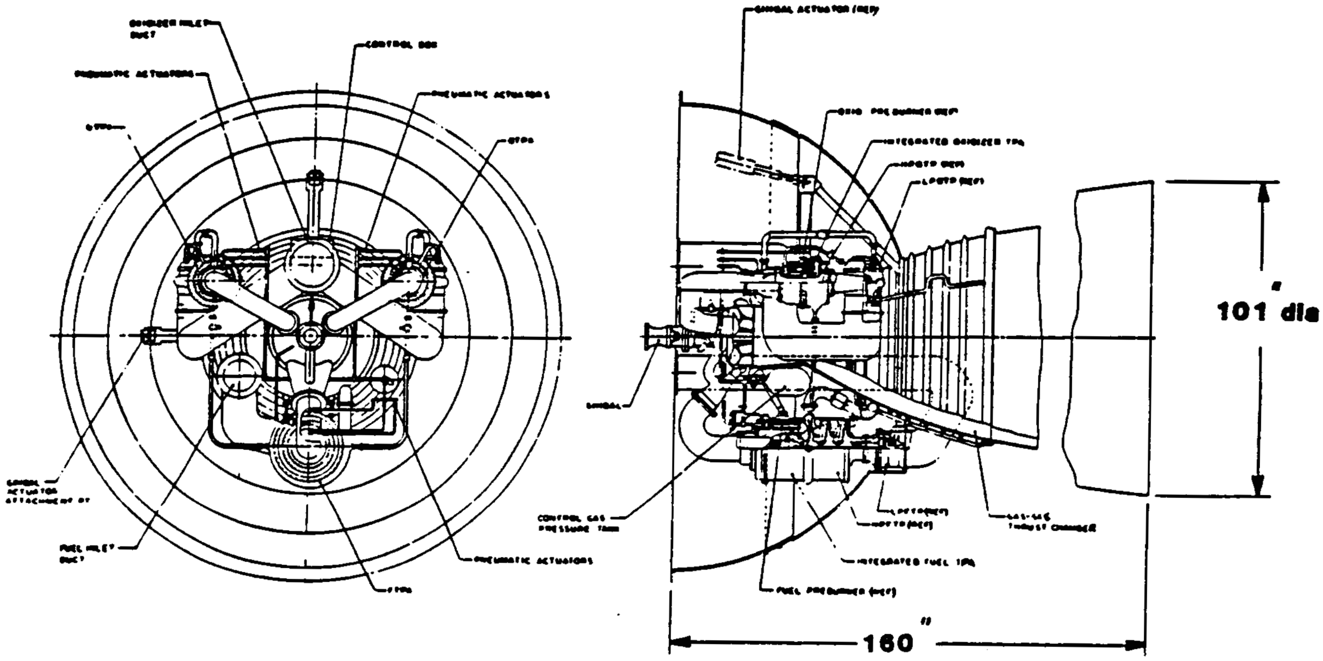

Figure 3.3.1-18 LOX/LH_2 Engine Assembly

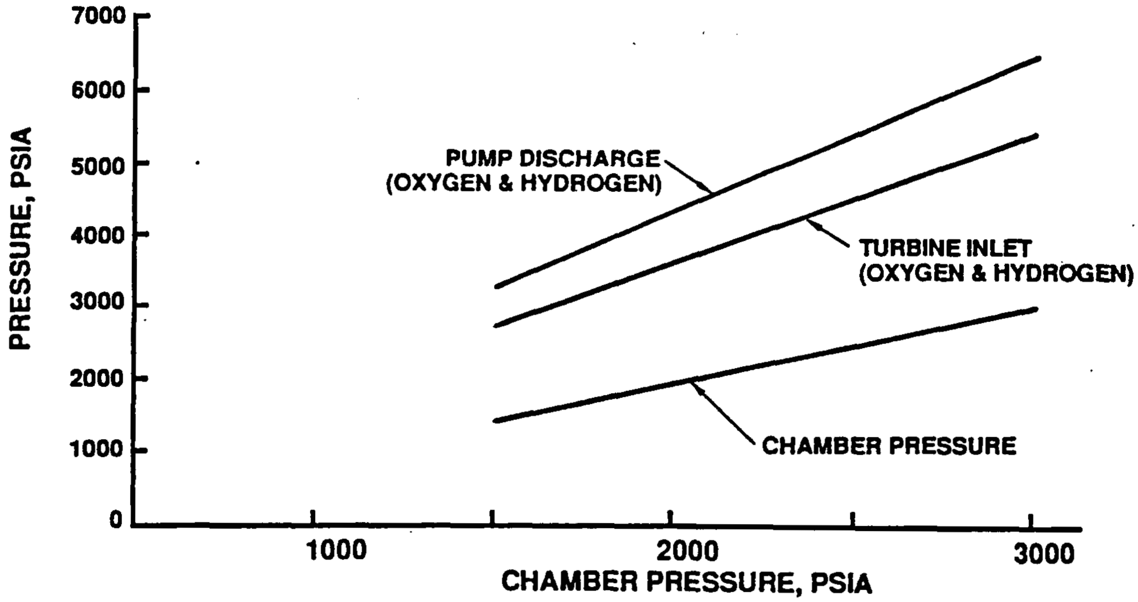

Figure 3.3.1-19 Pressure Pump Discharge and Turbine Inlet Versus Chamber Pressure

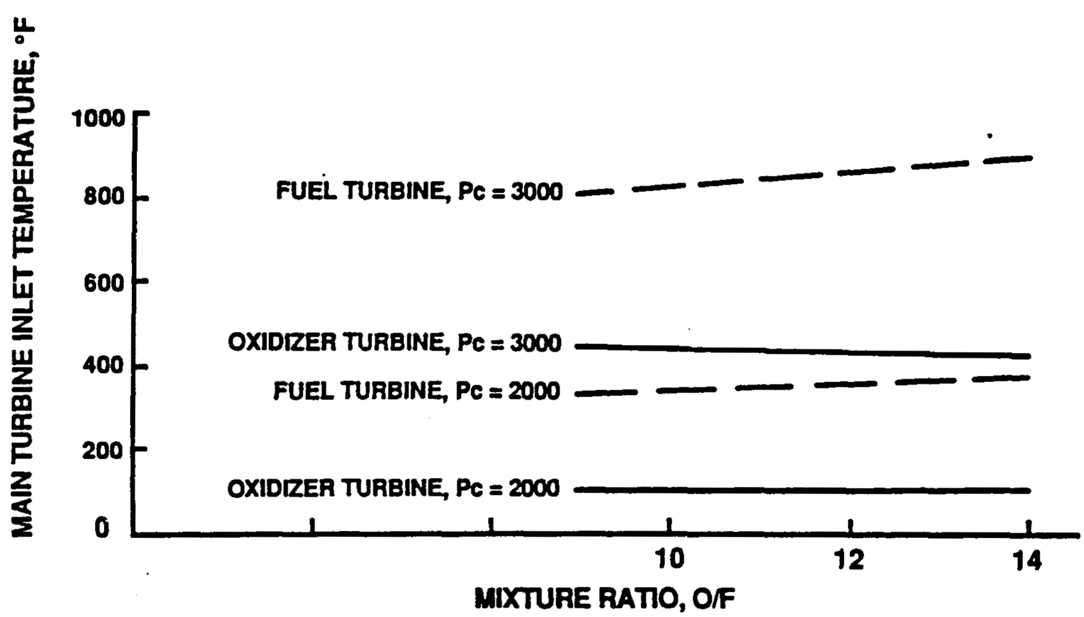

Figure 3.3.1-20 Turbine Inlet Gas Temperature Versus Mixture Ratio and Chamber Pressure

4.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions discussed below are based on results obtained directly from the study effort, as accomplished in accordance with meeting the study objectives, combined with additional insights gained from discussions of the study results with engine contractor and NASA personnel. Our recommendations are based on not only these conclusions but also on results from related (but outside the contract statement of work) IR&D studies.

4.1 CONCLUSIONS

The following main conclusions were drawn from the study effort:

a. Optimum staging velocity for an unmanned two-stage, parallel-burn, partially reusable heavy lift vehicle of the type selected for this study, for minimum dry weight, is about 5000 feet per second. The high propellant mass fraction of the second stage drives the staging velocity regardless of engine type or propellant used by the booster. Therefore, the partially reusable second stages of all vehicle options examined are all nearly identical.

b. The use of hydrocarbon fuel minimizes two-stage and SSTO vehicle dry weight. For example, the lowest dry weight for the booster element (and total vehicle) of the partially reusable, two-stage, unmanned heavy lift vehicle concept was obtained through use of a new LOX/CH_4, high chamber pressure booster engine using LH_2 regenerative engine cooling.

c. The extra tank, plumbing and other related provisions for the LH_2 coolant of this booster, in conjunction with the fairly large CH_4 tank (required by the relatively low density of the CH_4, e.g., compared to RP-1) and the small wing consistent with the light weight booster, indicate that a canard lifting surface may be required to allow adequate aerodynamic trim (during the subsonic portion of the flight following deceleration from about Mach 5). Thus, the $LOX/CH_4/LH_2$ cooled booster could be further complicated and its weight impacted to the point where it would no longer the lightest option (e.g., compared to the relatively compact LOX/CH_4/CH_4 cooled booster which also uses a lower chamber pressure engine).

d. The lowest dry weight booster (LOX/CH_4/LH_2 cooled) discussed above is only about 15% lighter than a booster using a low chamber pressure (1300 PSIA) LOX/RP 1/RP-1 cooled engine. The relatively large powerhead of this engine can still be configured to provide an acceptable booster aerodynamic configuration, even avoiding the use of a canard. The engine and vehicle simplicity and resulting lower development costs should be traded-off against potential operational impact due to using RP-1 as a coolant. These include both in-flight purge (with GN_2, upon shutdown), ground solvent flush requirements for the engine downstream of the propellant shut-off valves, and the need for a high level of fuel purity to prevent cuprous sulfite build-up within the engine due to sulfur impurities in the fuel.

e. The complexities of using either propellant crossfeed, or an engine with two position nozzle on the booster are both counter-productive as applied to dry weight minimization of the two-stage launch vehicle. The booster provides only about a quarter of the delta velocity required to reach orbit and needs to be as simple, reliable and affordable as reasonable for low cost operations (including turn-around, check-out, etc.).

   Its high mass fraction, compared to the partially recoverable second stage, also contributes to the ineffectiveness of these options.

f. The use of subcooled propane did not minimize dry weight for the two-stage system. In addition, ground infrastructure and safety potential impacts caused us to further conclude that subcooled propane is an inappropriate fuel for this application.

g. Another complexity that was found to be inappropriate for the two stage system was the use of a new variable mixture ratio LOX/LH_2 engine on the booster (or second stage) element. For the system concept considered (flyback booster with staging at around Mach 5), we concluded that using a single mixture ratio of about 9.0:1 produces approximately the same vehicle dry weight minimization and avoids potential inter-granular weakening effects within the engine through initial LOX-rich, followed by fuel-rich combustion.

h. The use of a high mixture ratio (9.0:1) booster engine is quite effective in reducing the dry weight of the two-stage system. Further, by operating in a slightly lower, but still high mixture ratio mode (7.5:1), the same engine could be used effectively for an SSTO vehicle provided that a two-position nozzle would also be utilized. The resulting all LOX/LH_2 two-stage vehicle is quite simple and is potentially the best overall approach, although being about 20% heavier (dry weight) than the best hydrocarbon fueled concept.

i. Increasing chamber pressure has a diminishing effect on minimizing dry weight. In order to reduce new engine development cost the chamber pressure can be lowered (providing that the resulting cluster of engines will still fit within the booster aft section) without seriously impacting two-stage vehicle dry weight.

j. The desired vacuum thrust range for a new engine for the booster element of the two-stage, partially reusable, unmanned vehicle is 600,000 to 700,000 lb. depending on propellants and engine types utilized.

k. The use of subcooled propane fuel produced only a slightly lower SSTO vehicle dry weight than could be obtained using normal boiling point propane. The difference does not appear to justify the subcooled propane facilities complexities. Probably more important, safety concerns using propane (liquid pooling and heavy vapors in the event of a spill, etc.) in conjunction with the availability of nearly as effective weight reduction strategies using other fuels caused us to conclude that the use of subcooled propane fuel is not the preferred approach even for an SSTO vehicle.

l. Designing an SSTO vehicle on the basis of minimum dry weight does not appear to be the best overall strategy. The focus becomes improving on technology (which is expensive and therefore counter-productive to reducing inert weight in order to reduce cost). We realized this paradox upon determining that significant reductions in across-the-board component weight technology levels, relative to the Advanced Launch System (ALS) type weights used for the two-stage vehicle portion of the study, were required to allow any of the SSTO vehicle options to reach polar orbit. Subsequently, on IR&D, we allowed GLOW to increase in order to minimize required reductions of component weight technology levels, at the expense of increasing vehicle dry weight.

m. This parallel IR&D effort, outside of the contract statement of work (dry weight minimization), resulted in the finding that a LOX/LH_2 SSTO vehicle could use nearly as low an overall component technology level as possible for a hydrocarbon fueled (early burn phase) plus LH_2 fueled SSTO vehicle. The LOX/LH_2 vehicle would merely have a slightly higher dry weight, but would be much simpler in overall design, using only one type of engine and only two main propellant tanks. Each engine would operate at a single mixture ratio of about 7.5:1 throughout the burn and would be equipped with a dual position nozzle capable of being actuated during the vehicle's continuous burn from lift-off to MECO. Engine-out capability is also feasible within the ALS type overall weight component technology level availability.

4.2 RECOMMENDATIONS

The following recommendations are based on some of the comments of 4.1 above as well as other data developed in-house or otherwise obtained outside of the contract effort:

a. Whatever LOX/hydrocarbon booster engine turns out to be most suitable, we recommend that the advantages and disadvantages of its use on a two-stage, unmanned partially reusable booster be defined in greater detail relative to using a single type of LOX/LH_2 engine on the same vehicle concept. This is because using two different types of engines on the vehicle (plus, if required, incorporating the complexities of LH_2 engine cooling on the hydrocarbon fueled booster) may not turn out to be the most cost effective solution. Based on the study results, this effort sould consider a constant high mixture ratio (e.g., 9.0:1) LOX/LH_2 engine on the booster, with a higher expansion ratio nozzle plus reduced LOX flow (to provide a 6.0:1 mixture ratio) version of the same engine on the partially reusable second stage.

b. Since it is not clear at this time whether or not the partially reusable, two-stage vehicle approach selected for this study will actually turn out to be the preferred concept for an advanced launch system, we recommend that a similar study be performed for a fully expendable, modularly adaptable (for different levels of launch capability) type of vehicle such as discussed section in 3.1.3 of this report.

c. Finally, we recommend expanding the SSTO portion of this study to consider use of the alternative optimization criteria developed under IR&D and summarized in section 3.1.3 of this report. This is because the revised strategy shows promise for defining a more near-term SSTO vehicle for military sortie missions and low cost manned access to the Space Station (e.g., by year 2000) than previously thought feasible.

APPENDIX A

DETAILED MASS AND PERFORMANCE DATA

FOR OPTIMUM CONFIGURATIONS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2540000.00	0.00
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1035400.00	0.00
FUEL WEIGHT IN BOOSTER * LBS	147910.00	0.00
OXIDIZER WEIGHT IN BOOSTER * LBS	887450.00	0.00
FUEL RESERVES * LBS	636.01	0.00
OXIDIZER RESERVES * LBS	3816.10	0.00
FUEL RESIDUAL WEIGHT * LBS	78.34	0.00
OXIDIZER RESIDUAL WEIGHT * LBS	544.38	0.00
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	444.68	0.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2886.60	0.00
TOTAL TANK WEIGHT * LBS	13199.00	0.00
FUEL TANK LINE WEIGHT * LBS	2065.10	0.00
OXIDIZER TANK LINE WEIGHT * LBS	201.23	0.00
FUEL TANK INSULATION WEIGHT * LBS	3447.90	0.00
OXIDIZER TANK INSULATION WEIGHT * LBS	1833.60	0.00
GAS LINE WEIGHT * LBS	105.38	0.00
ENGINE BAY LINE WEIGHT * LBS	505.86	0.00
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1062.00	0.00
WEIGHT OF EACH BOOSTER ENGINE * LBS	6790.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	9730.90	0.00
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1504600.00	0.00
FUEL WEIGHT IN ORBITER * LBS	214950.00	0.00
OXIDIZER WEIGHT IN ORBITER * LBS	1289700.00	0.00
FUEL RESERVES * LBS	924.28	0.00
OXIDIZER RESERVES * LBS	5545.70	0.00
FUEL RESIDUAL WEIGHT * LBS	109.79	0.00
OXIDIZER RESIDUAL WEIGHT * LBS	749.23	0.00
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	602.39	0.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2933.00	0.00
TOTAL TANK WEIGHT * LBS	15330.00	0.00
FUEL TANK LINE WEIGHT * LBS	1387.10	0.00
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4200.50	0.00
OXIDIZER TANK INSULATION WEIGHT * LBS	1968.70	0.00
GAS LINE WEIGHT * LBS	99.02	0.00
ENGINE BAY LINE WEIGHT * LBS	293.62	0.00
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.50	0.00
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9453.50	0.00
TOTAL OMS PROPELLANT WEIGHT * LBS	18582.00	0.00
OMS HARDWARE WEIGHT * LBS	1010.10	0.00
TOTAL RCS WEIGHT * LBS	1369.00	0.00
RCS PROPELLANT WEIGHT * LBS	1805.60	0.00
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage SSME-Powered Baseline Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	405140.00	0.00
GROSS LIFT OFF WEIGHT * LBS	3167600.00	0.00
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	241720.00	0.00
BODY WEIGHT * LBS	111950.00	0.00
GROWTH WEIGHT * LBS	13548.00	0.00
INERT WEIGHT * LBS	277620.00	0.00
EQUIPMENT WEIGHT * LBS	11083.00	0.00
TANK MOUNT WEIGHT * LBS	1231.30	0.00
STRUCTURAL WALL WEIGHT * LBS	23938.00	0.00
APU PROPELLANT WEIGHT * LBS	3151.00	0.00
LANDING WEIGHT * LBS	248330.00	0.00
FLYBACK SYSTEM INERT WEIGHT * LBS	29339.00	0.00
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	15995.00	0.00
FLYBACK SYSTEM WEIGHT * LBS	45372.00	0.00
LANDING GEAR WEIGHT * LBS	6953.10	0.00
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	42331.00	0.00
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	2985.10	0.00
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1854600.00	0.00
ORBITER DRY WEIGHT * LBS	163420.00	0.00
BODY WEIGHT * LBS	111640.00	0.00
GROWTH WEIGHT * LBS	9475.20	0.00
INERT WEIGHT * LBS	190510.00	0.00
EQUIPMENT WEIGHT * LBS	7011.20	0.00
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9038.60	0.00
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121780.00	0.00
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage SSME-Powered Baseline System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.53	0.00
NOMINAL LIFT OFF ACCELERATION	1.40	0.00
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	5000.00	0.00
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	437.68	0.00
QUANTITY OF ENGINES	7.00	0.00
PROPELLANT MASS FRACTION	0.79	0.00
BOOSTER LAUNCH MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	452200.00	0.00
ENGINE RATED VACUUM THRUST * LBS	494400.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	35.15	0.00
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	3.00	0.00
THROTTLE SETTING OF 1ST STAGE ENGINES	0.89	0.00
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.00
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.68	0.00
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage SSME-Powered Baseline Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	149.65	0.00
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	5.04	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	35.00	0.00
FUEL LINE DIAMETER * IN	18.38	0.00
OXIDIZER LINE DIAMETER * IN	19.24	0.00
FUEL TANK HEAD HEIGHT * IN	139.99	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	509.81	0.00
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	0.00	0.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.06	0.00
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	3832.10	0.00
WING SPAN * FT	88.85	0.00
SINGLE FIN EXPOSED AREA * SQ FT	166.63	0.00
EXPOSED FIN SPAN * FT	15.21	0.00
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	251.50	0.00
LENGTH/DIAMETER RATIO OF VEHICLE	7.62	0.00
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	0.00
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	729.31	0.00
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	41.62	0.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	0.00
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage SSME-Powered Baseline Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2674700.00	5.30
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1074100.00	3.74
FUEL WEIGHT IN BOOSTER * LBS	107690.00	-27.19
OXIDIZER WEIGHT IN BOOSTER * LBS	966380.00	8.89
FUEL RESERVES * LBS	463.05	-27.19
OXIDIZER RESERVES * LBS	4155.40	8.89
FUEL RESIDUAL WEIGHT * LBS	59.06	-24.62
OXIDIZER RESIDUAL WEIGHT * LBS	584.82	7.43
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	324.03	-27.13
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2282.20	-20.94
TOTAL TANK WEIGHT * LBS	11121.00	-15.74
FUEL TANK LINE WEIGHT * LBS	1559.40	-24.49
OXIDIZER TANK LINE WEIGHT * LBS	216.35	7.51
FUEL TANK INSULATION WEIGHT * LBS	2833.30	-17.83
OXIDIZER TANK INSULATION WEIGHT * LBS	1650.70	-9.97
GAS LINE WEIGHT * LBS	95.39	-9.48
ENGINE BAY LINE WEIGHT * LBS	450.09	-11.02
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	955.20	-10.06
WEIGHT OF EACH BOOSTER ENGINE * LBS	8019.90	18.11
WEIGHT OF THRUST STRUCTURE * LBS	7966.60	-18.13
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1600700.00	6.39
FUEL WEIGHT IN ORBITER * LBS	228670.00	6.38
OXIDIZER WEIGHT IN ORBITER * LBS	1372000.00	6.38
FUEL RESERVES * LBS	983.27	6.38
OXIDIZER RESERVES * LBS	5899.60	6.38
FUEL RESIDUAL WEIGHT * LBS	116.15	5.79
OXIDIZER RESIDUAL WEIGHT * LBS	790.39	5.49
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	639.97	6.24
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2937.40	0.15
TOTAL TANK WEIGHT * LBS	16162.00	5.43
FUEL TANK LINE WEIGHT * LBS	1403.60	1.19
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4351.50	3.59
OXIDIZER TANK INSULATION WEIGHT * LBS	2016.00	2.40
GAS LINE WEIGHT * LBS	103.17	4.19
ENGINE BAY LINE WEIGHT * LBS	293.80	0.06
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.77	0.04
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9499.80	0.49
TOTAL OMS PROPELLANT WEIGHT * LBS	18676.00	0.51
OMS HARDWARE WEIGHT * LBS	1013.90	0.38
TOTAL RCS WEIGHT * LBS	1377.80	0.64
RCS PROPELLANT WEIGHT * LBS	1825.80	1.12
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized LOX/LH_2 with Fixed Mixture Ratio Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	361850.00	-10.69
GROSS LIFT OFF WEIGHT * LBS	3253700.00	2.72
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	197470.00	-18.31
BODY WEIGHT * LBS	89134.00	-20.38
GROWTH WEIGHT * LBS	10979.00	-18.96
INERT WEIGHT * LBS	227380.00	-18.10
EQUIPMENT WEIGHT * LBS	10298.00	-7.08
TANK MOUNT WEIGHT * LBS	988.61	-19.71
STRUCTURAL WALL WEIGHT * LBS	19206.00	-19.77
APU PROPELLANT WEIGHT * LBS	2709.80	-14.00
LANDING WEIGHT * LBS	202970.00	-18.27
FLYBACK SYSTEM INERT WEIGHT * LBS	19656.00	-33.00
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	11550.00	-27.79
FLYBACK SYSTEM WEIGHT * LBS	31233.00	-31.16
LANDING GEAR WEIGHT * LBS	5683.10	-18.27
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	34422.00	-18.68
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	2963.80	-0.71
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1952200.00	5.26
ORBITER DRY WEIGHT * LBS	164380.00	0.59
BODY WEIGHT * LBS	112440.00	0.72
GROWTH WEIGHT * LBS	9542.80	0.71
INERT WEIGHT * LBS	192050.00	0.81
EQUIPMENT WEIGHT * LBS	7086.40	1.07
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	8967.40	-0.79
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	122010.00	0.19
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized LOX/LH_2 with Fixed Mixture Ratio System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.15	-24.45
NOMINAL LIFT OFF ACCELERATION	1.32	-5.43
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4523.60	-9.53
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	416.13	-4.92
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.83	4.66
BOOSTER LAUNCH MIXTURE RATIO	8.97	49.57
DELIVERED THRUST AT IGNITION * LBS	607760.00	34.40
ENGINE RATED VACUUM THRUST * LBS	671110.00	35.74
NOMINAL FUEL TANK PRESSURE * PSIA	35.13	-0.05
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	4000.00	22.32
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES.	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.89	-0.51
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.59
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.64	-0.11
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized LOX/LH_2 with Fixed Mixture Ratio Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	30.47	-7.66
VEHICLE LENGTH * FT	138.19	-7.66
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	53.33	-7.66
MAIN ENGINE THROAT DIAMETER * FT	0.87	2.51
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	6.17	22.52
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	50.00	42.86
FUEL LINE DIAMETER * IN	15.58	-15.23
OXIDIZER LINE DIAMETER * IN	19.85	3.17
FUEL TANK HEAD HEIGHT * IN	129.17	-7.73
CYLINDRICAL LENGTH OF FUEL TANK * IN	435.93	-14.49
OXIDIZER TANK HEAD HEIGHT * IN	130.23	-7.68
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	29.24	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-7.79
THICKNESS OF OXIDIZER TANK WALL * IN	0.13	184.83
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	3132.20	-18.26
WING SPAN * FT	80.33	-9.59
SINGLE FIN EXPOSED AREA * SQ FT	144.23	-13.44
EXPOSED FIN SPAN * FT	14.15	-6.96
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	265.59	5.60
LENGTH/DIAMETER RATIO OF VEHICLE	8.05	5.60
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.98	0.04
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	775.82	6.38
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	56.21	35.06
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.11
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized LOX/LH$_2$ with Fixed Mixture Ratio Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2923300.00	15.09
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1329200.00	28.38
FUEL WEIGHT IN BOOSTER * LBS	299220.00	102.30
OXIDIZER WEIGHT IN BOOSTER * LBS	1030000.00	16.06
FUEL RESERVES * LBS	1286.60	102.29
OXIDIZER RESERVES * LBS	4428.90	16.06
FUEL RESIDUAL WEIGHT * LBS	201.83	157.62
OXIDIZER RESIDUAL WEIGHT * LBS	617.35	13.40
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	0.00	-100.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2053.20	-28.87
TOTAL TANK WEIGHT * LBS	9153.70	-30.65
FUEL TANK LINE WEIGHT * LBS	789.18	-61.78
OXIDIZER TANK LINE WEIGHT * LBS	234.76	16.66
FUEL TANK INSULATION WEIGHT * LBS	49.03	-98.58
OXIDIZER TANK INSULATION WEIGHT * LBS	1642.50	-10.42
GAS LINE WEIGHT * LBS	67.49	-35.96
ENGINE BAY LINE WEIGHT * LBS	366.42	-27.56
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	974.33	-8.26
WEIGHT OF EACH BOOSTER ENGINE * LBS	5868.40	-13.57
WEIGHT OF THRUST STRUCTURE * LBS	7904.50	-18.77
WEIGHT OF HYDROGEN COOLANT * LBS	17062.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	465.30	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	220.19	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	1438.30	N/A
PRESSURANT WEIGHT * LBS	318.17	N/A
PRESSURE TANK WEIGHT * LBS	2312.50	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1577100.00	4.82
FUEL WEIGHT IN ORBITER * LBS	225300.00	4.82
OXIDIZER WEIGHT IN ORBITER * LBS	1351800.00	4.82
FUEL RESERVES * LBS	968.81	4.82
OXIDIZER RESERVES * LBS	5812.80	4.82
FUEL RESIDUAL WEIGHT * LBS	114.59	4.37
OXIDIZER RESIDUAL WEIGHT * LBS	780.28	4.14
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	630.77	4.71
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2936.40	0.12
TOTAL TANK WEIGHT * LBS	15958.00	4.10
FUEL TANK LINE WEIGHT * LBS	1399.60	0.90
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4314.50	2.71
OXIDIZER TANK INSULATION WEIGHT * LBS	2004.40	1.81
GAS LINE WEIGHT * LBS	102.15	3.16
ENGINE BAY LINE WEIGHT * LBS	293.75	0.04
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.70	0.03
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9488.30	0.37
TOTAL OMS PROPELLANT WEIGHT * LBS	18653.00	0.38
OMS HARDWARE WEIGHT * LBS	1013.10	0.30
TOTAL RCS WEIGHT * LBS	1375.80	0.50
RCS PROPELLANT WEIGHT * LBS	1820.80	0.84
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	331780.00	-18.11
GROSS LIFT OFF WEIGHT * LBS	3469800.00	9.54
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	167630.00	-30.65
BODY WEIGHT * LBS	79356.00	-29.11
GROWTH WEIGHT * LBS	9648.00	-28.79
INERT WEIGHT * LBS	195350.00	-29.63
EQUIPMENT WEIGHT * LBS	9788.80	-11.68
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	9089.20	-62.03
APU PROPELLANT WEIGHT * LBS	2298.30	-27.06
LANDING WEIGHT * LBS	172560.00	-30.51
FLYBACK SYSTEM INERT WEIGHT * LBS	19367.00	-33.99
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	8895.30	-44.39
FLYBACK SYSTEM WEIGHT * LBS	28284.00	-37.66
LANDING GEAR WEIGHT * LBS	4831.70	-30.51
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	28940.00	-31.63
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3038.50	1.79
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1928300.00	3.97
ORBITER DRY WEIGHT * LBS	164150.00	0.45
BODY WEIGHT * LBS	112240.00	0.54
GROWTH WEIGHT * LBS	9526.20	0.54
INERT WEIGHT * LBS	191670.00	0.61
EQUIPMENT WEIGHT * LBS	7068.00	0.81
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	8984.30	-0.60
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121950.00	0.14
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled *System Weights*

C-3

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.10	-28.02
NOMINAL LIFT OFF ACCELERATION	1.26	-9.77
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4232.20	-15.36
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	325.59	-25.61
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.86	9.35
BOOSTER LAUNCH MIXTURE RATIO	3.26	-45.71
DELIVERED THRUST AT IGNITION * LBS	622830.00	37.73
ENGINE RATED VACUUM THRUST * LBS	656340.00	32.75
NOMINAL FUEL TANK PRESSURE * PSIA	17.25	-50.94
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	4000.00	22.32
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	23.00	283.33
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.01	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.89	-0.20
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.45
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.65	-0.08
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	29.41	-10.88
VEHICLE LENGTH * FT	133.37	-10.88
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	51.47	-10.88
MAIN ENGINE THROAT DIAMETER * FT	0.84	-1.80
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	4.49	-10.89
ENGINE SECTION LENGTH * FT	8.09	-30.27
NOZZLE EXPANSION RATIO	28.82	-17.65
FUEL LINE DIAMETER * IN	14.36	-21.89
OXIDIZER LINE DIAMETER * IN	20.56	6.86
FUEL TANK HEAD HEIGHT * IN	126.03	-9.97
CYLINDRICAL LENGTH OF FUEL TANK * IN	110.11	-78.40
OXIDIZER TANK HEAD HEIGHT * IN	125.68	-10.91
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	64.57	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.27	353.37
THICKNESS OF OXIDIZER TANK WALL * IN	0.15	226.30
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2662.80	-30.51
WING SPAN * FT	74.06	-16.64
SINGLE FIN EXPOSED AREA * SQ FT	129.21	-22.46
EXPOSED FIN SPAN * FT	13.40	-11.94
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	264.34	5.11
LENGTH/DIAMETER RATIO OF VEHICLE	8.01	5.11
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.98	0.04
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	764.42	4.81
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	52.63	26.46
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.08
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled *Dimensions*

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	3057500.00	20.37
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1442200.00	39.29
FUEL WEIGHT IN BOOSTER * LBS	338020.00	128.53
OXIDIZER WEIGHT IN BOOSTER * LBS	1104200.00	24.42
FUEL RESERVES * LBS	1453.50	128.53
OXIDIZER RESERVES * LBS	4747.90	24.42
FUEL RESIDUAL WEIGHT * LBS	223.11	184.79
OXIDIZER RESIDUAL WEIGHT * LBS	655.16	20.35
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	0.00	-100.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2032.20	-29.60
TOTAL TANK WEIGHT * LBS	11189.00	-15.23
FUEL TANK LINE WEIGHT * LBS	890.12	-56.90
OXIDIZER TANK LINE WEIGHT * LBS	258.51	28.46
FUEL TANK INSULATION WEIGHT * LBS	49.92	-98.55
OXIDIZER TANK INSULATION WEIGHT * LBS	1686.80	-8.01
GAS LINE WEIGHT * LBS	72.04	-31.64
ENGINE BAY LINE WEIGHT * LBS	411.13	-18.73
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1076.10	1.33
WEIGHT OF EACH BOOSTER ENGINE * LBS	6099.70	-10.17
WEIGHT OF THRUST STRUCTURE * LBS	8226.60	-15.46
WEIGHT OF HYDROGEN COOLANT * LBS	12517.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	416.44	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	179.11	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	1169.90	N/A
PRESSURANT WEIGHT * LBS	356.27	N/A
PRESSURE TANK WEIGHT * LBS	2589.50	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1602900.00	6.53
FUEL WEIGHT IN ORBITER * LBS	228980.00	6.53
OXIDIZER WEIGHT IN ORBITER * LBS	1373900.00	6.53
FUEL RESERVES * LBS	984.63	6.53
OXIDIZER RESERVES * LBS	5907.80	6.53
FUEL RESIDUAL WEIGHT * LBS	116.30	5.93
OXIDIZER RESIDUAL WEIGHT * LBS	791.32	5.62
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	640.83	6.38
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2937.50	0.15
TOTAL TANK WEIGHT * LBS	16181.00	5.55
FUEL TANK LINE WEIGHT * LBS	1404.00	1.22
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4354.90	3.68
OXIDIZER TANK INSULATION WEIGHT * LBS	2017.10	2.46
GAS LINE WEIGHT * LBS	103.27	4.29
ENGINE BAY LINE WEIGHT * LBS	293.80	0.06
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.77	0.04
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9500.60	0.50
TOTAL OMS PROPELLANT WEIGHT * LBS	18678.00	0.52
OMS HARDWARE WEIGHT * LBS	1014.00	0.39
TOTAL RCS WEIGHT * LBS	1378.10	0.66
RCS PROPELLANT WEIGHT * LBS	1826.20	1.14
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled, 2500-psia (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	336030.00	-17.06
GROSS LIFT OFF WEIGHT * LBS	3609300.00	13.94
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	171620.00	-29.00
BODY WEIGHT * LBS	80993.00	-27.65
GROWTH WEIGHT * LBS	9845.80	-27.33
INERT WEIGHT * LBS	200130.00	-27.91
EQUIPMENT WEIGHT * LBS	9785.20	-11.71
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	9355.30	-60.92
APU PROPELLANT WEIGHT * LBS	2293.30	-27.22
LANDING WEIGHT * LBS	176570.00	-28.90
FLYBACK SYSTEM INERT WEIGHT * LBS	19365.00	-34.00
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	8877.10	-44.50
FLYBACK SYSTEM WEIGHT * LBS	28263.00	-37.71
LANDING GEAR WEIGHT * LBS	4943.80	-28.90
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	29721.00	-29.79
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3134.60	5.01
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1954500.00	5.39
ORBITER DRY WEIGHT * LBS	164410.00	0.61
BODY WEIGHT * LBS	112450.00	0.73
GROWTH WEIGHT * LBS	9544.40	0.73
INERT WEIGHT * LBS	192080.00	0.82
EQUIPMENT WEIGHT * LBS	7088.10	1.10
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	8965.90	-0.80
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	122010.00	0.19
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled, 2500-psia (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.10	-28.02
NOMINAL LIFT OFF ACCELERATION	1.26	-9.45
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4172.70	-16.55
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	310.87	-28.97
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.87	10.52
BOOSTER LAUNCH MIXTURE RATIO	3.15	-47.49
DELIVERED THRUST AT IGNITION * LBS	661170.00	46.21
ENGINE RATED VACUUM THRUST * LBS	690530.00	39.67
NOMINAL FUEL TANK PRESSURE * PSIA	16.72	-52.43
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	2500.00	-23.55
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	23.00	283.33
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.01	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.90	0.52
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.60
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.64	-0.11
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled, 2500-psia (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	29.31	-11.20
VEHICLE LENGTH * FT	132.90	-11.19
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	51.28	-11.20
MAIN ENGINE THROAT DIAMETER * FT	1.09	27.41
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	4.20	-16.59
ENGINE SECTION LENGTH * FT	7.78	-32.92
NOZZLE EXPANSION RATIO	15.00	-57.14
FUEL LINE DIAMETER * IN	15.36	-16.43
OXIDIZER LINE DIAMETER * IN	21.43	11.39
FUEL TANK HEAD HEIGHT * IN	125.59	-10.29
CYLINDRICAL LENGTH OF FUEL TANK * IN	125.28	-75.43
OXIDIZER TANK HEAD HEIGHT * IN	125.23	-11.23
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	83.71	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.28	385.42
THICKNESS OF OXIDIZER TANK WALL * IN	0.18	279.51
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2724.70	-28.90
WING SPAN * FT	74.92	-15.68
SINGLE FIN EXPOSED AREA * SQ FT	131.19	-21.27
EXPOSED FIN SPAN * FT	13.50	-11.27
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	265.71	5.65
LENGTH/DIAMETER RATIO OF VEHICLE	8.05	5.65
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.98	0.05
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	776.90	6.53
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	56.54	35.86
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.11
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, LH_2-Cooled, (Near-Term) 2500-psia (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	3357800.00	32.20
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1864500.00	80.08
FUEL WEIGHT IN BOOSTER * LBS	449100.00	203.63
OXIDIZER WEIGHT IN BOOSTER * LBS	1415400.00	59.49
FUEL RESERVES * LBS	1931.10	203.63
OXIDIZER RESERVES * LBS	6086.00	59.48
FUEL RESIDUAL WEIGHT * LBS	282.61	260.73
OXIDIZER RESIDUAL WEIGHT * LBS	811.47	49.06
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	0.00	-100.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1976.40	-31.53
TOTAL TANK WEIGHT * LBS	23518.00	78.18
FUEL TANK LINE WEIGHT * LBS	1182.70	-42.73
OXIDIZER TANK LINE WEIGHT * LBS	326.06	62.03
FUEL TANK INSULATION WEIGHT * LBS	48.67	-98.59
OXIDIZER TANK INSULATION WEIGHT * LBS	1828.80	-0.26
GAS LINE WEIGHT * LBS	93.19	-11.57
ENGINE BAY LINE WEIGHT * LBS	512.18	1.25
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1327.70	25.02
WEIGHT OF EACH BOOSTER ENGINE * LBS	5902.80	-13.07
WEIGHT OF THRUST STRUCTURE * LBS	9025.20	-7.25
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	385.27	N/A
PRESSURE TANK WEIGHT * LBS	2800.30	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1493400.00	-0.74
FUEL WEIGHT IN ORBITER * LBS	213340.00	-0.75
OXIDIZER WEIGHT IN ORBITER * LBS	1280000.00	-0.75
FUEL RESERVES * LBS	917.35	-0.75
OXIDIZER RESERVES * LBS	5504.10	-0.75
FUEL RESIDUAL WEIGHT * LBS	109.04	-0.68
OXIDIZER RESIDUAL WEIGHT * LBS	744.33	-0.65
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	597.97	-0.73
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2932.50	-0.02
TOTAL TANK WEIGHT * LBS	15232.00	-0.64
FUEL TANK LINE WEIGHT * LBS	1385.10	-0.14
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4182.80	-0.42
OXIDIZER TANK INSULATION WEIGHT * LBS	1963.10	-0.28
GAS LINE WEIGHT * LBS	98.54	-0.49
ENGINE BAY LINE WEIGHT * LBS	293.60	-0.01
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.47	0.00
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9448.00	-0.06
TOTAL OMS PROPELLANT WEIGHT * LBS	18571.00	-0.06
OMS HARDWARE WEIGHT * LBS	1009.80	-0.03
TOTAL RCS WEIGHT * LBS	1368.20	-0.06
RCS PROPELLANT WEIGHT * LBS	1803.30	-0.13
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	353810.00	-12.67
GROSS LIFT OFF WEIGHT * LBS	3934400.00	24.21
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	190500.00	-21.19
BODY WEIGHT * LBS	87885.00	-21.50
GROWTH WEIGHT * LBS	10820.00	-20.14
INERT WEIGHT * LBS	226770.00	-18.32
EQUIPMENT WEIGHT * LBS	10174.00	-8.20
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	7968.20	-66.71
APU PROPELLANT WEIGHT * LBS	2742.40	-12.97
LANDING WEIGHT * LBS	195930.00	-21.10
FLYBACK SYSTEM INERT WEIGHT * LBS	19852.00	-32.34
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	13357.00	-16.49
FLYBACK SYSTEM WEIGHT * LBS	33241.00	-26.74
LANDING GEAR WEIGHT * LBS	5485.90	-21.10
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	33983.00	-19.72
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3346.70	12.11
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1843100.00	-0.62
ORBITER DRY WEIGHT * LBS	163310.00	-0.07
BODY WEIGHT * LBS	111550.00	-0.08
GROWTH WEIGHT * LBS	9467.30	-0.08
INERT WEIGHT * LBS	190320.00	-0.10
EQUIPMENT WEIGHT * LBS	7002.40	-0.13
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9047.40	0.10
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121750.00	-0.02
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.12	-26.60
NOMINAL LIFT OFF ACCELERATION	1.26	-9.41
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	5278.20	5.56
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	294.12	-32.80
QUANTITY OF ENGINES	6.00	-14.29
PROPELLANT MASS FRACTION	0.89	13.06
BOOSTER LAUNCH MIXTURE RATIO	3.15	-47.48
DELIVERED THRUST AT IGNITION * LBS	619830.00	37.07
ENGINE RATED VACUUM THRUST * LBS	675400.00	36.61
NOMINAL FUEL TANK PRESSURE * PSIA	13.40	-61.89
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	1300.00	-60.24
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	23.00	283.33
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.91	1.82
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	-0.07
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.68	0.01
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	27.20	-17.58
VEHICLE LENGTH * FT	123.34	-17.58
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	47.60	-17.58
MAIN ENGINE THROAT DIAMETER * FT	1.49	75.28
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	5.78	14.75
ENGINE SECTION LENGTH * FT	9.70	-16.34
NOZZLE EXPANSION RATIO	15.00	-57.14
FUEL LINE DIAMETER * IN	17.37	-5.51
OXIDIZER LINE DIAMETER * IN	23.69	23.10
FUEL TANK HEAD HEIGHT * IN	116.56	-16.74
CYLINDRICAL LENGTH OF FUEL TANK * IN	193.12	-62.12
OXIDIZER TANK HEAD HEIGHT * IN	116.20	-17.63
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	218.39	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.36	514.67
THICKNESS OF OXIDIZER TANK WALL * IN	0.27	480.54
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	3023.50	-21.10
WING SPAN * FT	78.92	-11.17
SINGLE FIN EXPOSED AREA * SQ FT	140.75	-15.53
EXPOSED FIN SPAN * FT	13.98	-8.09
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	259.90	3.34
LENGTH/DIAMETER RATIO OF VEHICLE	7.88	3.34
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	-0.01
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	723.85	-0.75
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	39.90	-4.12
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	0.01
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	3000000.00	18.11
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1576600.00	52.27
FUEL WEIGHT IN BOOSTER * LBS	450440.00	204.54
OXIDIZER WEIGHT IN BOOSTER * LBS	1126100.00	26.89
FUEL RESERVES * LBS	1936.90	204.54
OXIDIZER RESERVES * LBS	4842.30	26.89
FUEL RESIDUAL WEIGHT * LBS	283.34	261.67
OXIDIZER RESIDUAL WEIGHT * LBS	666.02	22.34
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	0.00	-100.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1573.40	-45.49
TOTAL TANK WEIGHT * LBS	22945.00	73.84
FUEL TANK LINE WEIGHT * LBS	1324.30	-35.87
OXIDIZER TANK LINE WEIGHT * LBS	311.63	54.86
FUEL TANK INSULATION WEIGHT * LBS	46.42	-98.65
OXIDIZER TANK INSULATION WEIGHT * LBS	1591.20	-13.22
GAS LINE WEIGHT * LBS	91.19	-13.47
ENGINE BAY LINE WEIGHT * LBS	552.62	9.24
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1394.60	31.32
WEIGHT OF EACH BOOSTER ENGINE * LBS	7320.30	7.81
WEIGHT OF THRUST STRUCTURE * LBS	8653.40	-11.07
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	492.34	N/A
PRESSURE TANK WEIGHT * LBS	3578.50	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1423400.00	-5.40
FUEL WEIGHT IN ORBITER * LBS	203350.00	-5.40
OXIDIZER WEIGHT IN ORBITER * LBS	1220100.00	-5.40
FUEL RESERVES * LBS	874.39	-5.40
OXIDIZER RESERVES * LBS	5246.40	-5.40
FUEL RESIDUAL WEIGHT * LBS	104.40	-4.91
OXIDIZER RESIDUAL WEIGHT * LBS	714.26	-4.67
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	570.54	-5.29
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2929.30	-0.13
TOTAL TANK WEIGHT * LBS	14625.00	-4.60
FUEL TANK LINE WEIGHT * LBS	1373.10	-1.01
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4072.90	-3.04
OXIDIZER TANK INSULATION WEIGHT * LBS	1928.60	-2.04
GAS LINE WEIGHT * LBS	95.51	-3.54
ENGINE BAY LINE WEIGHT * LBS	293.46	-0.05
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.28	-0.04
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9414.40	-0.41
TOTAL OMS PROPELLANT WEIGHT * LBS	18503.00	-0.43
OMS HARDWARE WEIGHT * LBS	1007.00	-0.31
TOTAL RCS WEIGHT * LBS	1361.70	-0.53
RCS PROPELLANT WEIGHT * LBS	1788.70	-0.94
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Far-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	349940.00	-13.62
GROSS LIFT OFF WEIGHT * LBS	3569300.00	12.68
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	187330.00	-22.50
BODY WEIGHT * LBS	84796.00	-24.26
GROWTH WEIGHT * LBS	10516.00	-22.38
INERT WEIGHT * LBS	220710.00	-20.50
EQUIPMENT WEIGHT * LBS	9886.70	-10.79
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	7548.00	-68.47
APU PROPELLANT WEIGHT * LBS	2579.90	-18.12
LANDING WEIGHT * LBS	192090.00	-22.65
FLYBACK SYSTEM INERT WEIGHT * LBS	19714.00	-32.81
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	12082.00	-24.46
FLYBACK SYSTEM WEIGHT * LBS	31824.00	-29.86
LANDING GEAR WEIGHT * LBS	5378.30	-22.65
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	33586.00	-20.66
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3353.80	12.35
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1772000.00	-4.45
ORBITER DRY WEIGHT * LBS	162610.00	-0.50
BODY WEIGHT * LBS	110970.00	-0.60
GROWTH WEIGHT * LBS	9418.40	-0.60
INERT WEIGHT * LBS	189210.00	-0.68
EQUIPMENT WEIGHT * LBS	6947.60	-0.91
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9104.20	0.73
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121580.00	-0.16
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Far-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.27	-17.02
NOMINAL LIFT OFF ACCELERATION	1.47	5.52
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	5075.10	1.50
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	303.51	-30.65
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.88	11.24
BOOSTER LAUNCH MIXTURE RATIO	2.50	-58.33
DELIVERED THRUST AT IGNITION * LBS	800190.00	76.95
ENGINE RATED VACUUM THRUST * LBS	855660.00	73.07
NOMINAL FUEL TANK PRESSURE * PSIA	14.85	-57.74
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	1650.00	-49.54
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	23.00	283.33
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.91	2.55
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.88	-0.55
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.71	0.09
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1, RP-1 Cooled (Far-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	26.00	-21.21
VEHICLE LENGTH * FT	117.91	-21.21
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	45.50	-21.21
MAIN ENGINE THROAT DIAMETER * FT	1.49	75.13
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	5.78	14.65
ENGINE SECTION LENGTH * FT	9.95	-14.24
NOZZLE EXPANSION RATIO	15.00	-57.14
FUEL LINE DIAMETER * IN	19.03	3.54
OXIDIZER LINE DIAMETER * IN	23.23	20.73
FUEL TANK HEAD HEIGHT * IN	111.42	-20.41
CYLINDRICAL LENGTH OF FUEL TANK * IN	212.10	-58.40
OXIDIZER TANK HEAD HEIGHT * IN	111.07	-21.27
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	177.54	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.37	536.40
THICKNESS OF OXIDIZER TANK WALL * IN	0.31	549.28
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2964.60	-22.64
WING SPAN * FT	78.15	-12.05
SINGLE FIN EXPOSED AREA * SQ FT	138.87	-16.66
EXPOSED FIN SPAN * FT	13.89	-8.71
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	256.19	1.86
LENGTH/DIAMETER RATIO OF VEHICLE	7.76	1.87
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	-0.04
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	689.98	-5.39
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	29.28	-29.64
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	0.09
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/RP-1 Cooled (Far-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2751300.00	8.32
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1221100.00	17.94
FUEL WEIGHT IN BOOSTER * LBS	238170.00	61.02
OXIDIZER WEIGHT IN BOOSTER * LBS	982920.00	10.76
FUEL RESERVES * LBS	1024.10	61.02
OXIDIZER RESERVES * LBS	4226.60	10.76
FUEL RESIDUAL WEIGHT * LBS	151.81	93.78
OXIDIZER RESIDUAL WEIGHT * LBS	593.34	8.99
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	667.88	50.19
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2249.00	-22.09
TOTAL TANK WEIGHT * LBS	5043.30	-61.79
FUEL TANK LINE WEIGHT * LBS	768.48	-62.79
OXIDIZER TANK LINE WEIGHT * LBS	204.79	1.77
FUEL TANK INSULATION WEIGHT * LBS	54.84	-98.41
OXIDIZER TANK INSULATION WEIGHT * LBS	1653.90	-9.80
GAS LINE WEIGHT * LBS	66.38	-37.01
ENGINE BAY LINE WEIGHT * LBS	330.77	-34.61
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	865.64	-18.49
WEIGHT OF EACH BOOSTER ENGINE * LBS	5237.90	-22.86
WEIGHT OF THRUST STRUCTURE * LBS	7618.40	-21.71
WEIGHT OF HYDROGEN COOLANT * LBS	22929.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	526.71	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	268.15	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	1751.60	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1507400.00	0.19
FUEL WEIGHT IN ORBITER * LBS	215340.00	0.18
OXIDIZER WEIGHT IN ORBITER * LBS	1292000.00	0.18
FUEL RESERVES * LBS	925.94	0.18
OXIDIZER RESERVES * LBS	5555.70	0.18
FUEL RESIDUAL WEIGHT * LBS	109.97	0.16
OXIDIZER RESIDUAL WEIGHT * LBS	750.34	0.15
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	603.46	0.18
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2933.20	0.01
TOTAL TANK WEIGHT * LBS	15354.00	0.16
FUEL TANK LINE WEIGHT * LBS	1387.60	0.04
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4204.80	0.10
OXIDIZER TANK INSULATION WEIGHT * LBS	1970.00	0.07
GAS LINE WEIGHT * LBS	99.14	0.12
ENGINE BAY LINE WEIGHT * LBS	293.62	0.00
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.51	0.00
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9455.00	0.02
TOTAL OMS PROPELLANT WEIGHT * LBS	18585.00	0.02
OMS HARDWARE WEIGHT * LBS	1010.40	0.03
TOTAL RCS WEIGHT * LBS	1369.60	0.04
RCS PROPELLANT WEIGHT * LBS	1806.20	0.03
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane LH_2-Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	322600.00	-20.37
GROSS LIFT OFF WEIGHT * LBS	3289100.00	3.84
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	159150.00	-34.16
BODY WEIGHT * LBS	76629.00	-31.55
GROWTH WEIGHT * LBS	9276.40	-31.53
INERT WEIGHT * LBS	187780.00	-32.36
EQUIPMENT WEIGHT * LBS	9707.00	-12.42
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	8785.60	-63.30
APU PROPELLANT WEIGHT * LBS	2153.40	-31.66
LANDING WEIGHT * LBS	164910.00	-33.59
FLYBACK SYSTEM INERT WEIGHT * LBS	19494.00	-33.56
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	10059.00	-37.11
FLYBACK SYSTEM WEIGHT * LBS	29577.00	-34.81
LANDING GEAR WEIGHT * LBS	4617.40	-33.59
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	27288.00	-35.54
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	2913.80	-2.39
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1857400.00	0.15
ORBITER DRY WEIGHT * LBS	163450.00	0.02
BODY WEIGHT * LBS	111660.00	0.02
GROWTH WEIGHT * LBS	9477.20	0.02
INERT WEIGHT * LBS	190550.00	0.02
EQUIPMENT WEIGHT * LBS	7013.40	0.03
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9036.50	-0.02
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121780.00	0.00
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane LH_2-Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.10	-28.02
NOMINAL LIFT OFF ACCELERATION	1.25	-10.22
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4743.80	-5.12
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	347.01	-20.72
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.85	8.16
BOOSTER LAUNCH MIXTURE RATIO	3.77	-37.23
DELIVERED THRUST AT IGNITION * LBS	573120.00	26.74
ENGINE RATED VACUUM THRUST * LBS	596070.00	20.56
NOMINAL FUEL TANK PRESSURE * PSIA	26.81	-23.73
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	4300.00	31.50
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.02	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.88	-1.28
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.02
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.68	0.00
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane LH_2-Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	30.34	-8.05
VEHICLE LENGTH * FT	137.61	-8.05
LENGTH/DIAMETER RATIO OF VEHICLE	4.54	0.01
NOSE LENGTH	53.10	-8.05
MAIN ENGINE THROAT DIAMETER * FT	0.78	-8.38
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	3.72	-26.25
ENGINE SECTION LENGTH * FT	7.01	-39.61
NOZZLE EXPANSION RATIO	22.68	-35.21
FUEL LINE DIAMETER * IN	14.19	-22.82
OXIDIZER LINE DIAMETER * IN	19.39	0.76
FUEL TANK HEAD HEIGHT * IN	130.04	-7.11
CYLINDRICAL LENGTH OF FUEL TANK * IN	145.68	-71.42
OXIDIZER TANK HEAD HEIGHT * IN	129.68	-8.07
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	34.83	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.09	55.83
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	9.46
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2544.90	-33.59
WING SPAN * FT	72.40	-18.51
SINGLE FIN EXPOSED AREA * SQ FT	125.44	-24.72
EXPOSED FIN SPAN * FT	13.20	-13.23
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	260.64	3.63
LENGTH/DIAMETER RATIO OF VEHICLE	7.90	3.64
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	0.00
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	730.63	0.18
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	42.03	0.99
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	0.00
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane LH_2-Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	3014800.00	18.69
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1468900.00	41.87
FUEL WEIGHT IN BOOSTER * LBS	312500.00	111.28
OXIDIZER WEIGHT IN BOOSTER * LBS	1156400.00	30.31
FUEL RESERVES * LBS	1343.70	111.27
OXIDIZER RESERVES * LBS	4972.60	30.31
FUEL RESIDUAL WEIGHT * LBS	190.80	143.54
OXIDIZER RESIDUAL WEIGHT * LBS	681.40	25.17
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	816.46	83.61
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1622.20	-43.80
TOTAL TANK WEIGHT * LBS	18332.00	38.89
FUEL TANK LINE WEIGHT * LBS	1012.10	-50.99
OXIDIZER TANK LINE WEIGHT * LBS	241.13	19.83
FUEL TANK INSULATION WEIGHT * LBS	50.90	-98.52
OXIDIZER TANK INSULATION WEIGHT * LBS	1627.90	-11.22
GAS LINE WEIGHT * LBS	85.37	-18.99
ENGINE BAY LINE WEIGHT * LBS	408.15	-19.32
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1040.00	-2.07
WEIGHT OF EACH BOOSTER ENGINE * LBS	5908.00	-12.99
WEIGHT OF THRUST STRUCTURE * LBS	7577.80	-22.13
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1545900.00	2.74
FUEL WEIGHT IN ORBITER * LBS	220840.00	2.74
OXIDIZER WEIGHT IN ORBITER * LBS	1325100.00	2.74
FUEL RESERVES * LBS	949.63	2.74
OXIDIZER RESERVES * LBS	5697.80	2.74
FUEL RESIDUAL WEIGHT * LBS	112.53	2.50
OXIDIZER RESIDUAL WEIGHT * LBS	766.89	2.36
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	618.55	2.68
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2934.90	0.06
TOTAL TANK WEIGHT * LBS	15688.00	2.34
FUEL TANK LINE WEIGHT * LBS	1394.20	0.51
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4265.40	1.55
OXIDIZER TANK INSULATION WEIGHT * LBS	1989.00	1.03
GAS LINE WEIGHT * LBS	100.81	1.81
ENGINE BAY LINE WEIGHT * LBS	293.70	0.03
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.61	0.02
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9473.50	0.21
TOTAL OMS PROPELLANT WEIGHT * LBS	18622.00	0.22
OMS HARDWARE WEIGHT * LBS	1011.90	0.18
TOTAL RCS WEIGHT * LBS	1373.00	0.29
RCS PROPELLANT WEIGHT * LBS	1814.30	0.48
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane, Methane-Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	330960.00	-18.31
GROSS LIFT OFF WEIGHT * LBS	3564200.00	12.52
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	167130.00	-30.86
BODY WEIGHT * LBS	78184.00	-30.16
GROWTH WEIGHT * LBS	9599.20	-29.15
INERT WEIGHT * LBS	198740.00	-28.41
EQUIPMENT WEIGHT * LBS	9690.00	-12.57
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	6957.70	-70.93
APU PROPELLANT WEIGHT * LBS	2359.60	-25.12
LANDING WEIGHT * LBS	172570.00	-30.51
FLYBACK SYSTEM INERT WEIGHT * LBS	19661.00	-32.99
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	11598.00	-27.49
FLYBACK SYSTEM WEIGHT * LBS	31287.00	-31.04
LANDING GEAR WEIGHT * LBS	4831.80	-30.51
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	29642.00	-29.98
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3103.60	3.97
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1896500.00	2.26
ORBITER DRY WEIGHT * LBS	163830.00	0.25
BODY WEIGHT * LBS	111980.00	0.30
GROWTH WEIGHT * LBS	9504.30	0.31
INERT WEIGHT * LBS	191170.00	0.35
EQUIPMENT WEIGHT * LBS	7043.50	0.46
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9007.20	-0.35
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121880.00	0.08
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane, Methane-Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.10	-28.02
NOMINAL LIFT OFF ACCELERATION	1.26	-9.55
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	5135.60	2.71
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	338.54	-22.65
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.88	11.70
BOOSTER LAUNCH MIXTURE RATIO	3.70	-38.33
DELIVERED THRUST AT IGNITION * LBS	648780.00	43.47
ENGINE RATED VACUUM THRUST * LBS	690740.00	39.71
NOMINAL FUEL TANK PRESSURE * PSIA	25.20	-28.33
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3300.00	0.92
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.89	0.30
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.26
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.66	-0.05
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane, Methane-Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	26.60	-19.38
VEHICLE LENGTH * FT	120.65	-19.38
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	46.56	-19.38
MAIN ENGINE THROAT DIAMETER * FT	0.93	9.70
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	5.02	-0.29
ENGINE SECTION LENGTH * FT	8.80	-24.18
NOZZLE EXPANSION RATIO	28.92	-17.38
FUEL LINE DIAMETER * IN	16.15	-12.15
OXIDIZER LINE DIAMETER * IN	20.80	8.10
FUEL TANK HEAD HEIGHT * IN	114.01	-18.56
CYLINDRICAL LENGTH OF FUEL TANK * IN	248.78	-51.20
OXIDIZER TANK HEAD HEIGHT * IN	113.66	-19.43
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	167.02	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.25	330.32
THICKNESS OF OXIDIZER TANK WALL * IN	0.23	388.81
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2662.80	-30.51
WING SPAN * FT	74.06	-16.64
SINGLE FIN EXPOSED AREA * SQ FT	129.21	-22.46
EXPOSED FIN SPAN * FT	13.40	-11.94
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	262.68	4.45
LENGTH/DIAMETER RATIO OF VEHICLE	7.96	4.45
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	0.02
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	749.30	2.74
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	47.88	15.06
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.05
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Methane, Methane-Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2792900.00	9.96
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1264700.00	22.15
FUEL WEIGHT IN BOOSTER * LBS	273320.00	84.79
OXIDIZER WEIGHT IN BOOSTER * LBS	991370.00	11.71
FUEL RESERVES * LBS	1175.30	84.79
OXIDIZER RESERVES * LBS	4262.90	11.71
FUEL RESIDUAL WEIGHT * LBS	178.86	128.30
OXIDIZER RESIDUAL WEIGHT * LBS	597.54	9.77
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	2377.10	434.56
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2088.60	-27.64
TOTAL TANK WEIGHT * LBS	5024.20	-61.93
FUEL TANK LINE WEIGHT * LBS	847.53	-58.96
OXIDIZER TANK LINE WEIGHT * LBS	235.32	16.94
FUEL TANK INSULATION WEIGHT * LBS	51.61	-98.50
OXIDIZER TANK INSULATION WEIGHT * LBS	1625.40	-11.35
GAS LINE WEIGHT * LBS	68.84	-34.67
ENGINE BAY LINE WEIGHT * LBS	369.20	-27.02
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	975.96	-8.10
WEIGHT OF EACH BOOSTER ENGINE * LBS	4912.30	-27.65
WEIGHT OF THRUST STRUCTURE * LBS	8510.80	-12.54
WEIGHT OF HYDROGEN COOLANT * LBS	18343.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	495.96	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	231.08	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	1509.40	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1509900.00	0.35
FUEL WEIGHT IN ORBITER * LBS	215710.00	0.35
OXIDIZER WEIGHT IN ORBITER * LBS	1294200.00	0.35
FUEL RESERVES * LBS	927.54	0.35
OXIDIZER RESERVES * LBS	5565.20	0.35
FUEL RESIDUAL WEIGHT * LBS	110.15	0.33
OXIDIZER RESIDUAL WEIGHT * LBS	751.47	0.30
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	604.47	0.35
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2933.30	0.01
TOTAL TANK WEIGHT * LBS	15376.00	0.30
FUEL TANK LINE WEIGHT * LBS	1388.00	0.06
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4208.80	0.20
OXIDIZER TANK INSULATION WEIGHT * LBS	1971.30	0.13
GAS LINE WEIGHT * LBS	99.25	0.23
ENGINE BAY LINE WEIGHT * LBS	293.63	0.00
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.52	0.00
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9456.00	0.03
TOTAL OMS PROPELLANT WEIGHT * LBS	18587.00	0.03
OMS HARDWARE WEIGHT * LBS	1010.40	0.03
TOTAL RCS WEIGHT * LBS	1369.60	0.04
RCS PROPELLANT WEIGHT * LBS	1806.70	0.06
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized LOX/Propane, LH_2-Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	326950.00	-19.30
GROSS LIFT OFF WEIGHT * LBS	3336700.00	5.34
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	163480.00	-32.37
BODY WEIGHT * LBS	75681.00	-32.40
GROWTH WEIGHT * LBS	9348.90	-30.99
INERT WEIGHT * LBS	193790.00	-30.20
EQUIPMENT WEIGHT * LBS	9844.10	-11.18
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	8836.70	-63.09
APU PROPELLANT WEIGHT * LBS	2281.20	-27.60
LANDING WEIGHT * LBS	170810.00	-31.22
FLYBACK SYSTEM INERT WEIGHT * LBS	19408.00	-33.85
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	9269.90	-42.05
FLYBACK SYSTEM WEIGHT * LBS	28700.00	-36.75
LANDING GEAR WEIGHT * LBS	4782.70	-31.21
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	28564.00	-32.52
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3019.40	1.15
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1860000.00	0.29
ORBITER DRY WEIGHT * LBS	163470.00	0.03
BODY WEIGHT * LBS	111680.00	0.04
GROWTH WEIGHT * LBS	9479.00	0.04
INERT WEIGHT * LBS	190590.00	0.04
EQUIPMENT WEIGHT * LBS	7015.40	0.06
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9034.50	-0.05
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121790.00	0.01
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized NBP LOX/Propane, LH_2-Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.18	-22.78
NOMINAL LIFT OFF ACCELERATION	1.32	-5.44
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4425.30	-11.49
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	328.03	-25.05
QUANTITY OF ENGINES	6.00	-14.29
PROPELLANT MASS FRACTION	0.86	8.60
BOOSTER LAUNCH MIXTURE RATIO	3.40	-43.33
DELIVERED THRUST AT IGNITION * LBS	524670.00	16.03
ENGINE RATED VACUUM THRUST * LBS	545710.00	10.38
NOMINAL FUEL TANK PRESSURE * PSIA	36.89	4.93
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	4000.00	22.32
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.01	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.89	-0.07
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.03
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.67	-0.01
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized NBP LOX/Propane LH_2-Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	29.58	-10.35
VEHICLE LENGTH * FT	134.17	-10.34
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	51.77	-10.35
MAIN ENGINE THROAT DIAMETER * FT	0.77	-10.02
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	3.56	-29.38
ENGINE SECTION LENGTH * FT	6.74	-41.89
NOZZLE EXPANSION RATIO	21.56	-38.40
FUEL LINE DIAMETER * IN	15.07	-18.03
OXIDIZER LINE DIAMETER * IN	20.58	6.97
FUEL TANK HEAD HEIGHT * IN	126.79	-9.43
CYLINDRICAL LENGTH OF FUEL TANK * IN	135.51	-73.42
OXIDIZER TANK HEAD HEIGHT * IN	126.43	-10.38
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	52.27	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.06	-4.97
THICKNESS OF OXIDIZER TANK WALL * IN	0.15	213.86
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2635.50	-31.23
WING SPAN * FT	73.68	-17.07
SINGLE FIN EXPOSED AREA * SQ FT	128.34	-22.98
EXPOSED FIN SPAN * FT	13.35	-12.24
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	260.78	3.69
LENGTH/DIAMETER RATIO OF VEHICLE	7.90	3.69
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	0.00
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	731.88	0.35
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	42.42	1.94
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.01
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized NBP LOX/Propane, LH_2-Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	3176600.00	25.06
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1527700.00	47.55
FUEL WEIGHT IN BOOSTER * LBS	373240.00	152.34
OXIDIZER WEIGHT IN BOOSTER * LBS	1154400.00	30.08
FUEL RESERVES * LBS	1604.90	152.34
OXIDIZER RESERVES * LBS	4964.10	30.08
FUEL RESIDUAL WEIGHT * LBS	232.10	196.26
OXIDIZER RESIDUAL WEIGHT * LBS	680.45	25.00
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	3060.60	588.27
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1616.20	-44.01
TOTAL TANK WEIGHT * LBS	16965.00	28.53
FUEL TANK LINE WEIGHT * LBS	1139.10	-44.84
OXIDIZER TANK LINE WEIGHT * LBS	269.32	33.84
FUEL TANK INSULATION WEIGHT * LBS	48.91	-98.58
OXIDIZER TANK INSULATION WEIGHT * LBS	1619.00	-11.70
GAS LINE WEIGHT * LBS	87.27	-17.19
ENGINE BAY LINE WEIGHT * LBS	465.33	-8.01
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1165.40	9.74
WEIGHT OF EACH BOOSTER ENGINE * LBS	6440.60	-5.15
WEIGHT OF THRUST STRUCTURE * LBS	7893.40	-18.88
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1648900.00	9.59
FUEL WEIGHT IN ORBITER * LBS	235560.00	9.59
OXIDIZER WEIGHT IN ORBITER * LBS	1413400.00	9.59
FUEL RESERVES * LBS	1012.90	9.59
OXIDIZER RESERVES * LBS	6077.50	9.59
FUEL RESIDUAL WEIGHT * LBS	119.35	8.71
OXIDIZER RESIDUAL WEIGHT * LBS	810.97	8.24
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	658.82	9.37
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2939.60	0.23
TOTAL TANK WEIGHT * LBS	16580.00	8.15
FUEL TANK LINE WEIGHT * LBS	1412.00	1.80
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4427.30	5.40
OXIDIZER TANK INSULATION WEIGHT * LBS	2039.80	3.61
GAS LINE WEIGHT * LBS	105.26	6.30
ENGINE BAY LINE WEIGHT * LBS	293.89	0.09
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.90	0.06
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9522.80	0.73
TOTAL OMS PROPELLANT WEIGHT * LBS	18722.00	0.75
OMS HARDWARE WEIGHT * LBS	1015.80	0.56
TOTAL RCS WEIGHT * LBS	1382.20	0.96
RCS PROPELLANT WEIGHT * LBS	1835.90	1.68
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized NBP LOX/Propane, Propane-Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	335460.00	-17.20
GROSS LIFT OFF WEIGHT * LBS	3731900.00	17.81
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	170590.00	-29.43
BODY WEIGHT * LBS	77198.00	-31.04
GROWTH WEIGHT * LBS	9654.80	-28.74
INERT WEIGHT * LBS	202910.00	-26.91
EQUIPMENT WEIGHT * LBS	9761.20	-11.93
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	7493.00	-68.70
APU PROPELLANT WEIGHT * LBS	2425.90	-23.01
LANDING WEIGHT * LBS	178240.00	-28.22
FLYBACK SYSTEM INERT WEIGHT * LBS	19408.00	-33.85
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	9271.20	-42.04
FLYBACK SYSTEM WEIGHT * LBS	28701.00	-36.74
LANDING GEAR WEIGHT * LBS	4990.60	-28.22
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	30813.00	-27.21
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3219.00	7.84
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	2001300.00	7.91
ORBITER DRY WEIGHT * LBS	164870.00	0.89
BODY WEIGHT * LBS	112840.00	1.07
GROWTH WEIGHT * LBS	9577.00	1.07
INERT WEIGHT * LBS	192830.00	1.22
EQUIPMENT WEIGHT * LBS	7124.20	1.61
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	8934.00	-1.16
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	122120.00	0.28
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized NBP LOX/Propane, Propane-Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.10	-28.02
NOMINAL LIFT OFF ACCELERATION	1.27	-9.19
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4280.90	-14.38
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	316.00	-27.80
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.88	11.94
BOOSTER LAUNCH MIXTURE RATIO	3.09	-48.45
DELIVERED THRUST AT IGNITION * LBS	694890.00	53.67
ENGINE RATED VACUUM THRUST * LBS	740560.00	49.79
NOMINAL FUEL TANK PRESSURE * PSIA	34.88	-0.78
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	2600.00	-20.49
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.90	1.09
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.90	0.86
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.62	-0.17
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized NBP LOX/Propane, Propane-Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	26.31	-20.28
VEHICLE LENGTH * FT	119.30	-20.28
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	46.04	-20.28
MAIN ENGINE THROAT DIAMETER * FT	1.10	28.87
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	5.24	4.03
ENGINE SECTION LENGTH * FT	9.07	-21.85
NOZZLE EXPANSION RATIO	22.81	-34.84
FUEL LINE DIAMETER * IN	17.35	-5.60
OXIDIZER LINE DIAMETER * IN	21.81	13.37
FUEL TANK HEAD HEIGHT * IN	112.74	-19.47
CYLINDRICAL LENGTH OF FUEL TANK * IN	234.03	-54.09
OXIDIZER TANK HEAD HEIGHT * IN	112.38	-20.34
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	175.70	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.21	254.12
THICKNESS OF OXIDIZER TANK WALL * IN	0.26	445.85
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2750.40	-28.23
WING SPAN * FT	75.27	-15.28
SINGLE FIN EXPOSED AREA * SQ FT	132.01	-20.78
EXPOSED FIN SPAN * FT	13.54	-10.99
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	268.15	6.62
LENGTH/DIAMETER RATIO OF VEHICLE	8.13	6.62
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.98	0.07
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	799.20	9.58
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	63.53	52.67
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.17
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME BASELINE

Two-Stage Optimized NBP LOX/Propane, Propane-Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2809400.00	10.61
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1282300.00	23.85
FUEL WEIGHT IN BOOSTER * LBS	276750.00	87.11
OXIDIZER WEIGHT IN BOOSTER * LBS	1005500.00	13.30
FUEL RESERVES * LBS	1190.00	87.10
OXIDIZER RESERVES * LBS	4323.70	13.30
FUEL RESIDUAL WEIGHT * LBS	186.85	138.50
OXIDIZER RESIDUAL WEIGHT * LBS	604.76	11.09
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	903.16	103.10
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1984.60	-31.25
TOTAL TANK WEIGHT * LBS	8899.90	-32.57
FUEL TANK LINE WEIGHT * LBS	777.74	-62.34
OXIDIZER TANK LINE WEIGHT * LBS	233.22	15.90
FUEL TANK INSULATION WEIGHT * LBS	48.34	-98.60
OXIDIZER TANK INSULATION WEIGHT * LBS	1612.40	-12.06
GAS LINE WEIGHT * LBS	67.25	-36.18
ENGINE BAY LINE WEIGHT * LBS	363.00	-28.24
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	935.54	-11.91
WEIGHT OF EACH BOOSTER ENGINE * LBS	5780.30	-14.87
WEIGHT OF THRUST STRUCTURE * LBS	7858.30	-19.24
WEIGHT OF HYDROGEN COOLANT * LBS	17594.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	474.65	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	224.74	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	1468.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1509600.00	0.33
FUEL WEIGHT IN ORBITER * LBS	215660.00	0.33
OXIDIZER WEIGHT IN ORBITER * LBS	1293900.00	0.33
FUEL RESERVES * LBS	927.33	0.33
OXIDIZER RESERVES * LBS	5564.00	0.33
FUEL RESIDUAL WEIGHT * LBS	110.12	0.30
OXIDIZER RESIDUAL WEIGHT * LBS	751.30	0.28
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	604.34	0.32
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2933.30	0.01
TOTAL TANK WEIGHT * LBS	15373.00	0.28
FUEL TANK LINE WEIGHT * LBS	1387.90	0.06
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4208.30	0.19
OXIDIZER TANK INSULATION WEIGHT * LBS	1971.10	0.12
GAS LINE WEIGHT * LBS	99.24	0.22
ENGINE BAY LINE WEIGHT * LBS	293.63	0.00
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.51	0.00
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9455.60	0.02
TOTAL OMS PROPELLANT WEIGHT * LBS	18587.00	0.03
OMS HARDWARE WEIGHT * LBS	1010.40	0.03
TOTAL RCS WEIGHT * LBS	1369.60	0.04
RCS PROPELLANT WEIGHT * LBS	1806.70	0.06
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, LH_2-Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	328750.00	-18.86
GROSS LIFT OFF WEIGHT * LBS	3353700.00	5.88
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	165280.00	-31.62
BODY WEIGHT * LBS	77980.00	-30.34
GROWTH WEIGHT * LBS	9514.60	-29.77
INERT WEIGHT * LBS	194240.00	-30.03
EQUIPMENT WEIGHT * LBS	9725.10	-12.25
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	8547.00	-64.30
APU PROPELLANT WEIGHT * LBS	2253.80	-28.47
LANDING WEIGHT * LBS	171030.00	-31.13
FLYBACK SYSTEM INERT WEIGHT * LBS	19442.00	-33.73
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	9580.30	-40.10
FLYBACK SYSTEM WEIGHT * LBS	29045.00	-35.98
LANDING GEAR WEIGHT * LBS	4788.90	-31.13
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	28732.00	-32.13
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3015.30	1.01
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1859600.00	0.27
ORBITER DRY WEIGHT * LBS	163470.00	0.03
BODY WEIGHT * LBS	111680.00	0.04
GROWTH WEIGHT * LBS	9478.70	0.04
INERT WEIGHT * LBS	190590.00	0.04
EQUIPMENT WEIGHT * LBS	7015.10	0.06
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9034.80	-0.04
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121790.00	0.01
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, LH_2-Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.14	-25.38
NOMINAL LIFT OFF ACCELERATION	1.31	-6.44
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4518.50	-9.63
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	330.02	-24.60
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.86	8.84
BOOSTER LAUNCH MIXTURE RATIO	3.42	-43.05
DELIVERED THRUST AT IGNITION * LBS	624760.00	38.16
ENGINE RATED VACUUM THRUST * LBS	653940.00	32.27
NOMINAL FUEL TANK PRESSURE * PSIA	20.17	-42.63
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	4000.00	22.32
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.01	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.89	-0.16
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.03
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.67	-0.01
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, LH_2-Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	29.08	-11.89
VEHICLE LENGTH * FT	131.87	-11.88
LENGTH/DIAMETER RATIO OF VEHICLE	4.53	0.00
NOSE LENGTH	50.88	-11.89
MAIN ENGINE THROAT DIAMETER * FT	0.84	-1.60
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	4.19	-16.84
ENGINE SECTION LENGTH * FT	7.68	-33.81
NOZZLE EXPANSION RATIO	25.00	-28.58
FUEL LINE DIAMETER * IN	14.26	-22.43
OXIDIZER LINE DIAMETER * IN	20.50	6.56
FUEL TANK HEAD HEIGHT * IN	124.61	-10.99
CYLINDRICAL LENGTH OF FUEL TANK * IN	114.04	-77.63
OXIDIZER TANK HEAD HEIGHT * IN	124.25	-11.92
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	66.20	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.24	315.76
THICKNESS OF OXIDIZER TANK WALL * IN	0.16	241.00
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2639.20	-31.13
WING SPAN * FT	73.73	-17.01
SINGLE FIN EXPOSED AREA * SQ FT	128.45	-22.91
EXPOSED FIN SPAN * FT	13.36	-12.20
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	260.76	3.68
LENGTH/DIAMETER RATIO OF VEHICLE	7.90	3.68
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	0.00
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	731.71	0.33
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	42.37	1.81
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.01
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, LH_2-Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	2987900.00	17.63
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1454500.00	40.48
FUEL WEIGHT IN BOOSTER * LBS	334170.00	125.93
OXIDIZER WEIGHT IN BOOSTER * LBS	1120400.00	26.25
FUEL RESERVES * LBS	1436.90	125.92
OXIDIZER RESERVES * LBS	4817.60	26.24
FUEL RESIDUAL WEIGHT * LBS	218.20	178.52
OXIDIZER RESIDUAL WEIGHT * LBS	663.11	21.81
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	946.00	112.74
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1565.00	-45.78
TOTAL TANK WEIGHT * LBS	19789.00	49.93
FUEL TANK LINE WEIGHT * LBS	1022.30	-50.50
OXIDIZER TANK LINE WEIGHT * LBS	283.78	41.02
FUEL TANK INSULATION WEIGHT * LBS	42.26	-98.77
OXIDIZER TANK INSULATION WEIGHT * LBS	1569.00	-14.43
GAS LINE WEIGHT * LBS	84.02	-20.27
ENGINE BAY LINE WEIGHT * LBS	456.16	-9.82
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1141.40	7.48
WEIGHT OF EACH BOOSTER ENGINE * LBS	6540.20	-3.68
WEIGHT OF THRUST STRUCTURE * LBS	7866.60	-19.16
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1533400.00	1.91
FUEL WEIGHT IN ORBITER * LBS	219050.00	1.91
OXIDIZER WEIGHT IN ORBITER * LBS	1314300.00	1.91
FUEL RESERVES * LBS	941.92	1.91
OXIDIZER RESERVES * LBS	5651.50	1.91
FUEL RESIDUAL WEIGHT * LBS	111.70	1.74
OXIDIZER RESIDUAL WEIGHT * LBS	761.57	1.65
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	613.64	1.87
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2934.40	0.05
TOTAL TANK WEIGHT * LBS	15579.00	1.62
FUEL TANK LINE WEIGHT * LBS	1392.00	0.35
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4245.70	1.08
OXIDIZER TANK INSULATION WEIGHT * LBS	1982.80	0.72
GAS LINE WEIGHT * LBS	100.26	1.25
ENGINE BAY LINE WEIGHT * LBS	293.67	0.02
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.58	0.01
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9467.50	0.15
TOTAL OMS PROPELLANT WEIGHT * LBS	18610.00	0.15
OMS HARDWARE WEIGHT * LBS	1011.30	0.12
TOTAL RCS WEIGHT * LBS	1371.60	0.19
RCS PROPELLANT WEIGHT * LBS	1811.60	0.33
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, Propane-Cooled (Near-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	335690.00	-17.14
GROSS LIFT OFF WEIGHT * LBS	3541100.00	11.79
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	171980.00	-28.85
BODY WEIGHT * LBS	78133.00	-30.21
GROWTH WEIGHT * LBS	9717.40	-28.27
INERT WEIGHT * LBS	202760.00	-26.96
EQUIPMENT WEIGHT * LBS	9664.00	-12.80
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	6603.50	-72.41
APU PROPELLANT WEIGHT * LBS	2433.20	-22.78
LANDING WEIGHT * LBS	177450.00	-28.54
FLYBACK SYSTEM INERT WEIGHT * LBS	19493.00	-33.56
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	10051.00	-37.16
FLYBACK SYSTEM WEIGHT * LBS	29568.00	-34.83
LANDING GEAR WEIGHT * LBS	4968.40	-28.54
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	30935.00	-26.92
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3215.30	7.71
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1883800.00	1.57
ORBITER DRY WEIGHT * LBS	163710.00	0.18
BODY WEIGHT * LBS	111880.00	0.21
GROWTH WEIGHT * LBS	9495.40	0.21
INERT WEIGHT * LBS	190970.00	0.24
EQUIPMENT WEIGHT * LBS	7033.70	0.32
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	9016.60	-0.24
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	121840.00	0.05
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, Propane-Cooled (Near-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.19	-22.35
NOMINAL LIFT OFF ACCELERATION	1.37	-1.85
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4624.80	-7.50
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	317.76	-27.40
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.88	11.30
BOOSTER LAUNCH MIXTURE RATIO	3.35	-44.12
DELIVERED THRUST AT IGNITION * LBS	719070.00	59.02
ENGINE RATED VACUUM THRUST * LBS	766010.00	54.94
NOMINAL FUEL TANK PRESSURE * PSIA	17.57	-50.03
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3300.00	0.92
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.90	1.46
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.89	0.18
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.67	-0.03
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, Propane-Cooled (Near-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	25.30	-23.33
VEHICLE LENGTH * FT	114.74	-23.33
LENGTH/DIAMETER RATIO OF VEHICLE	4.54	0.01
NOSE LENGTH	44.28	-23.33
MAIN ENGINE THROAT DIAMETER * FT	1.00	17.67
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	5.31	5.47
ENGINE SECTION LENGTH * FT	9.25	-20.30
NOZZLE EXPANSION RATIO	28.12	-19.66
FUEL LINE DIAMETER * IN	16.22	-11.74
OXIDIZER LINE DIAMETER * IN	22.31	15.96
FUEL TANK HEAD HEIGHT * IN	108.43	-22.54
CYLINDRICAL LENGTH OF FUEL TANK * IN	181.65	-64.37
OXIDIZER TANK HEAD HEIGHT * IN	108.07	-23.39
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	197.77	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.34	474.20
THICKNESS OF OXIDIZER TANK WALL * IN	0.28	496.32
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2738.20	-28.55
WING SPAN * FT	75.11	-15.47
SINGLE FIN EXPOSED AREA * SQ FT	131.62	-21.01
EXPOSED FIN SPAN * FT	13.52	-11.12
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	262.02	4.18
LENGTH/DIAMETER RATIO OF VEHICLE	7.94	4.18
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.97	0.01
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	743.22	1.91
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	45.98	10.48
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.03
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled Propane, Propane-Cooled (Near-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	3046000.00	19.92
FIRST STAGE		
PROPELLANT WT FOR ASCENT * LBS	1406500.00	35.84
FUEL WEIGHT IN BOOSTER * LBS	316920.00	114.27
OXIDIZER WEIGHT IN BOOSTER * LBS	1089600.00	22.78
FUEL RESERVES * LBS	1362.80	114.27
OXIDIZER RESERVES * LBS	4685.20	22.77
FUEL RESIDUAL WEIGHT * LBS	208.83	166.56
OXIDIZER RESIDUAL WEIGHT * LBS	647.48	18.94
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	893.45	100.92
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1522.20	-47.27
TOTAL TANK WEIGHT * LBS	19195.00	45.43
FUEL TANK LINE WEIGHT * LBS	957.02	-53.66
OXIDIZER TANK LINE WEIGHT * LBS	265.65	32.01
FUEL TANK INSULATION WEIGHT * LBS	40.68	-98.82
OXIDIZER TANK INSULATION WEIGHT * LBS	1533.90	-16.34
GAS LINE WEIGHT * LBS	81.78	-22.40
ENGINE BAY LINE WEIGHT * LBS	423.36	-16.31
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	1069.80	0.73
WEIGHT OF EACH BOOSTER ENGINE * LBS	6251.90	-7.92
WEIGHT OF THRUST STRUCTURE * LBS	7565.30	-22.25
WEIGHT OF HYDROGEN COOLANT * LBS	0.00	N/A
HYDROGEN COOLANT FEED SYSTEM WEIGHT * LBS	0.00	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	0.00	N/A
WEIGHT OF HYDROGEN COOLANT TANK * LBS	0.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
SECOND STAGE		
PROPELLANT WT FOR ASCENT * LBS	1639500.00	8.97
FUEL WEIGHT IN ORBITER * LBS	234220.00	8.96
OXIDIZER WEIGHT IN ORBITER * LBS	1405300.00	8.96
FUEL RESERVES * LBS	1007.10	8.96
OXIDIZER RESERVES * LBS	6042.80	8.96
FUEL RESIDUAL WEIGHT * LBS	118.73	8.14
OXIDIZER RESIDUAL WEIGHT * LBS	806.96	7.71
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	655.14	8.76
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	2939.20	0.21
TOTAL TANK WEIGHT * LBS	16499.00	7.63
FUEL TANK LINE WEIGHT * LBS	1410.40	1.68
OXIDIZER TANK LINE WEIGHT * LBS	107.16	0.00
FUEL TANK INSULATION WEIGHT * LBS	4412.50	5.05
OXIDIZER TANK INSULATION WEIGHT * LBS	2035.20	3.38
GAS LINE WEIGHT * LBS	104.85	5.89
ENGINE BAY LINE WEIGHT * LBS	293.87	0.09
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	615.87	0.06
WEIGHT OF EACH ORBITER ENGINE * LBS	7000.00	0.00
WEIGHT OF THRUST STRUCTURE * LBS	6022.50	0.00
OMS PROPELLANT REQUIRED FOR CIR.	9518.40	0.69
TOTAL OMS PROPELLANT WEIGHT * LBS	18713.00	0.70
OMS HARDWARE WEIGHT * LBS	1015.40	0.52
TOTAL RCS WEIGHT * LBS	1381.30	0.90
RCS PROPELLANT WEIGHT * LBS	1833.90	1.57
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled LOX-Propane, Propane-Cooled (Far-Term) Propulsion Weights

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	331490.00	-18.18
GROSS LIFT OFF WEIGHT * LBS	3593600.00	13.45
FIRST STAGE		
BOOSTER DRY WEIGHT * LBS	166720.00	-31.03
BODY WEIGHT * LBS	76050.00	-32.07
GROWTH WEIGHT * LBS	9450.40	-30.25
INERT WEIGHT * LBS	195380.00	-29.62
EQUIPMENT WEIGHT * LBS	9538.70	-13.93
TANK MOUNT WEIGHT * LBS	0.00	-100.00
STRUCTURAL WALL WEIGHT * LBS	6446.80	-73.07
APU PROPELLANT WEIGHT * LBS	2353.80	-25.30
LANDING WEIGHT * LBS	171960.00	-30.75
FLYBACK SYSTEM INERT WEIGHT * LBS	19333.00	-34.10
FIRST VEHICLE FLYBACK FUEL WT INCLUDING RESERVES *	8582.40	-46.34
FLYBACK SYSTEM WEIGHT * LBS	27936.00	-38.43
LANDING GEAR WEIGHT * LBS	4814.70	-30.75
CANARD WEIGHT * LBS	0.00	N/A
WING WEIGHT * LBS	30002.00	-29.13
WEIGHT OF FIRST STAGE TPS * LBS	0.00	N/A
WEIGHT OF VEHICLE SUPPORT STRUCTURE * LBS	3186.70	6.75
SECOND STAGE		
LIFT OFF WEIGHT OF ORBITER * LBS	1991700.00	7.39
ORBITER DRY WEIGHT * LBS	164780.00	0.83
BODY WEIGHT * LBS	112760.00	1.00
GROWTH WEIGHT * LBS	9570.30	1.00
INERT WEIGHT * LBS	192670.00	1.13
EQUIPMENT WEIGHT * LBS	7116.80	1.51
TANK MOUNT WEIGHT * LBS	0.00	N/A
STRUCTURAL WALL WEIGHT * LBS	8940.40	-1.09
APU PROPELLANT WEIGHT * LBS	445.24	0.00
PROPULSION/AVIONICS MODULE RECOVERY SYSTEM WEIGHT	43208.00	0.00
WEIGHT OF PROPULSION/AVIONICS MODULE	122100.00	0.26
WEIGHT OF REENTRY INSULATION TILES * LBS	3198.80	0.00
PAYLOAD WEIGHT * LBS	150000.00	0.00
PAYLOAD BAY WEIGHT * LBS	25000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled LOX-Propane, Propane-Cooled (Far-Term) System Weights

	VALUE	PERCENT OF *REFERENCE
MINIMUM LIFTOFF ACCELERATION * G'S	1.14	-25.28
NOMINAL LIFT OFF ACCELERATION	1.32	-5.74
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	0.00	N/A
INERT WEIGHT FACTOR	1.00	0.00
STAGING VELOCITY * FPS	4180.60	-16.39
FIRST STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	324.55	-25.85
QUANTITY OF ENGINES	5.00	-28.57
PROPELLANT MASS FRACTION	0.88	11.35
BOOSTER LAUNCH MIXTURE RATIO	3.44	-42.70
DELIVERED THRUST AT IGNITION * LBS	694400.00	53.56
ENGINE RATED VACUUM THRUST * LBS	734680.00	48.60
NOMINAL FUEL TANK PRESSURE * PSIA	17,49	-50.24
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3900.00	19.27
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.00	N/A
NUMBER OF FIRST VEHICLE FLYBACK TURBOFAN ENGINES	2.00	-33.33
THROTTLE SETTING OF 1ST STAGE ENGINES	0.90	1.08
SECOND STAGE		
AVERAGE MAIN ENGINE SPECIFIC IMPULSE	453.52	0.00
QUANTITY OF ENGINES	4.00	0.00
PROPELLANT MASS FRACTION	0.90	0.80
OVERALL PROPELLANT MIXTURE RATIO	6.00	0.00
DELIVERED THRUST AT IGNITION * LBS	512300.00	0.00
ENGINE RATED VACUUM THRUST * LBS	512300.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	32.63	-0.15
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
MAXIMUM CHAMBER PRESSURE USED ON VEHICLE * PSIA	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
THRUST OF SECOND VEHICLE AT LIFTOFF	1675400.00	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Subcooled LOX/Propane, Propane-Cooled (Far-Term) Performance

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	80.00	0.00
PAYLOAD DIAMETER * FT	33.00	0.00
FIRST STAGE		
BODY DIAMETER * FT	24.80	-24.85
VEHICLE LENGTH * FT	112.47	-24.84
LENGTH/DIAMETER RATIO OF VEHICLE	4.54	0.01
NOSE LENGTH	43.40	-24.85
MAIN ENGINE THROAT DIAMETER * FT	0.90	6.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	4.92	-2.30
ENGINE SECTION LENGTH * FT	8.74	-24.63
NOZZLE EXPANSION RATIO	29.73	-15.06
FUEL LINE DIAMETER * IN	15.59	-15.20
OXIDIZER LINE DIAMETER * IN	21.69	12.71
FUEL TANK HEAD HEIGHT * IN	106.28	-24.08
CYLINDRICAL LENGTH OF FUEL TANK * IN	179.29	-64.83
OXIDIZER TANK HEAD HEIGHT * IN	105.92	-24.92
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	204.81	1.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.33	462.68
THICKNESS OF OXIDIZER TANK WALL * IN	0.28	483.50
FUEL TANK SOFI THICKNESS * IN	0.00	-100.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2653.20	-30.76
WING SPAN * FT	73.93	-16.79
SINGLE FIN EXPOSED AREA * SQ FT	128.90	-22.64
EXPOSED FIN SPAN * FT	13.38	-12.04
CANARD WING SPAN * FT	0.00	N/A
SECOND STAGE		
BODY DIAMETER * FT	33.00	0.00
VEHICLE LENGTH * FT	267.65	6.42
LENGTH/DIAMETER RATIO OF VEHICLE	8.11	6.42
NOSE LENGTH	57.75	0.00
MAIN ENGINE THROAT DIAMETER * FT	0.85	0.00
MAXIMUM MAIN ENGINE NOZZLE EXIT DIAMETER * FT	7.50	0.00
ENGINE SECTION LENGTH * FT	11.60	0.00
NOZZLE EXPANSION RATIO	77.50	0.00
FUEL LINE DIAMETER * IN	13.98	0.06
OXIDIZER LINE DIAMETER * IN	14.67	0.00
PROPELLANT TANK HEAD ELLIPSE RATIO	1.40	0.00
FUEL TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	794.64	8.96
OXIDIZER TANK HEAD HEIGHT * IN	141.07	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	62.10	49.23
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	-0.15
THICKNESS OF OXIDIZER TANK WALL * IN	0.05	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00

*TO THE SSME POWERED BASELINE

Two-Stage Optimized Optimized Subcooled LOX-Propane, Propane-Cooled (Far-Term) Dimensions

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	141020.00	34.70
GROSS LIFT OFF WEIGHT	1460000.00	21.92
BODY WEIGHT * LBS	83074.00	34.82
GROWTH WEIGHT * LBS	7278.70	29.24
INERT WEIGHT * LBS	165410.00	33.40
EQUIPMENT WEIGHT * LBS	12339.00	10.90
TANK MOUNT WEIGHT * LBS	846.34	67.17
STRUCTURAL WALL WEIGHT * LBS	61537.00	40.65
APU PROPELLANT WEIGHT * LBS	2913.20	28.45
LANDING WEIGHT * LBS	144810.00	34.73
LANDING GEAR WEIGHT * LBS	4407.70	31.68
CANARD WEIGHT * LBS	1966.50	34.73
WING WEIGHT * LBS	24193.00	32.84
WEIGHT OF REENTRY INSULATION TILES * LBS	9702.30	26.45
PAYLOAD WEIGHT * LBS	10000.00	0.00
PAYLOAD BAY WEIGHT * LBS	6704.40	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE SSME POINT DESIGN
PROPULSION WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	1283000.00	20.78
FUEL WEIGHT IN VEHICLE * LBS	183290.00	48.38
WEIGHT OF HYDROGEN USED AS FUEL	0.00	N/A
OXIDIZER WEIGHT IN VEHICLE * LBS	1099700.00	17.14
FUEL RESERVES * LBS	788.13	48.38
OXIDIZER RESERVES * LBS	4728.80	17.14
FUEL RESIDUAL WEIGHT * LBS	95.03	42.49
OXIDIZER RESIDUAL WEIGHT * LBS	652.82	14.51
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	534.46	48.90
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1978.70	49.56
TOTAL TANK WEIGHT * LBS	14529.00	27.16
FUEL TANK LINE WEIGHT * LBS	1590.60	34.75
OXIDIZER TANK LINE WEIGHT * LBS	136.04	26.47
FUEL TANK INSULATION WEIGHT * LBS	3708.90	30.56
OXIDIZER TANK INSULATION WEIGHT * LBS	1668.20	19.72
GAS LINE WEIGHT * LBS	113.78	16.53
ENGINE BAY LINE WEIGHT PER ENGINE * LBS	362.00	46.20
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	759.47	35.37
WEIGHT OF SSME	7393.00	53.82
WEIGHT OF THRUST STRUCTURE * LBS	6197.30	31.32
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
OMS PROPELLANT REQUIRED FOR CIR.	1574.10	30.84
TOTAL OMS PROPELLANT WEIGHT * LBS	5796.00	32.66
OMS HARDWARE WEIGHT * LBS	1053.20	19.65
TOTAL RCS WEIGHT * LBS	2261.80	21.54
RCS PROPELLANT WEIGHT * LBS	2916.80	33.02
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE SSME POINT DESIGN
SYSTEM WEIGHTS

	VALUE	PERCENT OF *REFERENCE
LIFT OFF ACCEL., ONE ENGINE OUT	1.50	25.00
NOMINAL LIFT OFF ACCELERATION	1.48	0.00
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	2.00	0.00
INERT WEIGHT FACTOR	0.75	0.00
PRIMARY ENGINE VACUUM ISP	447.60	5.22
NUMBER OF PRIMARY ENGINES	5.00	0.00
PROPELLANT MASS FRACTION	0.89	-1.08
PRIMARY ENGINE MIXTURE RATIO	6.00	-21.05
PRIMARY ENGINE LIFT OFF THRUST	438000.00	21.92
PRIMARY ENGINE VACUUM THRUST 1ST NOZZLE	504120.00	32.16
NOMINAL FUEL TANK PRESSURE * PSIA	34.13	0.35
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
ENGINE RATED CHAMBER PRESSURE * PSI	3270.00	-18.25
ENGINE RATED CHAMBER PRESSURE * PSI	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
LIFTOFF THROTTLE SETTING OF PRIMARY ENGINE	0.91	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE SSME POINT DESIGN
PERFORMANCE

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	30.00	0.00
PAYLOAD BAY DIAMETER * FT	15.00	0.00
BODY DIAMETER * FT	29.00	20.83
VEHICLE LENGTH * FT	154.75	4.07
LENGTH/DIAMETER RATIO OF VEHICLE	5.34	-13,88
NOSE LENGTH	36.25	20.83
PRIMARY ENGINE THROAT DIAMETER	0.85	27.50
MAX. PRIMARY ENGINE NOZZLE EXIT DIA.	10.42	56.33
PRIMARY ENGINE LENGTH	11.60	0.00
PRIMARY ENGINE FIRST EXPANSION RATIO	55.00	83.33
PRIMARY ENGINE SECOND EXPANSION RATIO	150.00	50.32
FUEL LINE DIAMETER * IN	15.56	23.71
OXIDIZER LINE DIAMETER * IN	16.25	10.64
FUEL TANK HEAD HEIGHT * IN	122.90	21.06
CYLINDRICAL LENGTH OF FUEL TANK * IN	819.10	1.26
OXIDIZER TANK HEAD HEIGHT * IN	123.92	20.91
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	88.61	-50.75
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.05	21.50
THICKNESS OF OXIDIZER TANK WALL * IN	0.04	-31.55
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	2413.50	34.73
WING SPAN * FT	67.85	16.08
TOTAL FIN EXPOSED AREA * SQ FT	115.51	18.99
EXPOSED FIN SPAN * FT	12.67	9.09
CANARD WING SPAN * FT	18.91	16.08

*OPTIMIZED LOX/LH2

SINGLE STAGE SSME POINT DESIGN
DIMENSIONS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	1062300.00	0.00
FUEL WEIGHT IN VEHICLE * LBS	123530.00	0.00
WEIGHT OF HYDROGEN USED AS FUEL	0.00	N/A
OXIDIZER WEIGHT IN VEHICLE * LBS	938800.00	0.00
FUEL RESERVES * LBS	531.16	0.00
OXIDIZER RESERVES * LBS	4036.80	0.00
FUEL RESIDUAL WEIGHT * LBS	66.69	0.00
OXIDIZER RESIDUAL WEIGHT * LBS	570.11	0.00
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	358.94	0.00
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1323.00	0.00
TOTAL TANK WEIGHT * LBS	11426.00	0.00
FUEL TANK LINE WEIGHT * LBS	1180.40	0.00
OXIDIZER TANK LINE WEIGHT * LBS	107.57	0.00
FUEL TANK INSULATION WEIGHT * LBS	2840.70	0.00
OXIDIZER TANK INSULATION WEIGHT * LBS	1393.40	0.00
GAS LINE WEIGHT * LBS	97.64	0.00
ENGINE BAY LINE WEIGHT PER ENGINE * LBS	247.61	0.00
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	561.05	0.00
WEIGHT OF SSME	4806.20	0.00
WEIGHT OF THRUST STRUCTURE * LBS	4719.10	0.00
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
OMS PROPELLANT REQUIRED FOR CIR.	1203.10	0.00
TOTAL OMS PROPELLANT WEIGHT * LBS	4369.10	0.00
OMS HARDWARE WEIGHT * LBS	880.27	0.00
TOTAL RCS WEIGHT * LBS	1861.00	0.00
RCS PROPELLANT WEIGHT * LBS	2192.80	0.00
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*SELF

SINGLE STAGE OPTIMIZED LOX/LH2 (NEAR TERM)
PROPULSION WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	104690.00	0.00
GROSS LIFT OFF WEIGHT	1197500.00	0.00
BODY WEIGHT * LBS	61619.00	0.00
GROWTH WEIGHT * LBS	5631.90	0.00
INERT WEIGHT * LBS	124000.00	0.00
EQUIPMENT WEIGHT * LBS	11126.00	0.00
TANK MOUNT WEIGHT * LBS	506.28	0.00
STRUCTURAL WALL WEIGHT * LBS	43752.00	0.00
APU PROPELLANT WEIGHT * LBS	2268.00	0.00
LANDING WEIGHT * LBS	107480.00	0.00
LANDING GEAR WEIGHT * LBS	3347.20	0.00
CANARD WEIGHT * LBS	1459.60	0.00
WING WEIGHT * LBS	18212.00	0.00
WEIGHT OF REENTRY INSULATION TILES * LBS	7672.60	0.00
PAYLOAD WEIGHT * LBS	10000.00	0.00
PAYLOAD BAY WEIGHT * LBS	6704.40	0.00

*SELF

SINGLE STAGE OPTIMIZED LOX/LH2 (NEAR TERM)
SYSTEM WEIGHTS

	VALUE	PERCENT OF *REFERENCE
LIFT OFF ACCEL., ONE ENGINE OUT	1.20	0.00
NOMINAL LIFT OFF ACCELERATION	1.48	0.00
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	2.00	0.00
INERT WEIGHT FACTOR	0.75	0.00
PRIMARY ENGINE VACUUM ISP	425.41	0.00
NUMBER OF PRIMARY ENGINES	5.00	0.00
PROPELLANT MASS FRACTION	0.90	0.00
PRIMARY ENGINE MIXTURE RATIO	7.60	0.00
PRIMARY ENGINE LIFT OFF THRUST	359260.00	0.00
PRIMARY ENGINE VACUUM THRUST 1ST NOZZLE	381440.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	34.01	0.00
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
ENGINE RATED CHAMBER PRESSURE * PSI	4000.00	0.00
ENGINE RATED CHAMBER PRESSURE * PSI	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
LIFTOFF THROTTLE SETTING OF PRIMARY ENGINE	0.91	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*SELF

SINGLE STAGE OPTIMIZED LOX/LH2 (NEAR TERM)
PERFORMANCE

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	30.00	0.00
PAYLOAD DIAMETER * FT	15.00	0.00
BODY DIAMETER * FT	24.00	0.00
VEHICLE LENGTH * FT	148.70	0.00
LENGTH/DIAMETER RATIO OF VEHICLE	6.20	0.00
NOSE LENGTH	30.00	0.00
PRIMARY ENGINE THROAT DIAMETER	0.67	0.00
MAX. PRIMARY ENGINE NOZZLE EXIT DIA.	6.66	0.00
PRIMARY ENGINE LENGTH	11.60	0.00
PRIMARY ENGINE FIRST EXPANSION RATIO	30.00	0.00
PRIMARY ENGINE SECOND EXPANSION RATIO	99.78	0.00
FUEL LINE DIAMETER * IN	12.58	0.00
OXIDIZER LINE DIAMETER * IN	14.69	0.00
FUEL TANK HEAD HEIGHT * IN	101.52	0.00
CYLINDRICAL LENGTH OF FUEL TANK * IN	808.93	0.00
OXIDIZER TANK HEAD HEIGHT * IN	102.49	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	179.93	0.00
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.04	0.00
THICKNESS OF OXIDIZER TANK WALL * IN	0.06	0.00
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	1791.30	0.00
WING SPAN * FT	58.45	0.00
TOTAL FIN EXPOSED AREA * SQ FT	97.07	0.00
EXPOSED FIN SPAN * FT	11.61	0.00
CANARD WING SPAN * FT	16.29	0.00

*SELF

SINGLE STAGE OPTIMIZED LOX/LH2 (NEAR TERM)
DIMENSIONS

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	102080.00	-2.49
GROSS LIFT OFF WEIGHT	1263600.00	5.52
BODY WEIGHT * LBS	58968.00	-4.30
GROWTH WEIGHT * LBS	5113.50	-9.20
INERT WEIGHT * LBS	122530.00	-1.19
EQUIPMENT WEIGHT * LBS	10397.00	-6.55
TANK MOUNT WEIGHT * LBS	414.25	-18.18
STRUCTURAL WALL WEIGHT * LBS	4300.70	-90.17
APU PROPELLANT WEIGHT * LBS	1735.00	-23.50
LANDING WEIGHT * LBS	105960.00	-1.41
LANDING GEAR WEIGHT * LBS	3299.50	-1.43
CANARD WEIGHT * LBS	1439.00	-1.41
WING WEIGHT * LBS	17924.00	-1.58
WEIGHT OF REENTRY INSULATION TILES * LBS	5002.50	-34.80
PAYLOAD WEIGHT * LBS	10000.00	0.00
PAYLOAD BAY WEIGHT * LBS	6704.40	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/RP-1, LH2 COOLED (NEAR TERM)
SYSTEM WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	1130300.00	6.40
FUEL WEIGHT IN VEHICLE * LBS	95640.00	-22.58
WEIGHT OF HYDROGEN USED AS FUEL	105710.00	N/A
OXIDIZER WEIGHT IN VEHICLE * LBS	924020.00	-1.57
FUEL RESERVES * LBS	411.25	-22.58
OXIDIZER RESERVES * LBS	3973.30	-1.57
FUEL RESIDUAL WEIGHT * LBS	176.91	165.26
OXIDIZER RESIDUAL WEIGHT * LBS	480.72	-15.68
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	2196.00	511.80
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1121.00	-15.27
TOTAL TANK WEIGHT * LBS	6166.30	-46.03
FUEL TANK LINE WEIGHT * LBS	617.05	-47.73
OXIDIZER TANK LINE WEIGHT * LBS	148.57	38.11
FUEL TANK INSULATION WEIGHT * LBS	1286.40	-54.72
OXIDIZER TANK INSULATION WEIGHT * LBS	1258.70	-9.67
GAS LINE WEIGHT * LBS	53.88	-44.82
ENGINE BAY LINE WEIGHT PER ENGINE * LBS	243.59	-1.62
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	665.68	18.65
WEIGHT OF HYDROCARBON ENGINE	3058.00	-36.37
WEIGHT OF SSME	7393.00	N/A
WEIGHT OF THRUST STRUCTURE * LBS	5040.50	6.81
WEIGHT OF HYDROGEN COOLANT * LBS	4981.90	N/A
LH2 FUEL+COOLANT FEED SYSTEM WEIGHT * LBS	750.30	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	604.13	N/A
WEIGHT OF LH2 FUEL+COOLANT TANK * LBS	3775.00	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
OMS PROPELLANT REQUIRED FOR CIR.	1190.50	-1.05
TOTAL OMS PROPELLANT WEIGHT * LBS	4317.90	-1.17
OMS HARDWARE WEIGHT * LBS	797.62	-9.39
TOTAL RCS WEIGHT * LBS	1770.30	-4.87
RCS PROPELLANT WEIGHT * LBS	2206.10	0.61
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/RP-1, LH2 COOLED (NEAR TERM)
PROPULSION WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	100040.00	-4.44
GROSS LIFT OFF WEIGHT	1168200.00	-2.45
BODY WEIGHT * LBS	58244.00	-5.48
GROWTH WEIGHT * LBS	5076.80	-9.86
INERT WEIGHT * LBS	118220.00	-4.66
EQUIPMENT WEIGHT * LBS	10381.00	-6.70
TANK MOUNT WEIGHT * LBS	414.31	-18.17
STRUCTURAL WALL WEIGHT * LBS	3658.10	-91.64
APU PROPELLANT WEIGHT * LBS	1676.30	-26.09
LANDING WEIGHT * LBS	102480.00	-4.65
LANDING GEAR WEIGHT * LBS	3201.40	-4.36
CANARD WEIGHT * LBS	1391.70	-4.65
WING WEIGHT * LBS	17271.00	-5.17
WEIGHT OF REENTRY INSULATION TILES * LBS	5023.80	-34.52
PAYLOAD WEIGHT * LBS	10000.00	0.00
PAYLOAD BAY WEIGHT * LBS	6704.40	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/METHANE, LH2 COOLED (NEAR TERM)
SYSTEM WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	1039200.00	-2.17
FUEL WEIGHT IN VEHICLE * LBS	53865.00	-56.40
WEIGHT OF HYDROGEN USED AS FUEL	107780.00	N/A
OXIDIZER WEIGHT IN VEHICLE * LBS	872340.00	-7.08
FUEL RESERVES * LBS	231.62	-56.39
OXIDIZER RESERVES * LBS	3751.10	-7.08
FUEL RESIDUAL WEIGHT * LBS	119.12	78.61
OXIDIZER RESIDUAL WEIGHT * LBS	470.70	-17.44
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	381.13	6.18
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1120.30	-15.32
TOTAL TANK WEIGHT * LBS	5897.70	-48.38
FUEL TANK LINE WEIGHT * LBS	578.60	-50.98
OXIDIZER TANK LINE WEIGHT * LBS	143.02	32.96
FUEL TANK INSULATION WEIGHT * LBS	1367.10	-51.87
OXIDIZER TANK INSULATION WEIGHT * LBS	1243.30	-10.77
GAS LINE WEIGHT * LBS	54.36	-44.33
ENGINE BAY LINE WEIGHT PER ENGINE * LBS	230.63	-6.86
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	634.44	13.08
WEIGHT OF HYDROCARBON ENGINE	2526.10	-47.44
WEIGHT OF SSME	7393.00	N/A
WEIGHT OF THRUST STRUCTURE * LBS	4840.20	2.57
WEIGHT OF HYDROGEN COOLANT * LBS	5301.20	N/A
LH2 FUEL+COOLANT FEED SYSTEM WEIGHT * LBS	781.34	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	620.87	N/A
WEIGHT OF LH2 FUEL+COOLANT TANK * LBS	3873.90	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
OMS PROPELLANT REQUIRED FOR CIR.	1151.80	-4.26
TOTAL OMS PROPELLANT WEIGHT * LBS	4169.10	-4.58
OMS HARDWARE WEIGHT * LBS	779.62	-11.43
TOTAL RCS WEIGHT * LBS	1731.20	-6.97
RCS PROPELLANT WEIGHT * LBS	2136.20	-2.58
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/METHANE, LH2 COOLED (NEAR TERM)
PROPULSION WEIGHTS

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	VALUE	PERCENT OF *REFERENCE
LIFT OFF ACCEL., ONE ENGINE OUT	1.22	1.51
NOMINAL LIFT OFF ACCELERATION	1.48	0.00
MAXIMUM LONGITUDINAL ACCELERATION • G'S	3.00	0.00
NUMBER OF CREW	2.00	0.00
INERT WEIGHT FACTOR	0.75	0.00
PRIMARY ENGINE VACUUM ISP	328.62	-22.75
NUMBER OF PRIMARY ENGINES	2.00	-60.00
NUMBER OF SSME ENGINES	3.00	N/A
PROPELLANT MASS FRACTION	0.89	-0.20
PRIMARY ENGINE MIXTURE RATIO	4.19	-44.87
SSME MIXTURE RATIO	6.00	0.00
PRIMARY ENGINE LIFT OFF THRUST	273470.00	-23.88
SSME LIFT OFF THRUST	504130.00	0.00
PRIMARY ENGINE VACUUM THRUST 1ST NOZZLE	280620.00	-26.43
SSME VACUUM THRUST	504130.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	20.57	-39.50
NOMINAL OXIDIZER TANK PRESSURE • PSIA	28.19	0.00
ENGINE RATED CHAMBER PRESSURE • PSI	4300.00	7.50
ENGINE RATED CHAMBER PRESSURE • PSI	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE • PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE • PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.02	N/A
LIFTOFF THROTTLE SETTING OF PRIMARY ENGINE	0.91	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/METHANE, LH2 COOLED (NEAR TERM)
PERFORMANCE

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH • FT	30.00	0.00
PAYLOAD BAY DIAMETER • FT	15.00	0.00
BODY DIAMETER * FT	24.00	0.00
VEHICLE LENGTH * FT	139.99	-5.86
LENGTH/DIAMETER RATIO OF VEHICLE	5.83	-5.86
NOSE LENGTH	75.03	150.09
PRIMARY ENGINE THROAT DIAMETER	0.54	-19.73
SSME THROAT DIAMETER	0.85	N/A
MAX. PRIMARY ENGINE NOZZLE EXIT DIA.	2.07	-68.88
SSME NOZZLE EXIT DIA.	10.42	N/A
PRIMARY ENGINE LENGTH	4.59	-60.42
SSME LENGTH	11.60	-36.44
PRIMARY ENGINE FIRST EXPANSION RATIO	15.00	-50.00
PRIMARY ENGINE SECOND EXPANSION RATIO	15.00	-84.97
SSME EXPANSION RATIO	55.00	N/A
FUEL LINE DIAMETER * IN	12.13	-3.58
OXIDIZER LINE DIAMETER * IN	16.61	13.05
FUEL TANK HEAD HEIGHT * IN	101.50	-0.02
CYLINDRICAL LENGTH OF FUEL TANK • IN	178.38	-77.95
OXIDIZER TANK HEAD HEIGHT • IN	102.49	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK • IN	116.29	-35.37
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS • IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.03	-26.99
THICKNESS OF OXIDIZER TANK WALL • IN	0.11	73.00
FUEL TANK SOFI THICKNESS • IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS • IN	1.00	0.00
WING REFERENCE AREA * SQ FT	1708.00	-4.65
WING SPAN * FT	57.08	-2.35
TOTAL FIN EXPOSED AREA • SQ FT	94.61	-2.54
EXPOSED FIN SPAN • FT	11.46	-1.28
CANARD WING SPAN * FT	15.91	-2.35

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/METHANE, LH2 COOLED (NEAR TERM)
DIMENSIONS

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	99216.00	-5.23
GROSS LIFT OFF WEIGHT	1157400.00	-3.35
BODY WEIGHT * LBS	57708.00	-6.35
GROWTH WEIGHT * LBS	5012.60	-11.00
INERT WEIGHT * LBS	117280.00	-5.42
EQUIPMENT WEIGHT * LBS	10302.00	-7.41
TANK MOUNT WEIGHT * LBS	414.31	-18.17
STRUCTURAL WALL WEIGHT * LBS	3689.00	-91.57
APU PROPELLANT WEIGHT * LBS	1678.20	-26.01
LANDING WEIGHT * LBS	101630.00	-5.44
LANDING GEAR WEIGHT * LBS	3177.00	-5.08
CANARD WEIGHT * LBS	1380.10	-5.45
WING WEIGHT * LBS	17111.00	-6.05
WEIGHT OF REENTRY INSULATION TILES * LBS	4816.10	-37.23
PAYLOAD WEIGHT * LBS	10000.00	0.00
PAYLOAD BAY WEIGHT * LBS	6704.40	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/SC PROPANE, LH2 COOLED (NEAR TERM)
SYSTEM WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	1029400.00	-3.10
FUEL WEIGHT IN VEHICLE * LBS	56493.00	-54.27
WEIGHT OF HYDROGEN USED AS FUEL	109480.00	N/A
OXIDIZER WEIGHT IN VEHICLE * LBS	859670.00	-8.43
FUEL RESERVES * LBS	242.92	-54.27
OXIDIZER RESERVES * LBS	3696.60	-8.43
FUEL RESIDUAL WEIGHT * LBS	142.83	114.16
OXIDIZER RESIDUAL WEIGHT * LBS	454.25	-20.32
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	344.04	-4.15
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1119.20	-15.40
TOTAL TANK WEIGHT * LBS	5335.70	-53.30
FUEL TANK LINE WEIGHT * LBS	541.78	-54.10
OXIDIZER TANK LINE WEIGHT * LBS	143.78	33.66
FUEL TANK INSULATION WEIGHT * LBS	1237.60	-56.43
OXIDIZER TANK INSULATION WEIGHT * LBS	1218.60	-12.54
GAS LINE WEIGHT * LBS	49.83	-48.96
ENGINE BAY LINE WEIGHT PER ENGINE * LBS	225.27	-9.02
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	620.57	10.61
WEIGHT OF HYDROCARBON ENGINE	2572.30	-46.48
WEIGHT OF SSME	7393.00	N/A
WEIGHT OF THRUST STRUCTURE * LBS	4835.50	2.47
WEIGHT OF HYDROGEN COOLANT * LBS	3800.90	N/A
LH2 FUEL+COOLANT FEED SYSTEM WEIGHT * LBS	710.57	N/A
INSULATION WEIGHT ON HYDROGEN COOLANT TANK * LBS	622.32	N/A
WEIGHT OF LH2 FUEL+COOLANT TANK * LBS	3882.50	N/A
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
OMS PROPELLANT REQUIRED FOR CIR.	1143.20	-4.98
TOTAL OMS PROPELLANT WEIGHT * LBS	4136.50	-5.32
OMS HARDWARE WEIGHT * LBS	777.96	-11.62
TOTAL RCS WEIGHT * LBS	1725.60	-7.28
RCS PROPELLANT WEIGHT * LBS	2121.90	-3.23
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/SC PROPANE, LH2 COOLED (NEAR TERM)
PROPULSION WEIGHTS

	VALUE	PERCENT OF *REFERENCE
LIFT OFF ACCEL., ONE ENGINE OUT	1.23	2.27
NOMINAL LIFT OFF ACCELERATION	1.48	0.00
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	2.00	0.00
INERT WEIGHT FACTOR	0.75	0.00
PRIMARY ENGINE VACUUM ISP	316.58	-25.58
NUMBER OF PRIMARY ENGINES	2.00	-60.00
NUMBER OF SSME ENGINES	3.00	N/A
PROPELLANT MASS FRACTION	0.89	-0.08
PRIMARY ENGINE MIXTURE RATIO	3.59	-52.78
SSME MIXTURE RATIO	6.00	0.00
PRIMARY ENGINE LIFT OFF THRUST	272160.00	-24.24
SSME LIFT OFF THRUST	504130.00	0.00
PRIMARY ENGINE VACUUM THRUST 1ST NOZZLE	279670.00	-26.68
SSME VACUUM THRUST	504130.00	0.00
NOMINAL FUEL TANK PRESSURE * PSIA	10.82	-68.18
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
ENGINE RATED CHAMBER PRESSURE * PSI	4000.00	0.00
ENGINE RATED CHAMBER PRESSURE * PSI	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	25.00	316.67
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
PERCENT OF TOTAL PROPELLANT USED FOR H2 COOLING	0.01	N/A
LIFTOFF THROTTLE SETTING OF PRIMARY ENGINE	0.91	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/SC PROPANE, LH2 COOLED (NEAR TERM)
PERFORMANCE

	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	30.00	0.00
PAYLOAD BAY DIAMETER * FT	15.00	0.00
BODY DIAMETER * FT	24.00	0.00
VEHICLE LENGTH * FT	134.61	-9.48
LENGTH/DIAMETER RATIO OF VEHICLE	5.61	-9.48
NOSE LENGTH	75.13	150.44
PRIMARY ENGINE THROAT DIAMETER	0.55	-17.76
SSME THROAT DIAMETER	0.85	N/A
MAX. PRIMARY ENGINE NOZZLE EXIT DIA.	2.12	-68.11
SSME NOZZLE EXIT DIA.	10.42	N/A
PRIMARY ENGINE LENGTH	4.65	-59.89
SSME LENGTH	11.60	-36.44
PRIMARY ENGINE FIRST EXPANSION RATIO	15.00	-50.00
PRIMARY ENGINE SECOND EXPANSION RATIO	15.00	-84.97
SSME EXPANSION RATIO	55.00	N/A
FUEL LINE DIAMETER * IN	11.69	-7.08
OXIDIZER LINE DIAMETER * IN	16.65	13.31
FUEL TANK HEAD HEIGHT * IN	101.50	-0.02
CYLINDRICAL LENGTH OF FUEL TANK * IN	122.96	-84.80
OXIDIZER TANK HEAD HEIGHT * IN	102.49	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	105.83	-41.18
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.03	-26.99
THICKNESS OF OXIDIZER TANK WALL * IN	0.10	72.34
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	1693.80	-5.44
WING SPAN * FT	56.84	-2.76
TOTAL FIN EXPOSED AREA * SQ FT	94.19	-2.98
EXPOSED FIN SPAN * FT	11.44	-1.50
CANARD WING SPAN * FT	15.84	-2.76

*OPTIMIZED LOX/LH2

SINGLE STAGE OPTIMIZED LOX/SC PROPANE, LH2 COOLED (NEAR TERM)
DIMENSIONS

	VALUE	PERCENT OF *REFERENCE
TOTAL DRY WEIGHT * LBS	103460.00	-1.17
GROSS LIFT OFF WEIGHT	1226700.00	2.44
BODY WEIGHT * LBS	63898.00	3.70
GROWTH WEIGHT * LBS	5736.50	1.86
INERT WEIGHT * LBS	123140.00	-0.69
EQUIPMENT WEIGHT * LBS	10747.00	-3.41
TANK MOUNT WEIGHT * LBS	505.53	-0.15
STRUCTURAL WALL WEIGHT * LBS	18089.00	-58.66
APU PROPELLANT WEIGHT * LBS	2033.30	-10.35
LANDING WEIGHT * LBS	106200.00	-1.19
LANDING GEAR WEIGHT * LBS	3311.40	-1.07
CANARD WEIGHT * LBS	1442.20	-1.19
WING WEIGHT * LBS	17973.00	-1.31
WEIGHT OF REENTRY INSULATION TILES * LBS	7272.30	-5.22
PAYLOAD WEIGHT * LBS	10000.00	0.00
PAYLOAD BAY WEIGHT * LBS	6704.40	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE ACUREX LOX/LH2 ENGINE POWERED
SYSTEM WEIGHTS

	VALUE	PERCENT OF *REFERENCE
TOTAL ASCENT PROPELLANT WEIGHT * LBS	1092400.00	2.83
FUEL WEIGHT IN VEHICLE * LBS	134290.00	8.71
WEIGHT OF HYDROGEN USED AS FUEL	0.00	N/A
OXIDIZER WEIGHT IN VEHICLE * LBS	958110.00	2.06
FUEL RESERVES * LBS	577.44	8.71
OXIDIZER RESERVES * LBS	4119.90	2.06
FUEL RESIDUAL WEIGHT * LBS	59.85	-10.25
OXIDIZER RESIDUAL WEIGHT * LBS	592.96	4.01
TOTAL FUEL AUTOGENOUS PRESSURANT WEIGHT * LBS	317.36	-11.58
TOTAL OXIDIZER AUTOGENOUS PRESSURANT WEIGHT * LBS	1383.00	4.54
TOTAL TANK WEIGHT * LBS	13322.00	16.59
FUEL TANK LINE WEIGHT * LBS	1266.10	7.26
OXIDIZER TANK LINE WEIGHT * LBS	142.65	32.61
FUEL TANK INSULATION WEIGHT * LBS	2623.70	-7.64
OXIDIZER TANK INSULATION WEIGHT * LBS	1430.20	2.64
GAS LINE WEIGHT * LBS	102.21	4.68
ENGINE BAY LINE WEIGHT PER ENGINE * LBS	323.98	30.84
PRESSURANT CONTROL HARDWARE WEIGHT * LBS	669.79	19.38
WEIGHT OF SSME	7104.20	47.81
WEIGHT OF THRUST STRUCTURE * LBS	4594.40	-2.64
PRESSURANT WEIGHT * LBS	0.00	N/A
PRESSURE TANK WEIGHT * LBS	0.00	N/A
OMS PROPELLANT REQUIRED FOR CIR.	1195.70	-0.62
TOTAL OMS PROPELLANT WEIGHT * LBS	4339.70	-0.67
OMS HARDWARE WEIGHT * LBS	843.82	-4.14
TOTAL RCS WEIGHT * LBS	1812.10	-2.63
RCS PROPELLANT WEIGHT * LBS	2176.30	-0.75
WEIGHT OF EACH OMS ENGINE * LBS	309.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE ACUREX LOX/LH2 ENGINE POWERED
PROPULSION WEIGHTS

	VALUE	PERCENT OF *REFERENCE
LIFT OFF ACCEL., ONE ENGINE OUT	1.20	0.00
NOMINAL LIFT OFF ACCELERATION	1.48	0.00
MAXIMUM LONGITUDINAL ACCELERATION * G'S	3.00	0.00
NUMBER OF CREW	2.00	0.00
INERT WEIGHT FACTOR	0.75	0.00
PRIMARY ENGINE VACUUM ISP	412.00	-3.15
NUMBER OF PRIMARY ENGINES	3.00	-40.00
PROPELLANT MASS FRACTION	0.90	0.36
PRIMARY ENGINE MIXTURE RATIO	9.00	18.42
PRIMARY ENGINE LIFT OFF THRUST	736040.00	104.88
PRIMARY ENGINE VACUUM THRUST 1ST NOZZLE	775570.00	103.33
NOMINAL FUEL TANK PRESSURE * PSIA	33.97	-0.11
NOMINAL OXIDIZER TANK PRESSURE * PSIA	28.19	0.00
ENGINE RATED CHAMBER PRESSURE * PSI	3000.00	-25.00
ENGINE RATED CHAMBER PRESSURE * PSI	3270.00	0.00
FUEL ULLAGE FRACTION	0.02	0.00
FUEL NET POSITIVE SUCTION PRESSURE	6.00	0.00
OXYGEN NET POSITIVE SUCTION PRESSURE	8.20	0.00
PRESSURE DROP ACROSS FUEL LINE * PSI	5.00	0.00
PRESSURE DROP ACROSS OXIDIZER LINE * PSI	5.00	0.00
LIFTOFF THROTTLE SETTING OF PRIMARY ENGINE	0.91	0.00
OMS ENGINE SPECIFIC IMPULSE	316.00	0.00
TOTAL VACUUM THRUST FOR SINGLE OMS ENGINE	6000.00	0.00

*OPTIMIZED LOX/LH2

SINGLE STAGE ACUREX LOX/LH2 ENGINE POWERED
PERFORMANCE

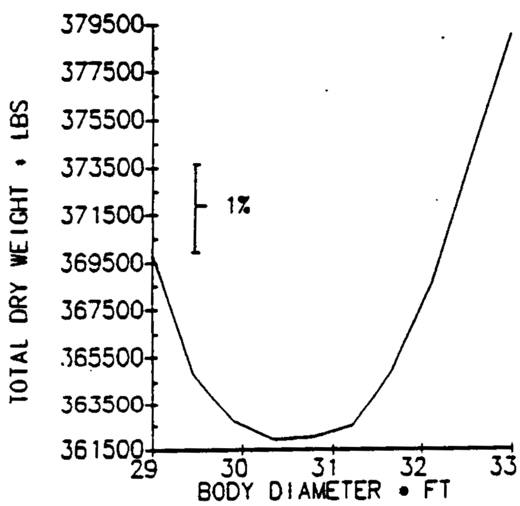
	VALUE	PERCENT OF *REFERENCE
PAYLOAD BAY LENGTH * FT	30.00	0.00
PAYLOAD DIAMETER * FT	15.00	0.00
BODY DIAMETER * FT	24.00	0.00
VEHICLE LENGTH * FT	142.29	-4.31
LENGTH/DIAMETER RATIO OF VEHICLE	5.93	-4.31
NOSE LENGTH	30.00	0.00
PRIMARY ENGINE THROAT DIAMETER	1.09	63.48
MAX. PRIMARY ENGINE NOZZLE EXIT DIA.	8.72	30.93
PRIMARY ENGINE LENGTH	11.60	0.00
PRIMARY ENGINE FIRST EXPANSION RATIO	20.00	-33.33
PRIMARY ENGINE SECOND EXPANSION RATIO	64.00	-35.86
FUEL LINE DIAMETER * IN	13.09	4.06
OXIDIZER LINE DIAMETER * IN	16.59	12.93
FUEL TANK HEAD HEIGHT * IN	101.49	-0.03
CYLINDRICAL LENGTH OF FUEL TANK * IN	716.45	-11.43
OXIDIZER TANK HEAD HEIGHT * IN	102.49	0.00
CYLINDRICAL LENGTH OF OXIDIZER TANK * IN	195.52	8.66
SPACE BETWEEN OXIDIZER AND FUEL TANK HEADS * IN	5.00	0.00
THICKNESS OF FUEL TANK WALL * IN	0.04	-0.14
THICKNESS OF OXIDIZER TANK WALL * IN	0.15	145.46
FUEL TANK SOFI THICKNESS * IN	1.00	0.00
OXIDIZER TANK SOFI THICKNESS * IN	1.00	0.00
WING REFERENCE AREA * SQ FT	1770.00	-1.19
WING SPAN * FT	58.10	-0.60
TOTAL FIN EXPOSED AREA * SQ FT	96.44	-0.65
EXPOSED FIN SPAN * FT	11.57	-0.33
CANARD WING SPAN * FT	16.19	-0.60

*OPTIMIZED LOX/LH2

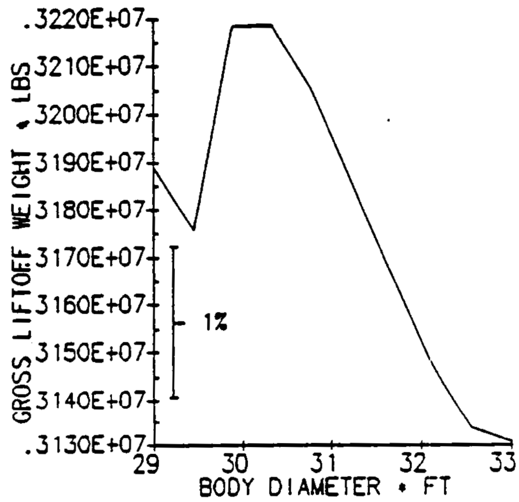
SINGLE STAGE ACUREX LOX/LH2 ENGINE POWERED
DIMENSIONS

APPENDIX B

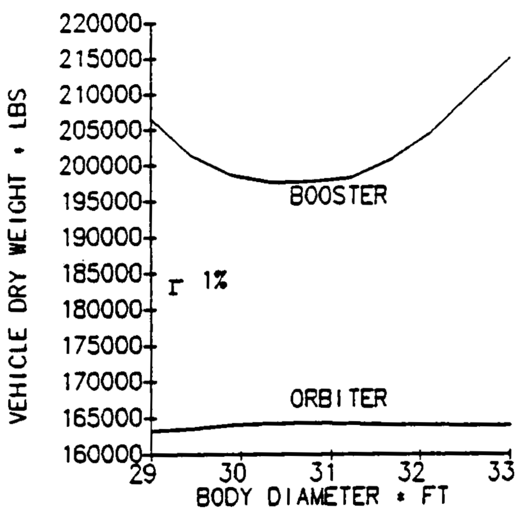
OPTIMIZED PARAMETER SENSITIVITES



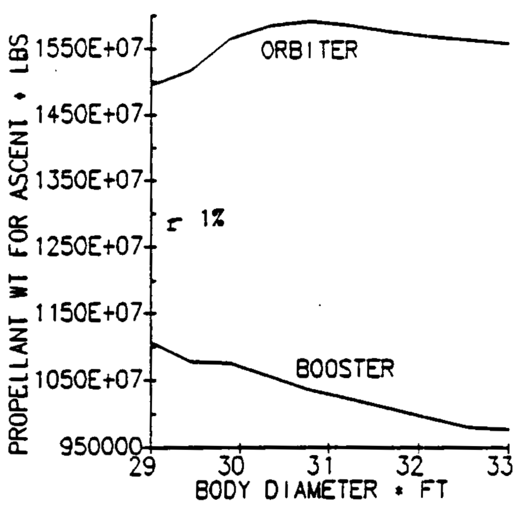
(b-1) Total Dry Weight Versus Body Diameter



(b-2) Gross Lift Off Weight Versus Body Diameter

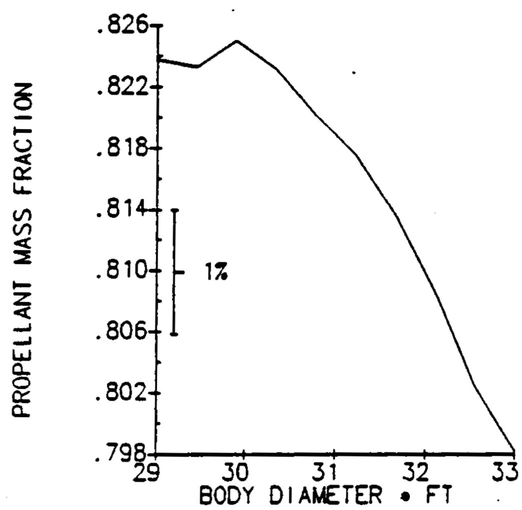


(b-3) Vehicle Dry Weight Versus Body Diameter

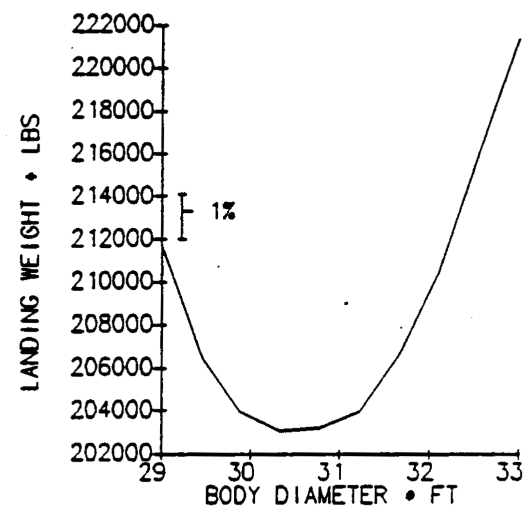


(b-4) Propellant Consumed Versus Body Diameter

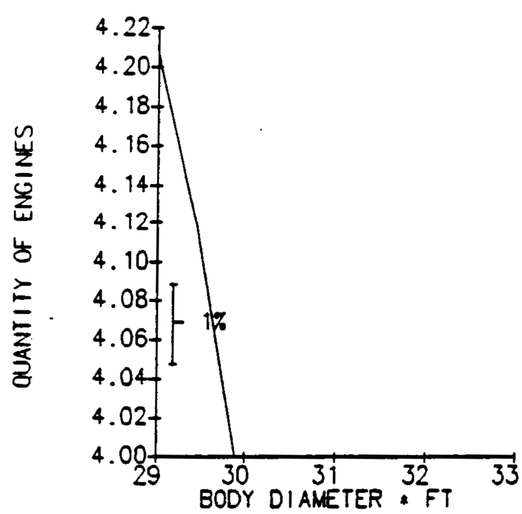
Configuration 2.B Sensitivity Studies



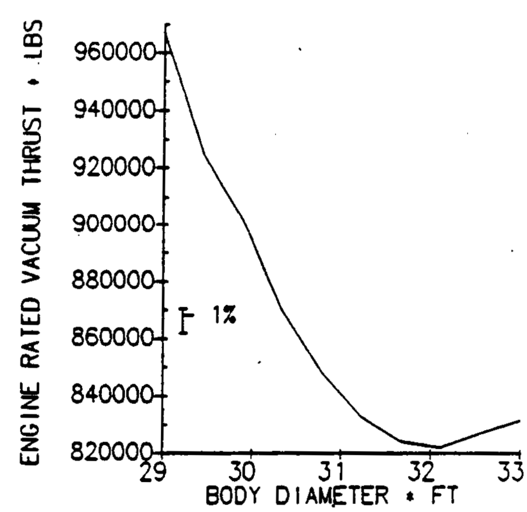
(b-5) Propellant Mass Fraction Versus Body Diameter



(b-6) Landing Weight Versus Body Diameter

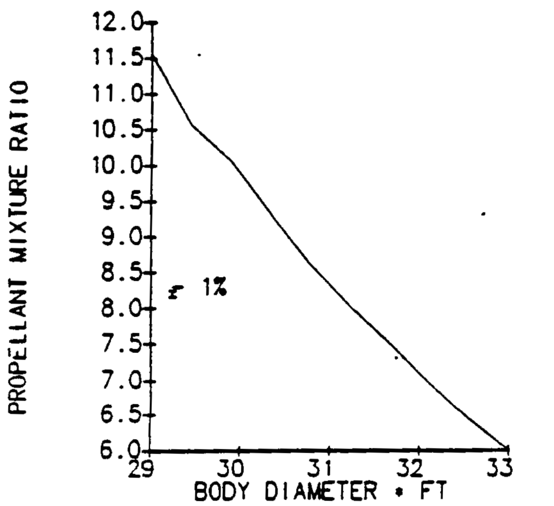


(b-7) Number of Booster Engines Versus Body Diameter

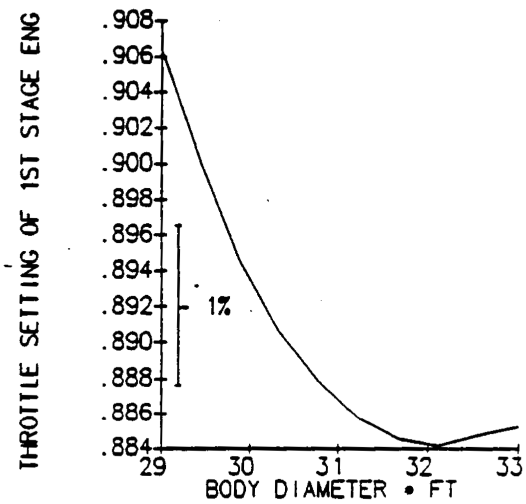


(b-8) Engine Rated Vacuum Thrust Versus Body Diameter

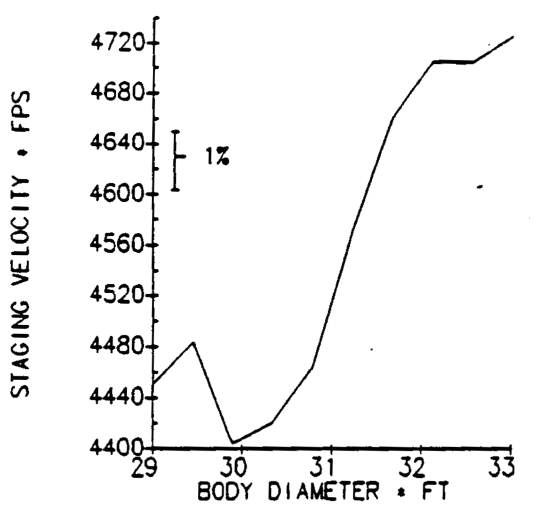
Configuration 2.B Sensitivity Studies (Continued)



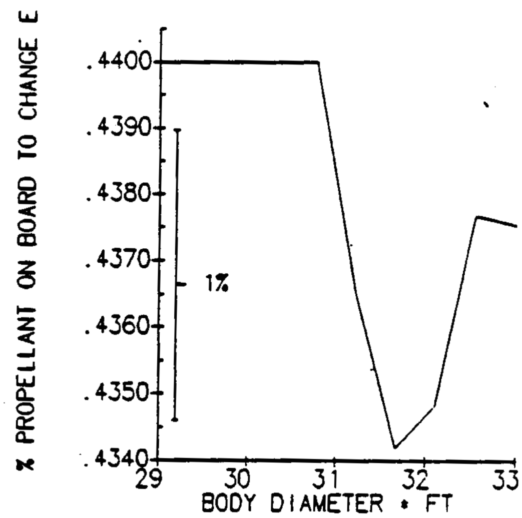
(b-9) Propellant Mixture Ratio Versus Body Diameter



(b-10) Initial Booster Throttle Setting Versus Body Diameter

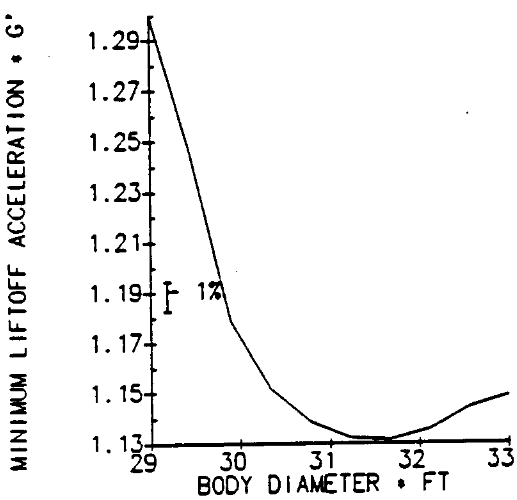


(b-11) Staging Velocity Versus Body Diameter

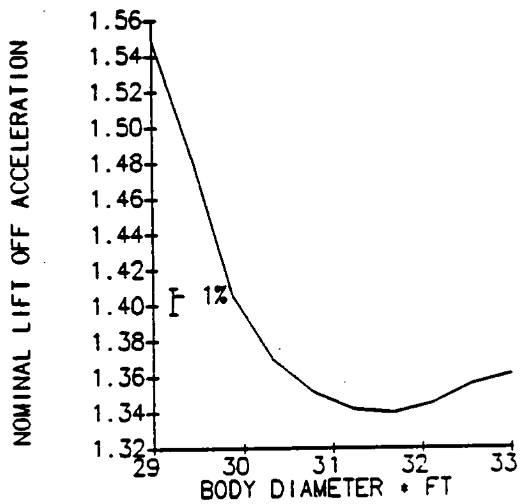


(b-12) Orbiter Propellant at Staging Versus Body Diameter

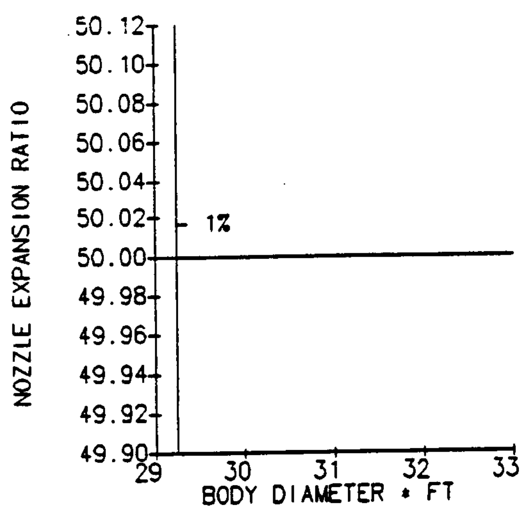
Configuration 2.B Sensitivity Studies (Continued)



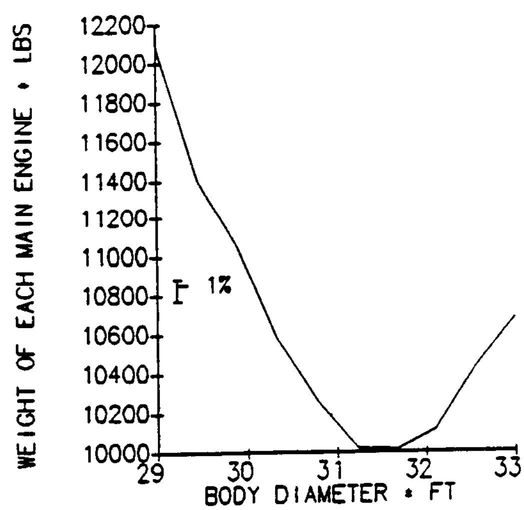
(b-13) Engine-out Lift Off Acceleration Versus Body Diameter



(b-14) Nominal Lift Off Acceleration Versus Body Diameter

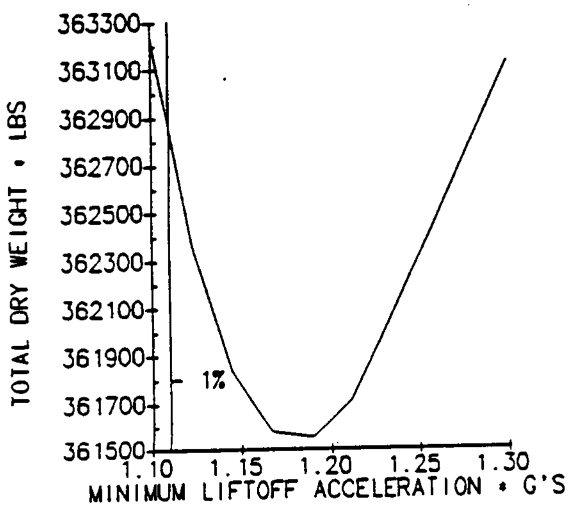


(b-15) Nozzle Expansion Ratio Versus Body Diameter

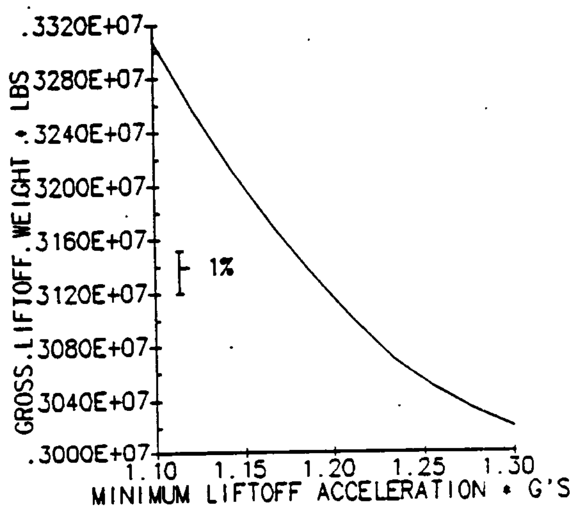


(b-16) Booster Engine Weight Versus Body Diameter

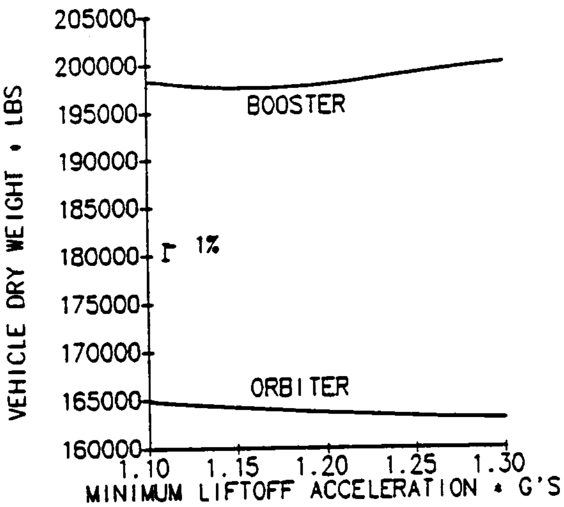
Configuration 2.B Sensitivity Studies (Continued)



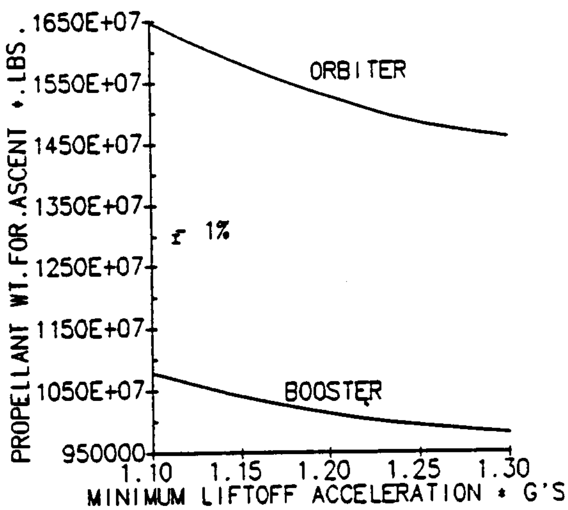
(b-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(b-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

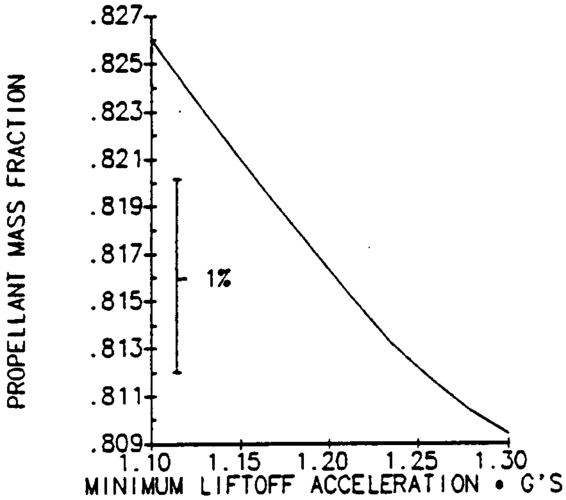


(b-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

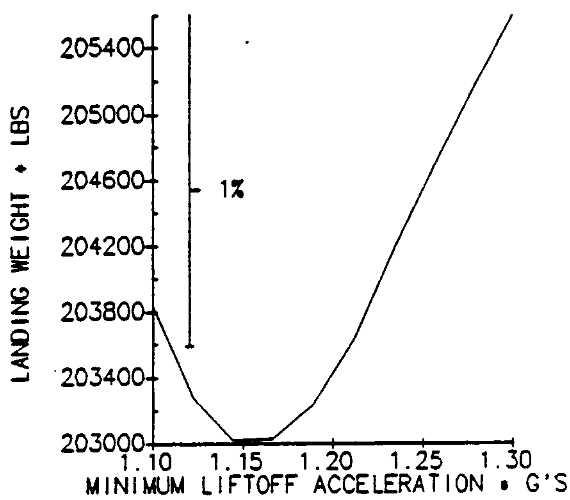


(b-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

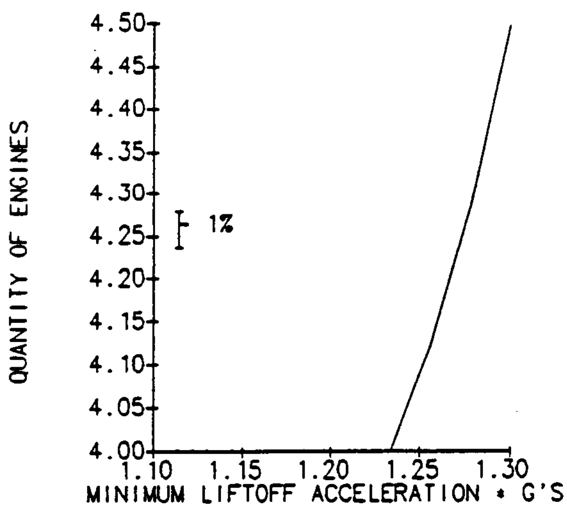
Configuration 2.B Sensitivity Studies (Continued)



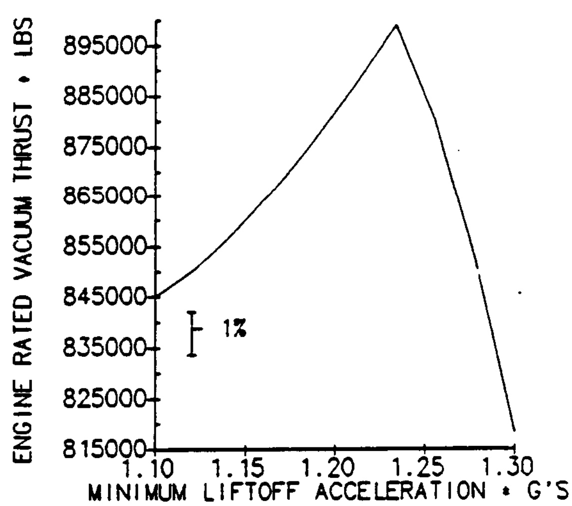
(b-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(b-22) Landing Weight Versus Engine-out Lift Off Acceleration

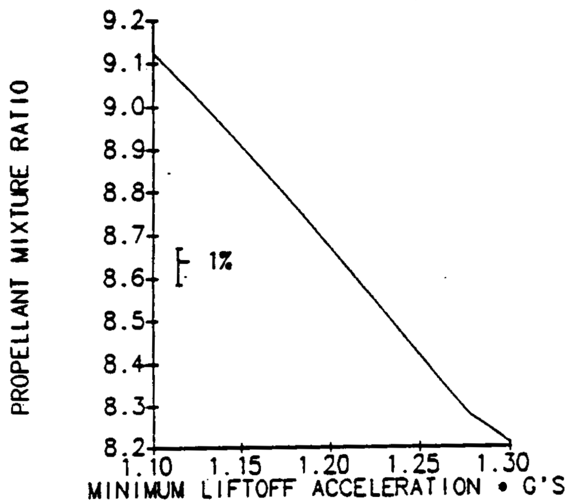


(b-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

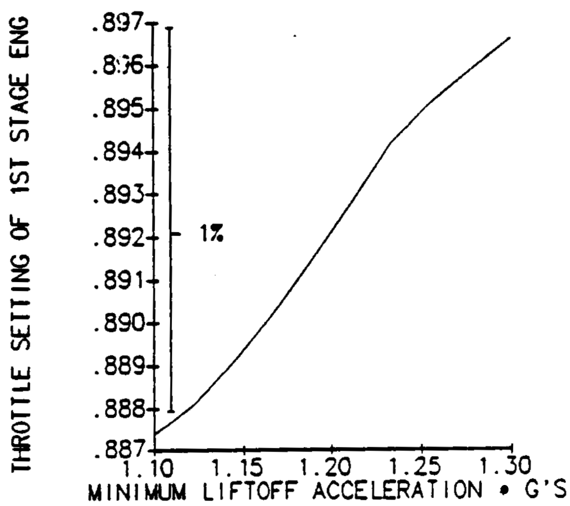


(b-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

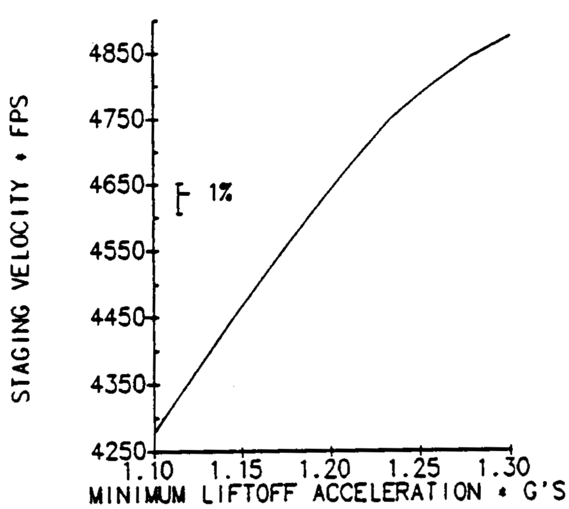
Configuration 2.B Sensitivity Studies (Continued)



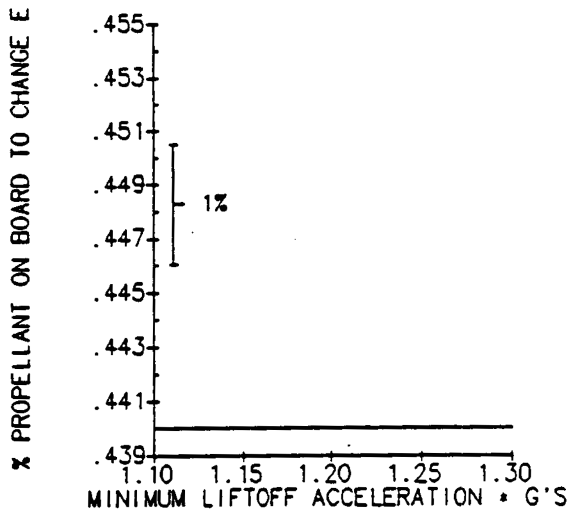
(b-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(b-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

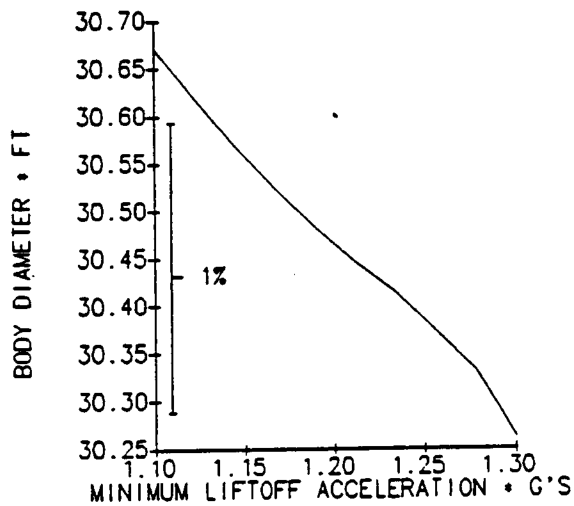


(b-27) Staging Velocity Versus Engine-out Lif* Off Acceleration

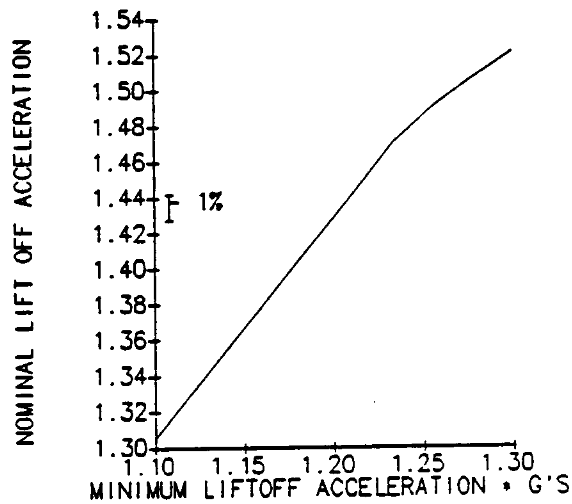


(b-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

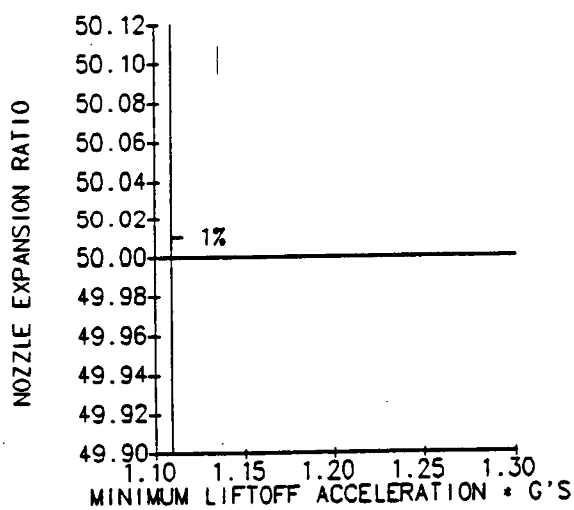
Configuration 2.B Sensitivity Studies (Continued)



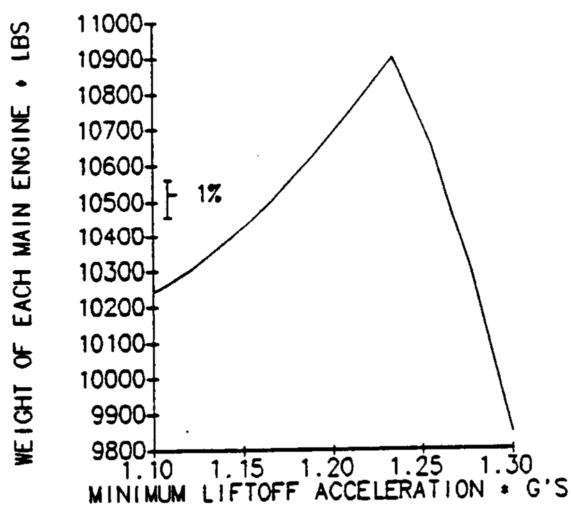
(b-29) Body Diameter Versus Engine-out Lift Off Acceleration



(b-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

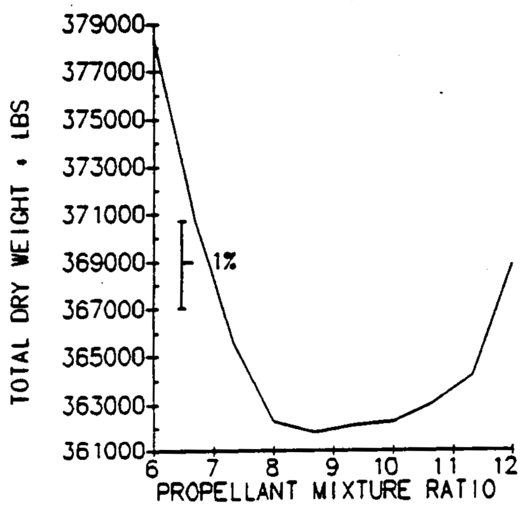


(b-31) Nozzle Expansion Ratio Versu- Engine-out Lift Off Acceleration

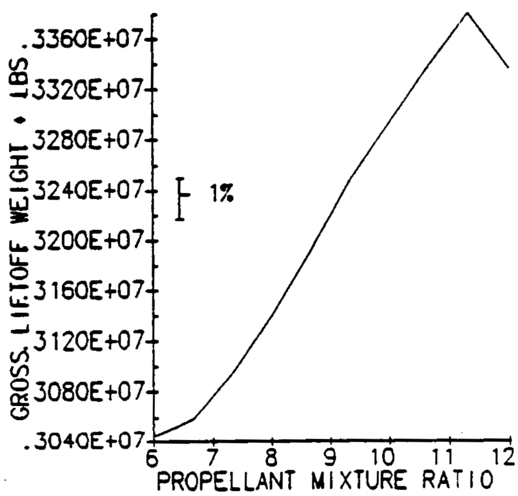


(b-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

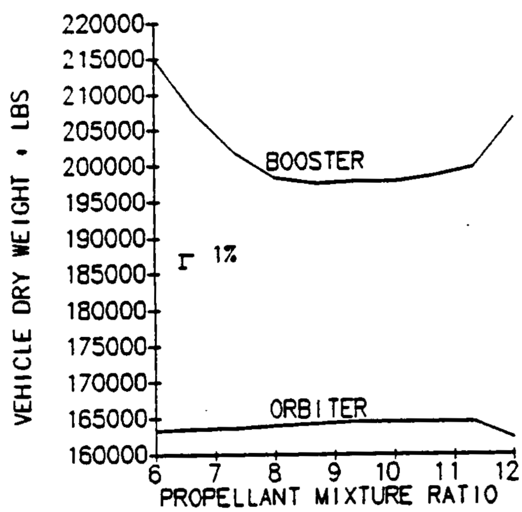
Configuration 2.B Sensitivity Studies (Continued)



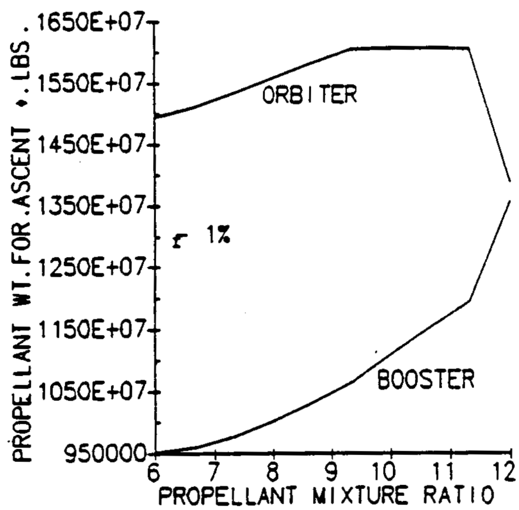
(b-33) Total Dry Weight Versus Propellant Mixture Ratio



(b-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

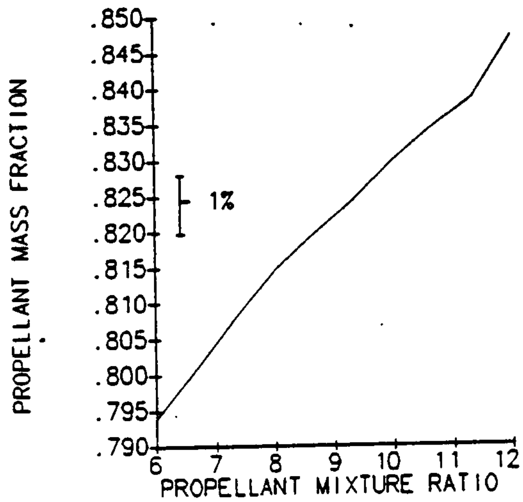


(b-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

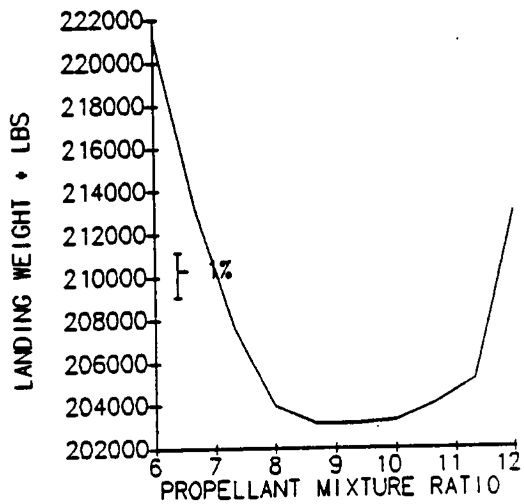


(b-36) Propellant Consumed Versus Propellant Mixture Ratio

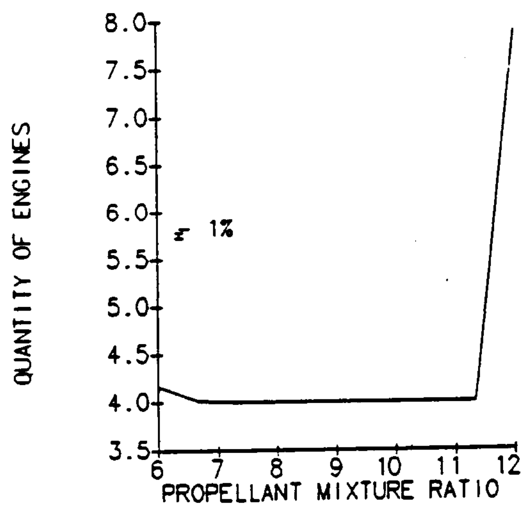
Configuration 2.B Sensitivity Studies (Continued)



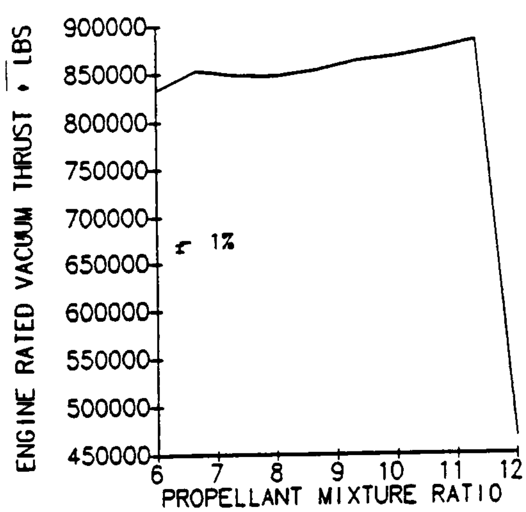
(b-37) Propellant Mas. Fraction Versus Propellant Mixture Ratio



(b-38) Landing Weight Versus Propellant Mixture Ratio

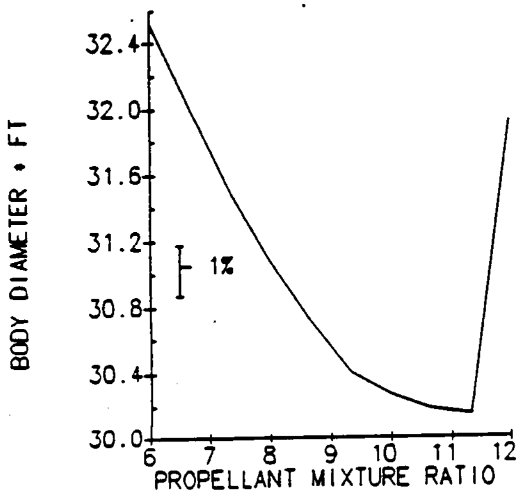


(b-39) Number of Booster Engines Ve-sus Propellant Mixture Ratio

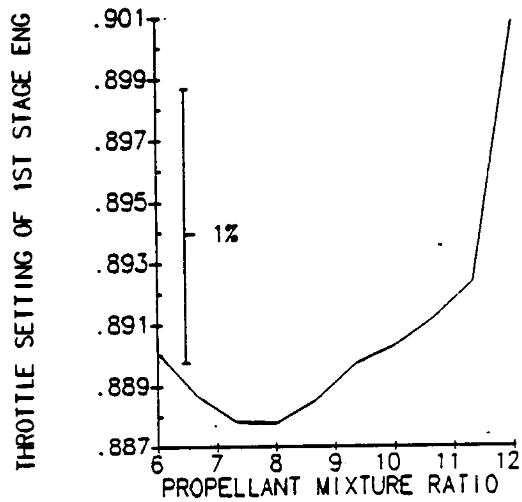


(b-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

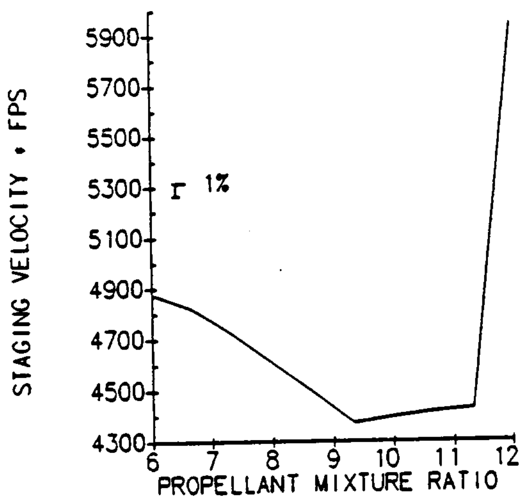
Configuration 2.B Sensitivity Studies (Continued)



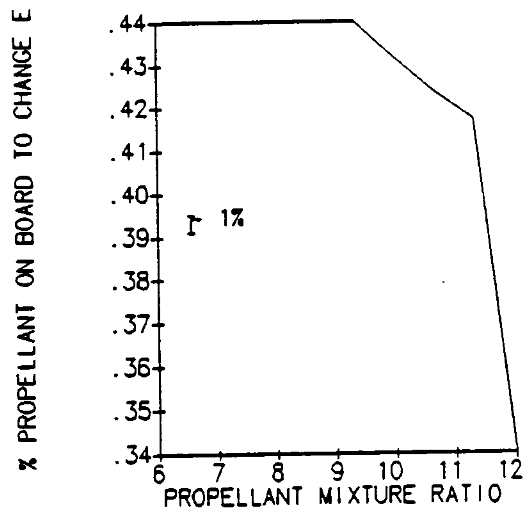
(b-41) Body Diameter Versus Propellant Mixture Ratio



(b-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

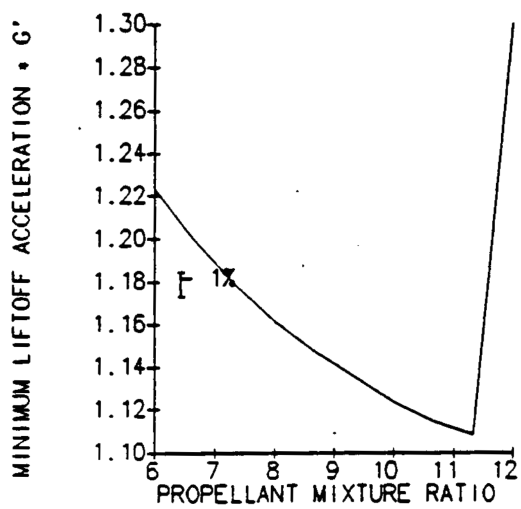


(b-43) Staging Velocity Versus Propellant Mixture Ratio

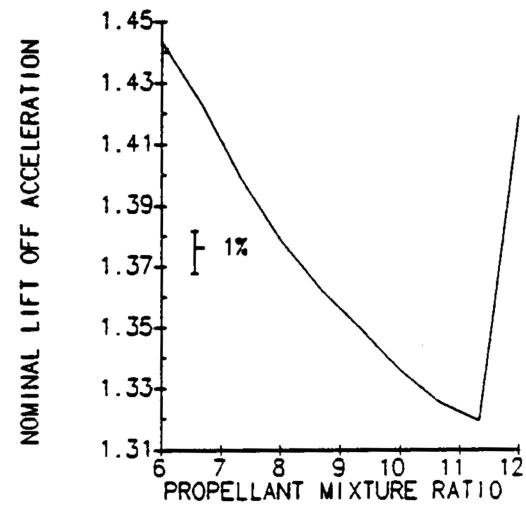


(b-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

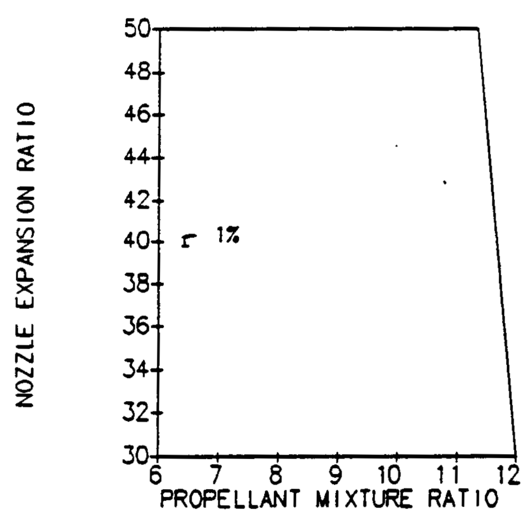
Configuration 2.B Sensitivity Studies (Continued)



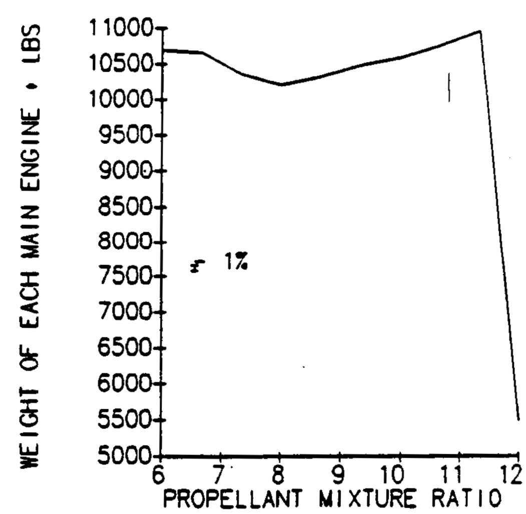
(b-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(b-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

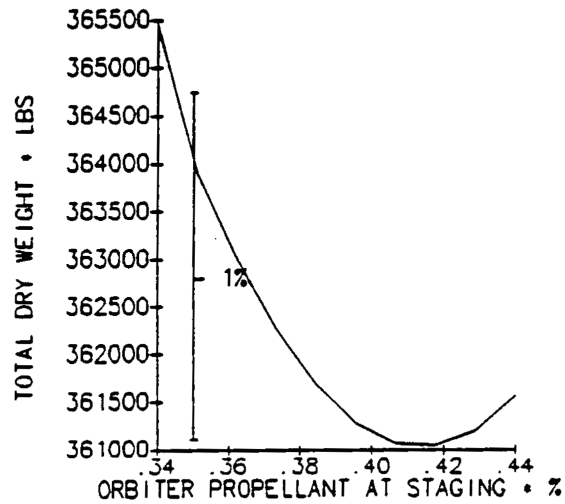


(b-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

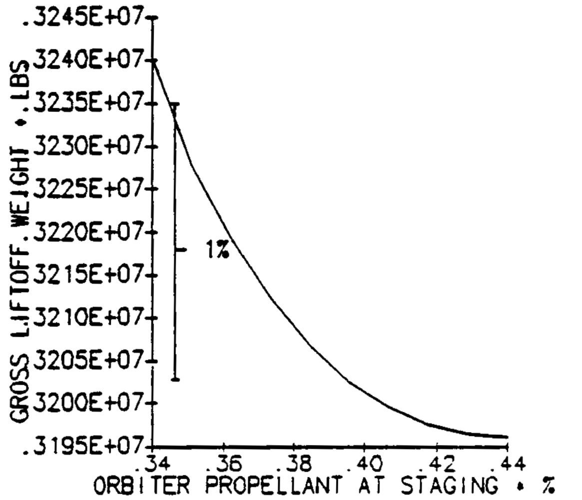


(b-48) Booster Engine Weight Versus Propellant Mixture Ratio

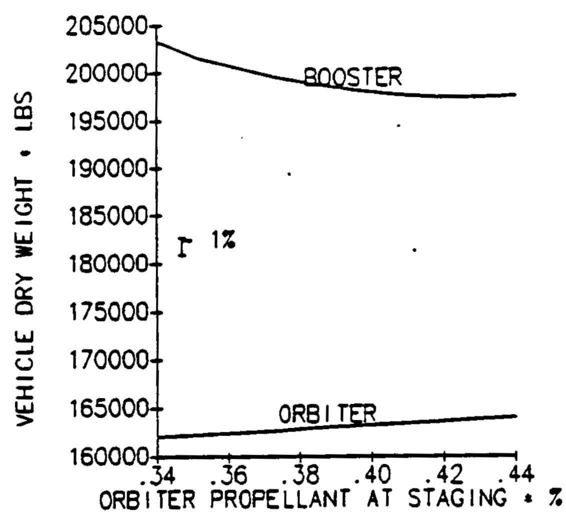
Configuration 2.B Sensitivity Studies (Continued)



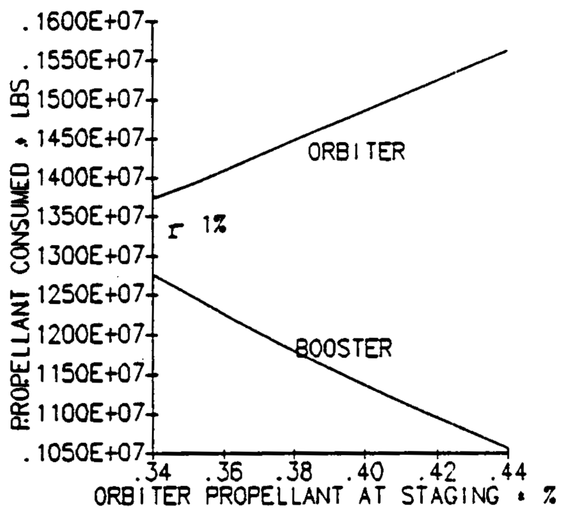
(b-49) Total Dry Weight Versus Orbiter Propellant at Staging



(b-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

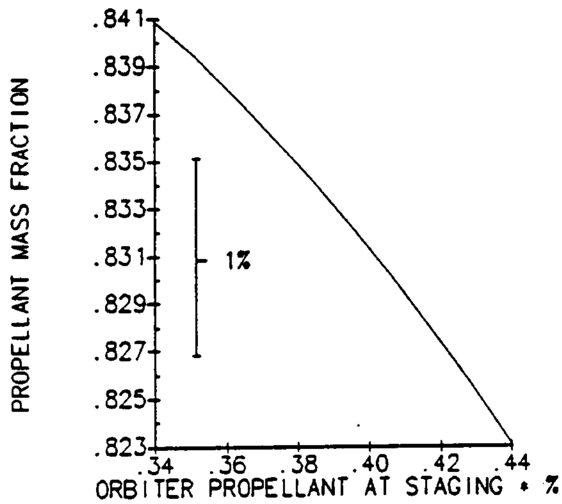


(b-51) Vehicle Dry Weight Versus Orbiter Propellant at Stagir g

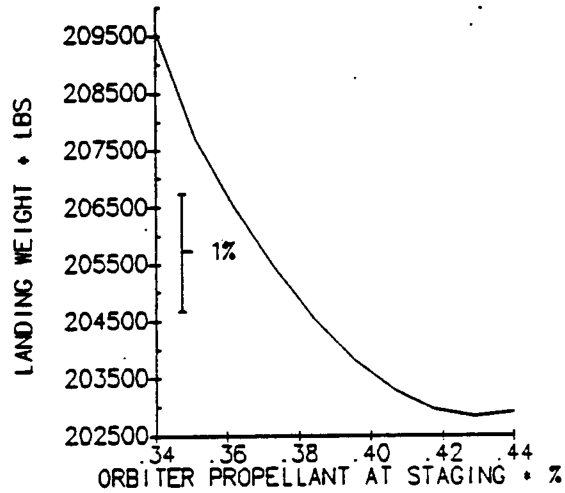


(b-52) Propellant Consumed Versus Orbiter Propellant at Staging

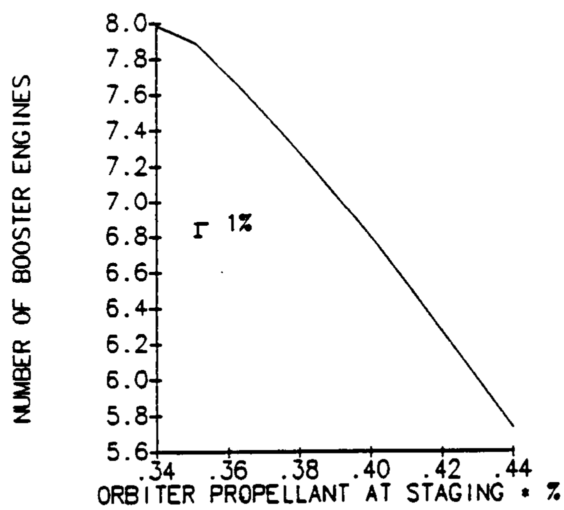
Configuration 2.B Sensitivity Studies (Continued)



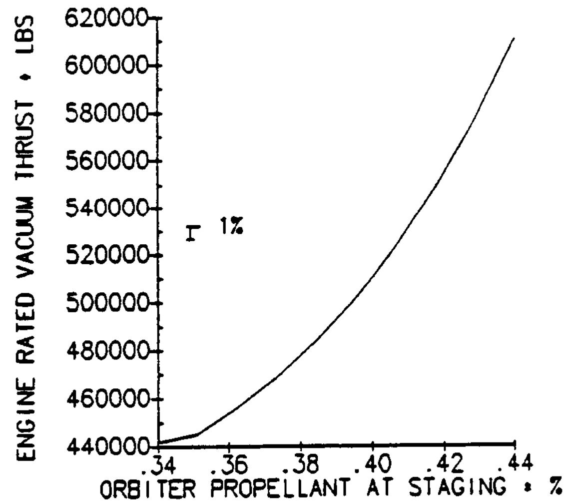
(b-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(b-54) Landing Weight Versus Orbiter Propellant at Staging

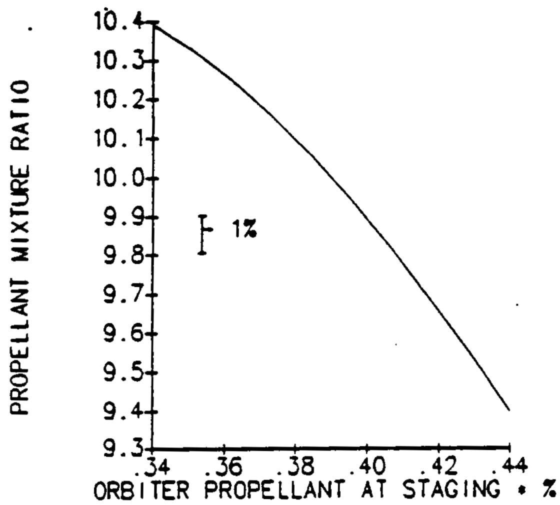


(b-55) Number of Booster Engines Versus Orbiter Propellant at Staging

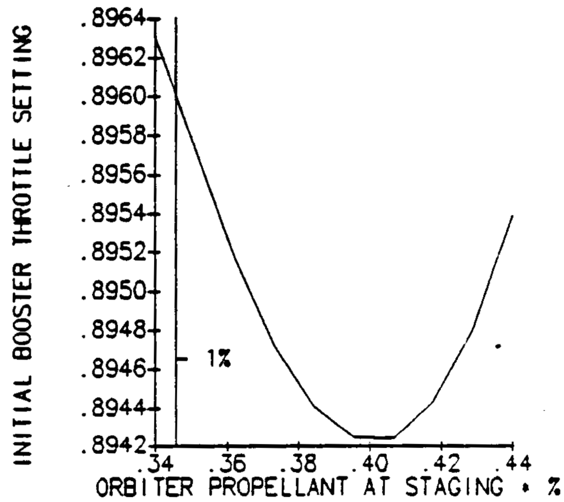


(b-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

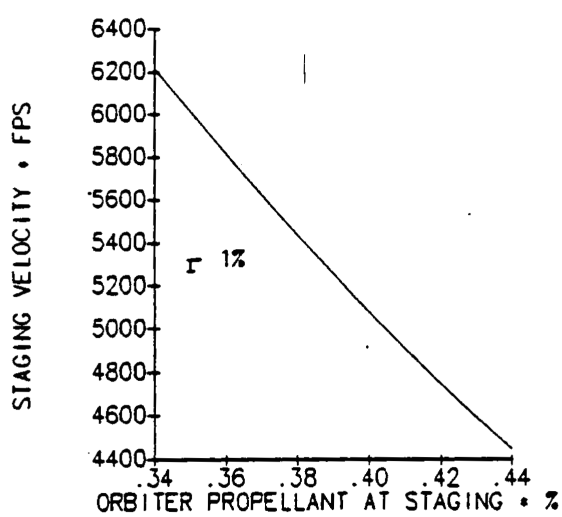
Configuration 2.B Sensitivity Studies (Continued)



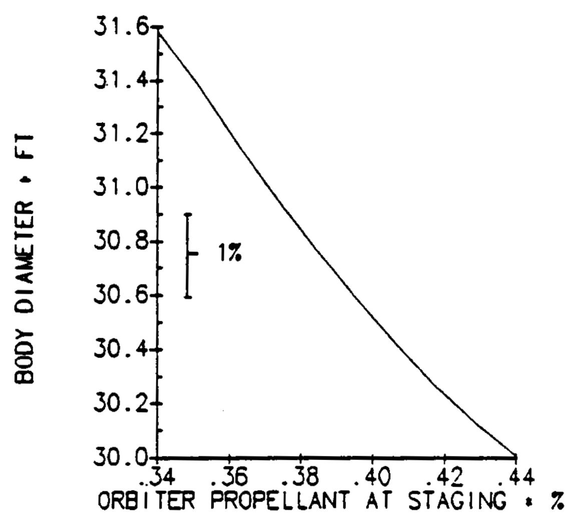
(b-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(b-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

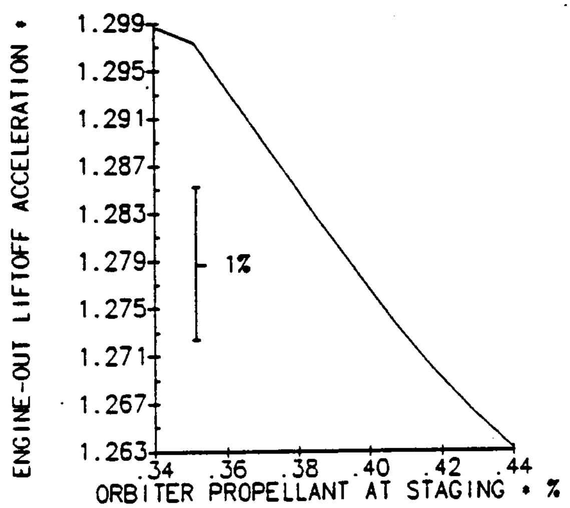


(b-59) Staging Velocity Versus Orbiter Propellant at Staging

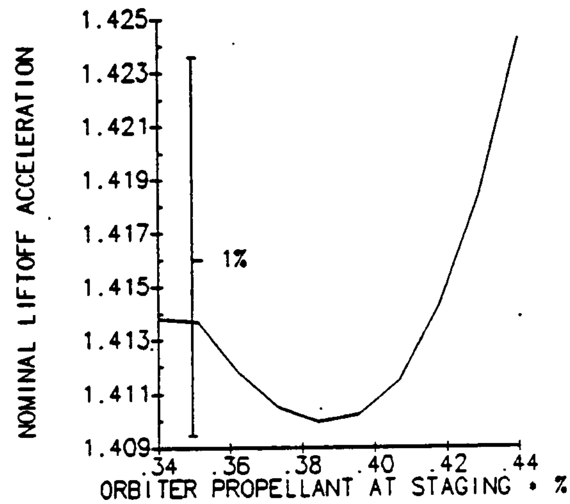


(b-60) Body Diameter Versus Orbiter Propellant at Staging

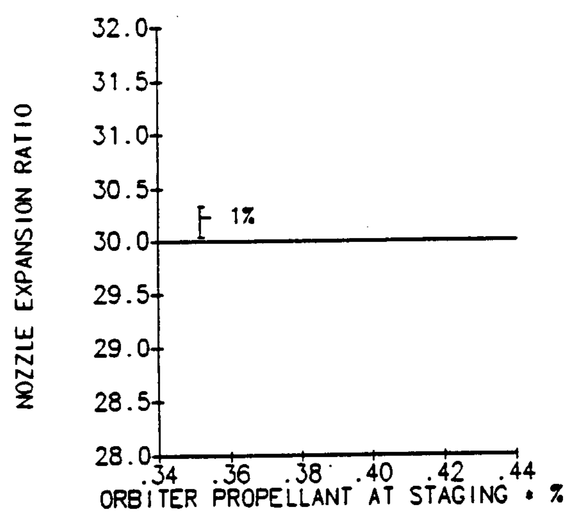
Configuration 2.B Sensitivity Studies (Continued)



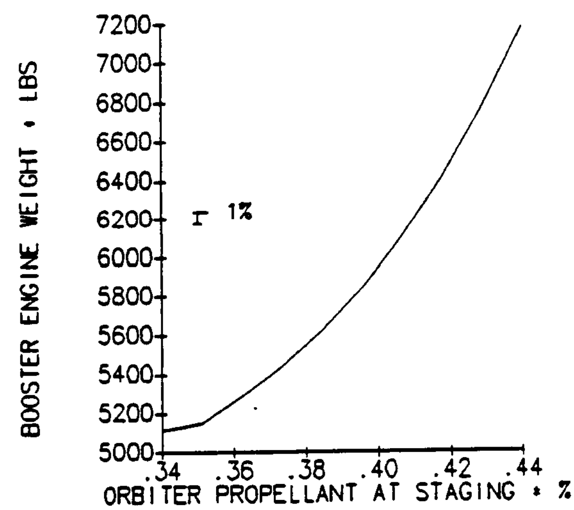
(b-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(b-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

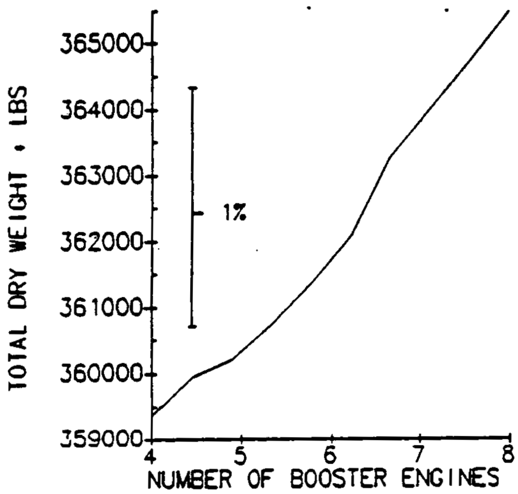


(b-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

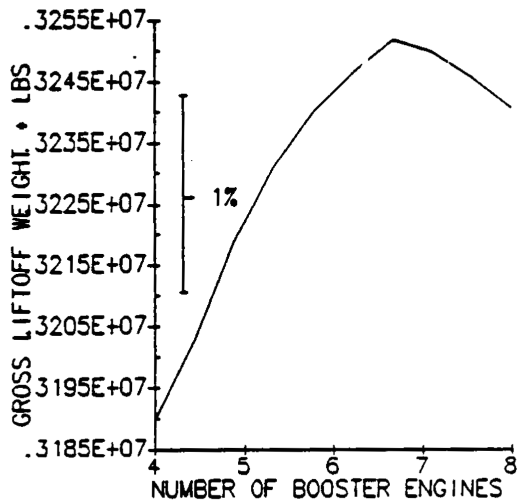


(b-64) Booster Engine Weight Versus Orbiter Propellant at Staging

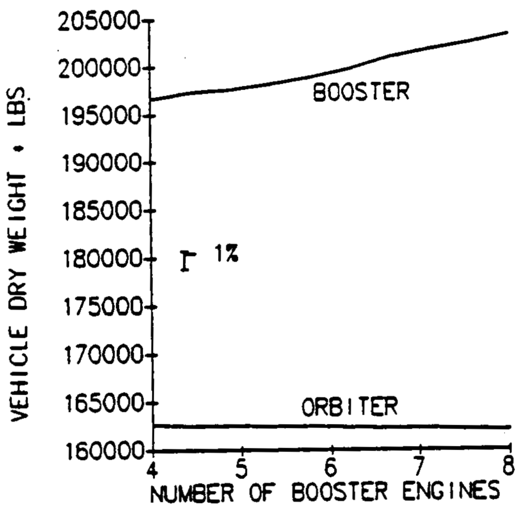
Configuration 2.B Sensitivity Studies (Continued)



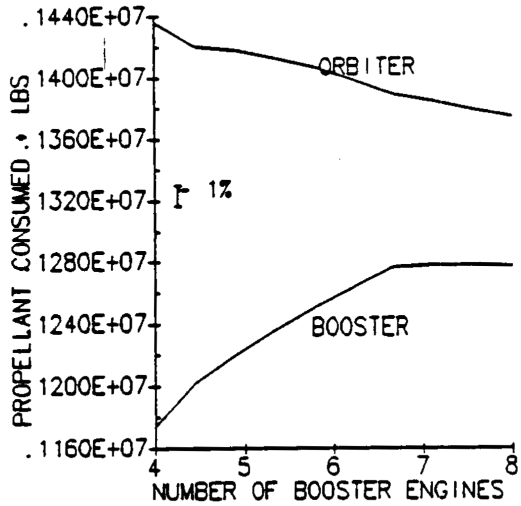
(b-65) Total Dry Weight Versus Number of Booster Engines



(b-66) Gross Lift Off Weight Versus Number of Booster Engines

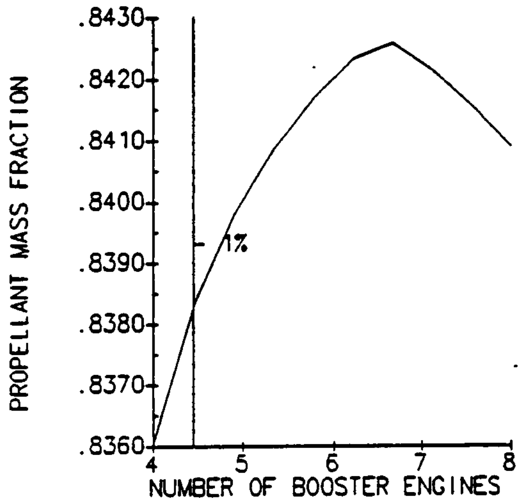


(b-67) Vehicle Dry Weight Versus Number of Booster Engines

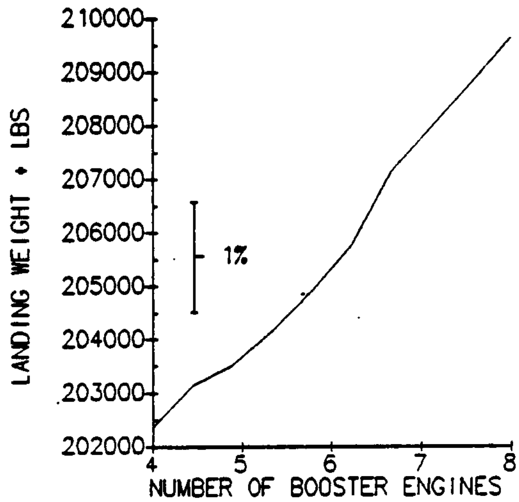


(b-68) Propellant Consumed Versus Number of Booster Engines

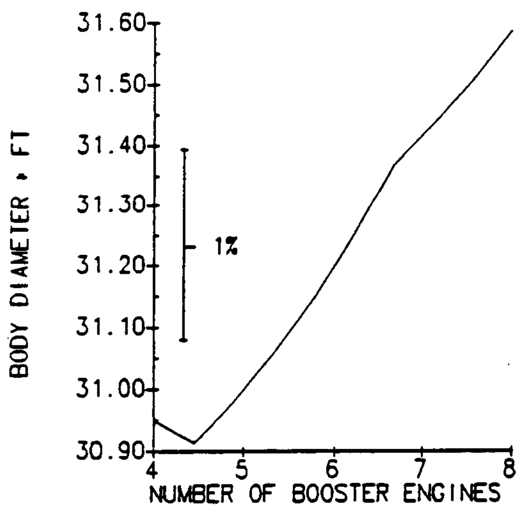
Configuration 2.B Sensitivity Studies (Continued)



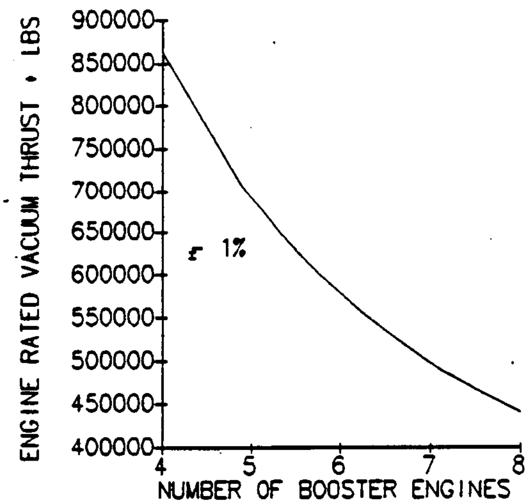
(b-69) Propellant Mass Fraction Versus Number of Booster Engines



(b-70) Landing Weight Versus Number of Booster Engines

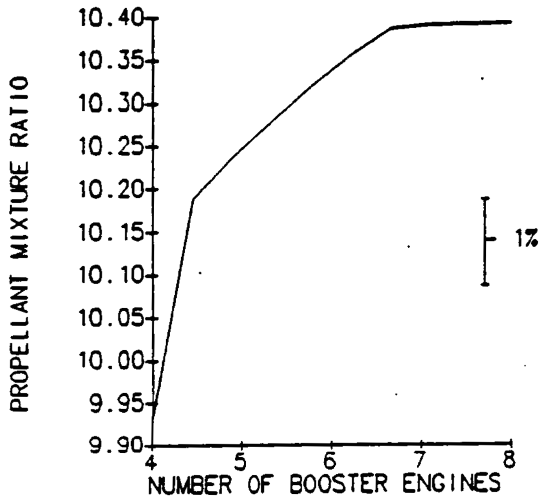


(b-71) Body Diameter Versus Number of Booster Engines

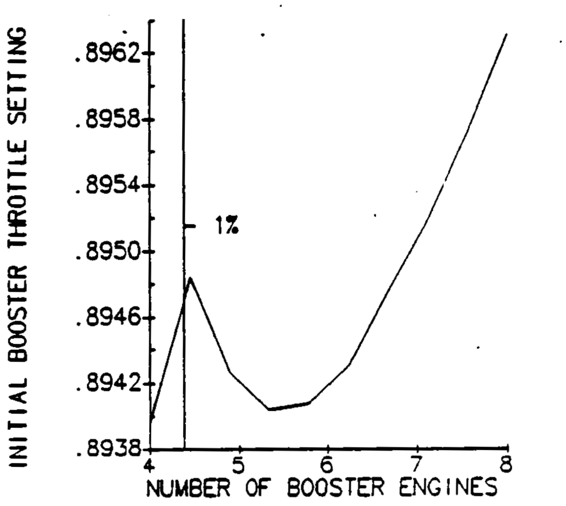


(b-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

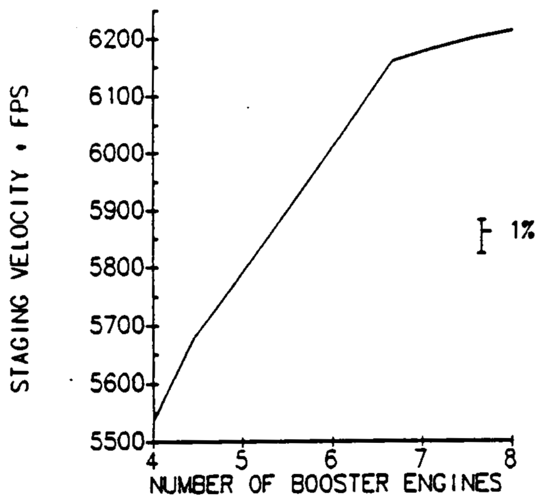
Configuration 2.B Sensitivity Studies (Continued)



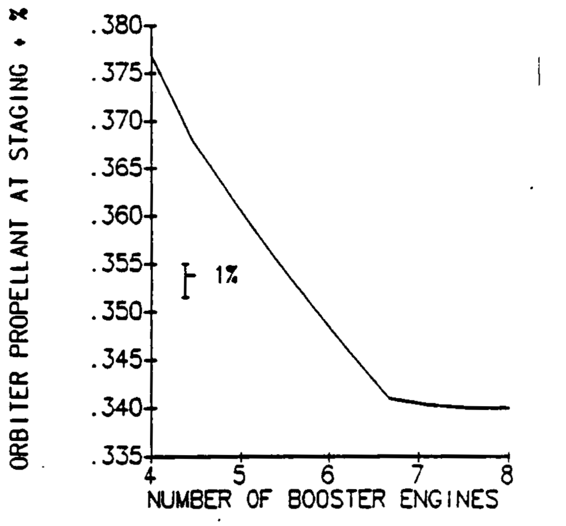
(b-73) Propellant Mixture Ratio Versus Number of Booster Engines



(b-74) Initial Booster Throttle Setting Versus Number of Booster Engines

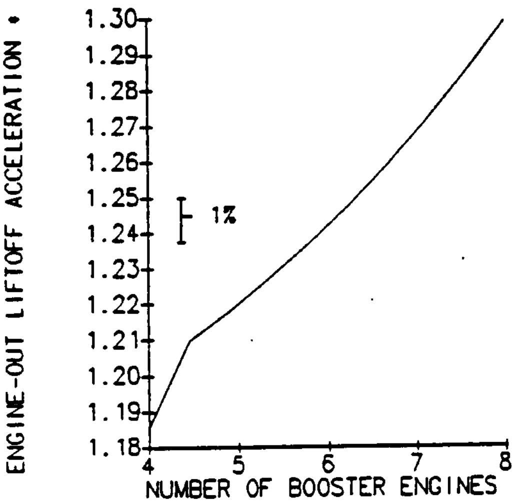


(b-75) Staging Velocity Versus Number of Booster Engines

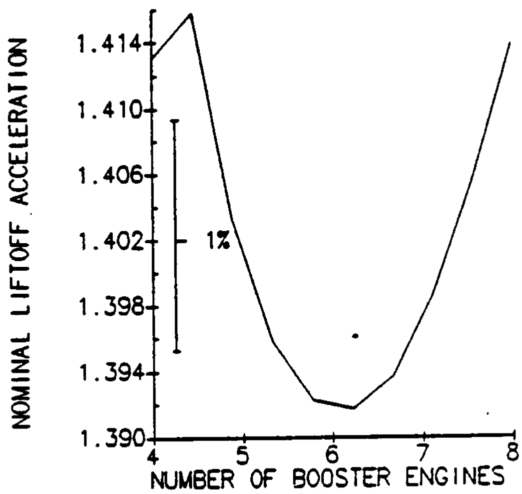


(b-76) Orbiter Propellant at Staging Versus Number of Booster Engines

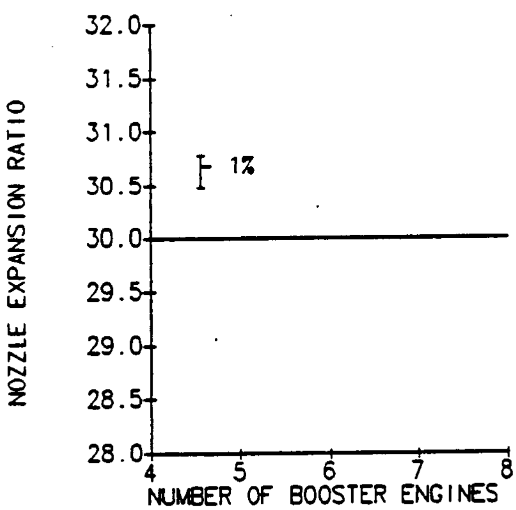
Configuration 2.B Sensitivity Studies (Continued)



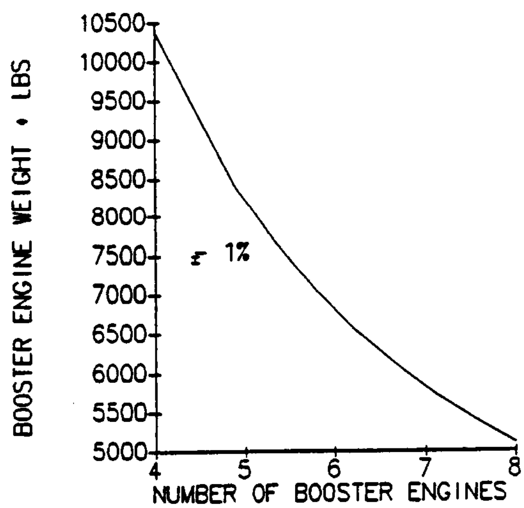
(b-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(b-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

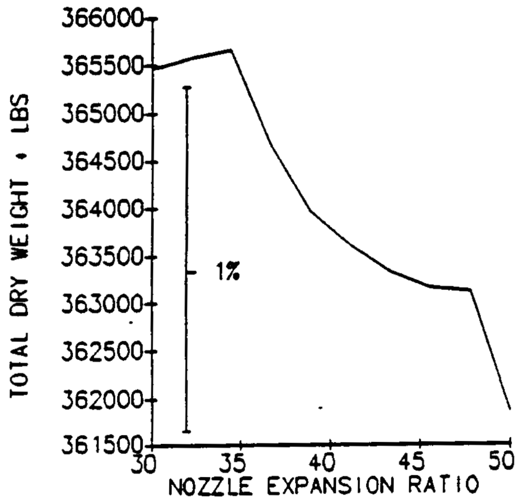


(b-79) Nozzle Expansion Ratio Versus Number of Booster Engines

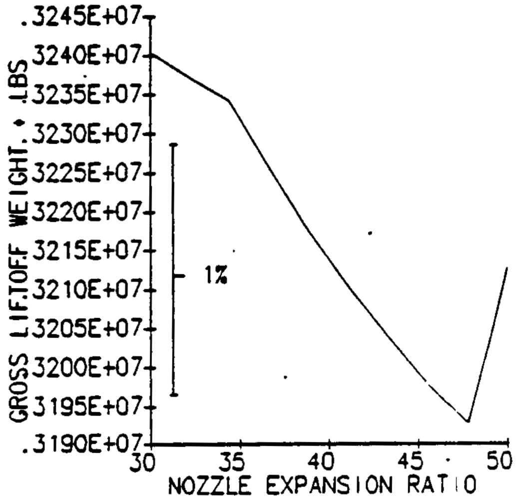


(b-80) Booster Engine Weight Versus Number of Booster Engines

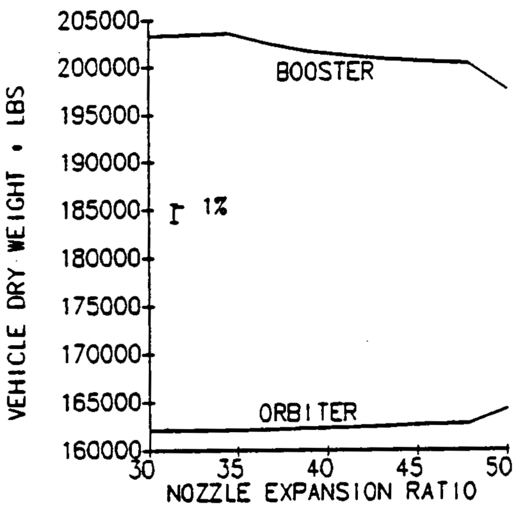
. *Configuration 2.B Sensitivity Studies (Continued)*



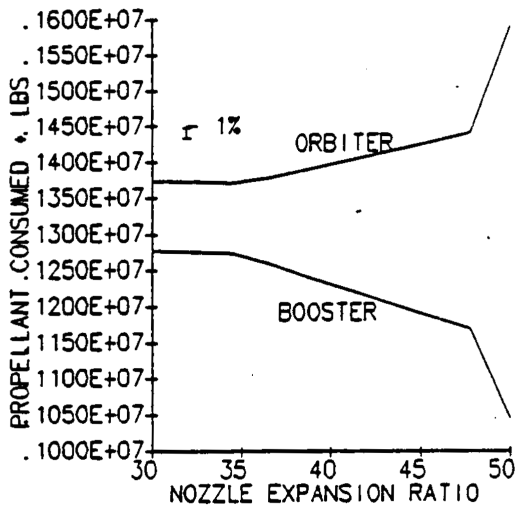
(b-81) Total Dry Weight Versus Nozzle Expansion Ratio



(b-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

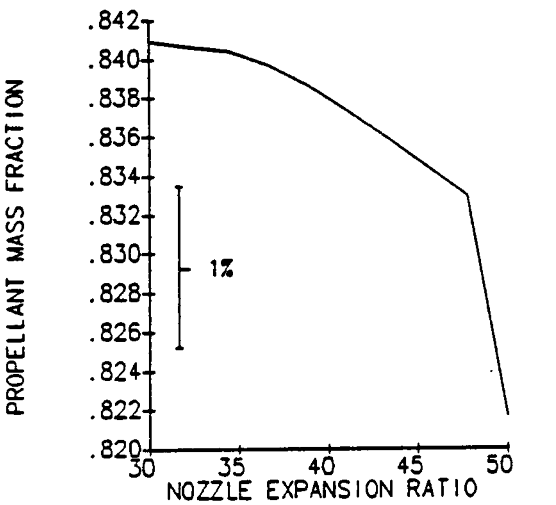


(b-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

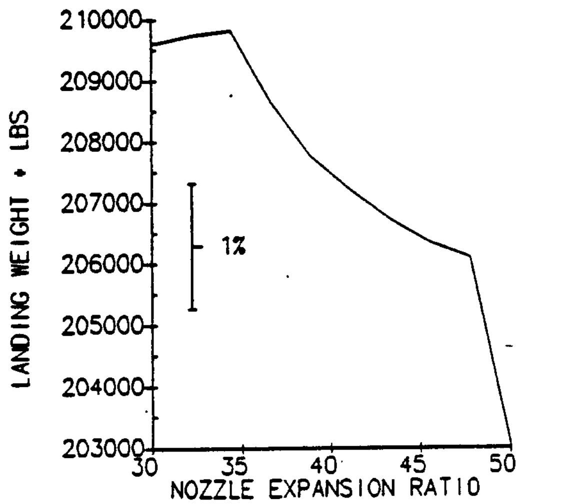


(b-84) Propellant Consumed Versus Nozzle Expansion Ratio

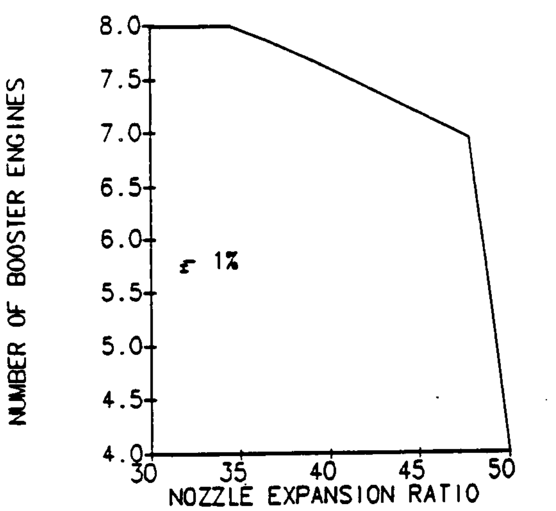
Configuration 2.B Sensitivity Studies (Continued)



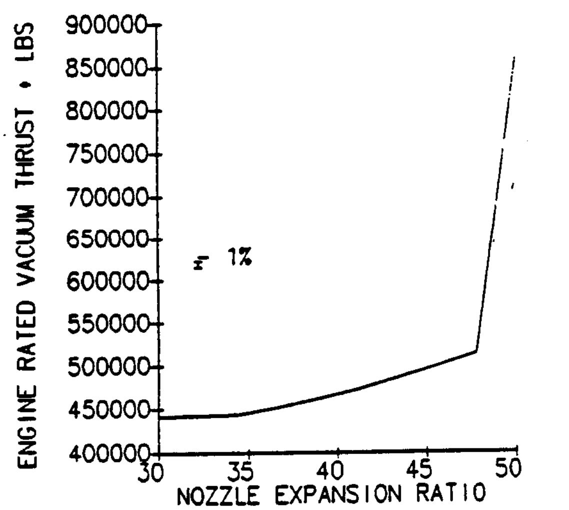
(b-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(b-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

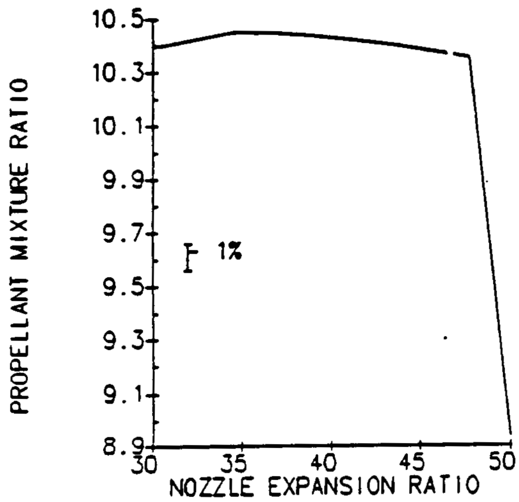


(b-87) Number of Booster Engines Versus Nozzle Expansion Ratio

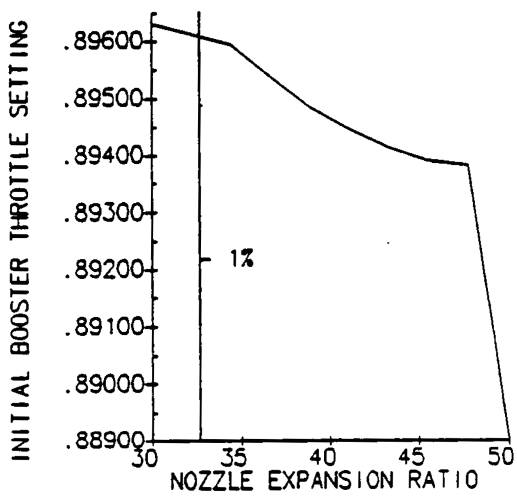


(b-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

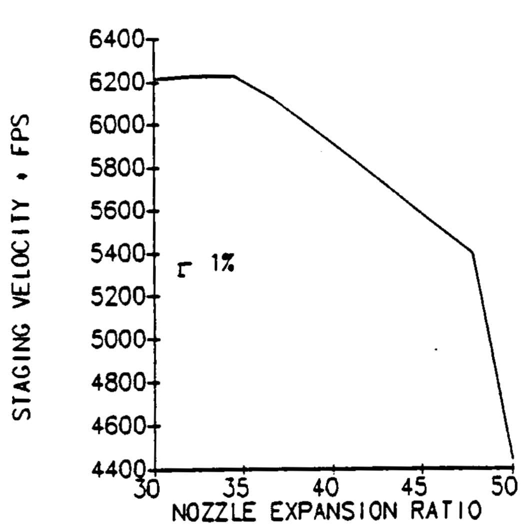
Configuration 2.B Sensitivity Studies (Continued)



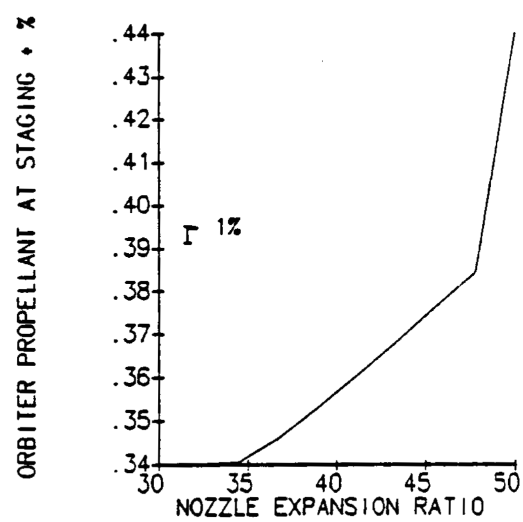
(b-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(b-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

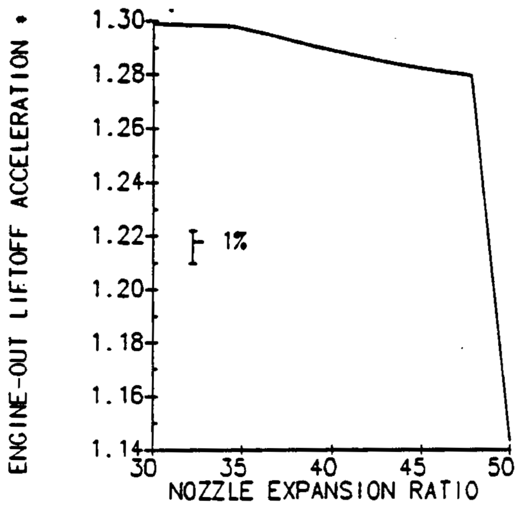


(b-91) Staging Velocity Versus Nozzle Expansion Ratio

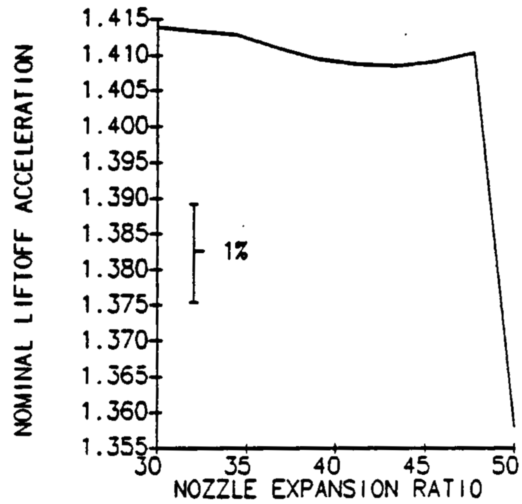


(b-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

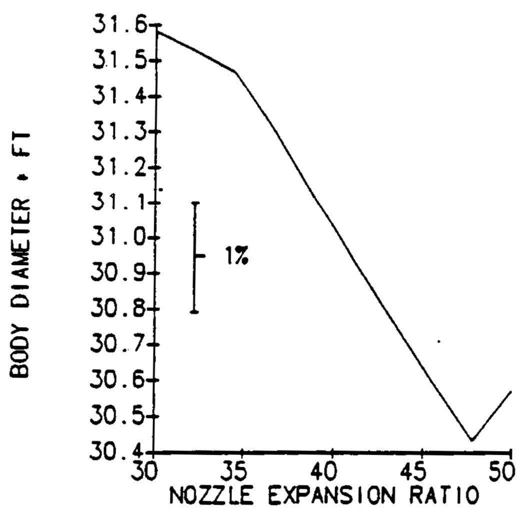
Configuration 2.B Sensitivity Studies (Continued)



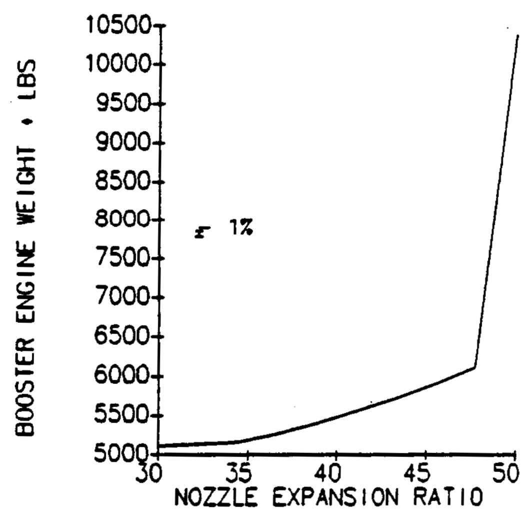
(b-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(b-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

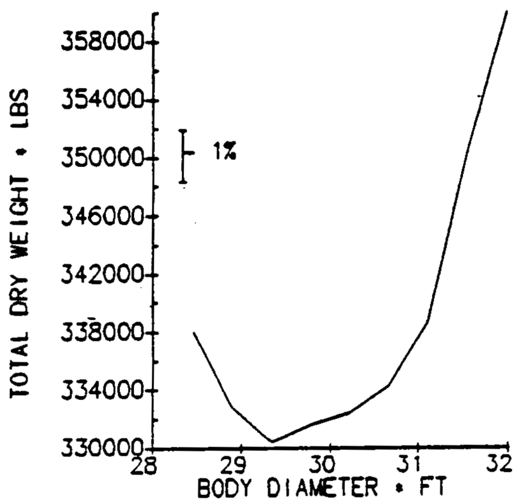


(b-95) Body Diameter Versus Nozzle Expansion Ratio

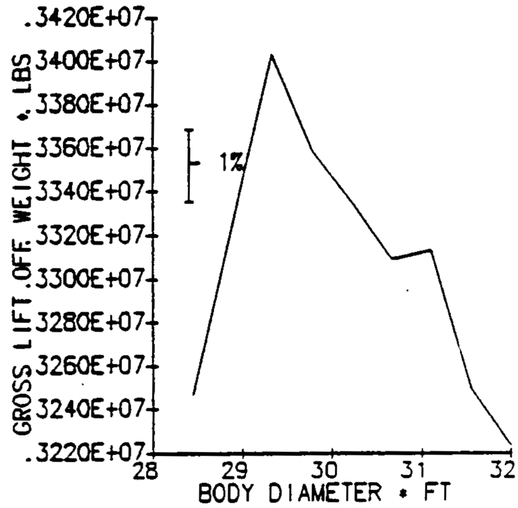


(b-96) Booster Engine Weight Versus Nozzle Expansion Ratio

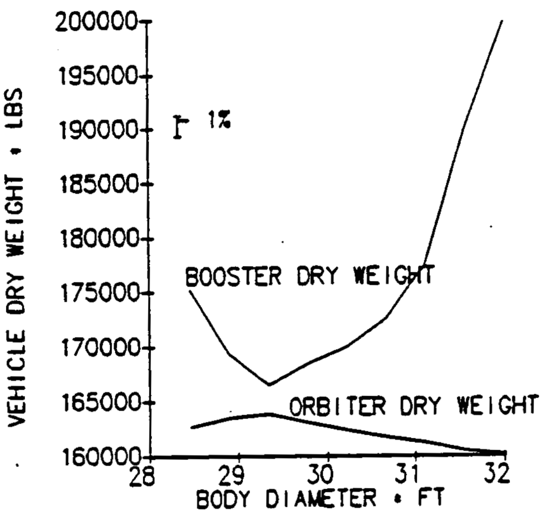
Configuration 2.B Sensitivity Studies (Continued)



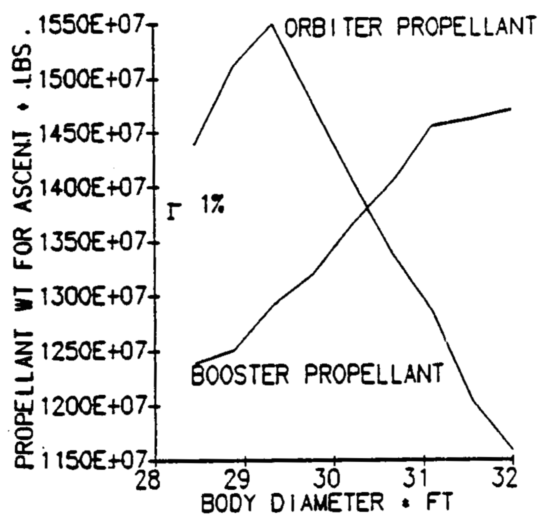
(c-1) **Total Dry Weight Versus Body Diameter**



(c-2) **Gross Lift Off Weight Versus Body Diameter**

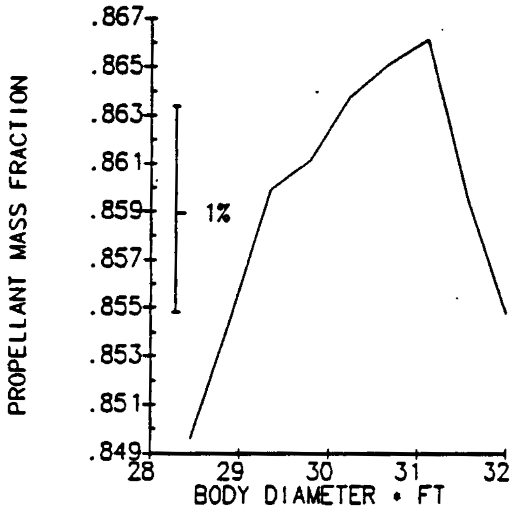


(c-3) **Vehicle Dry Weight Versus Body Diameter**

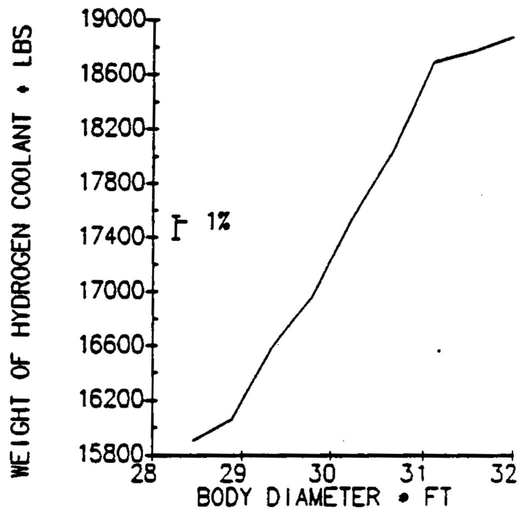


(c-4) **Propellant Consumed Versus Body Diameter**

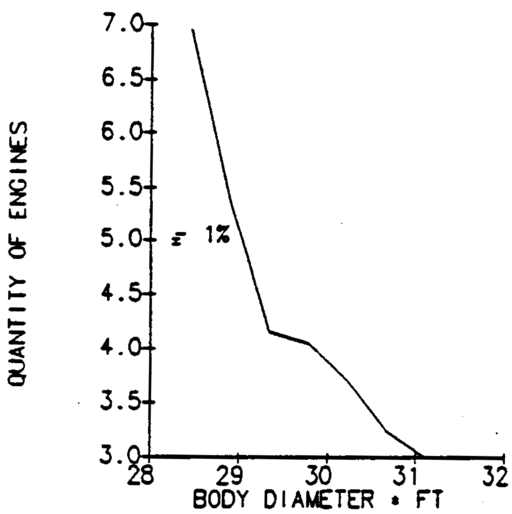
Configuration 2.C Sensitivity Studies



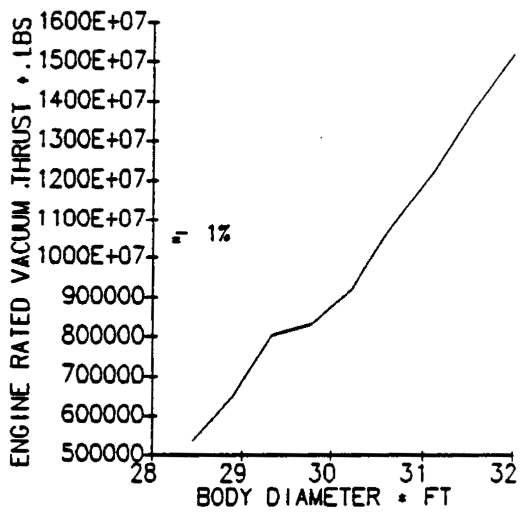
(c-5) **Propellant Mass Fraction Versus Body Diameter**



(c-6) **Weight of Hydrogen Coolant Versus Body Diameter**

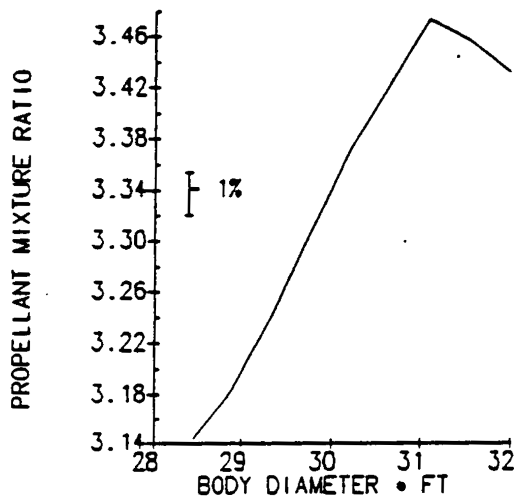


(c-7) **Number of Booster Engines Versus Body Diameter**

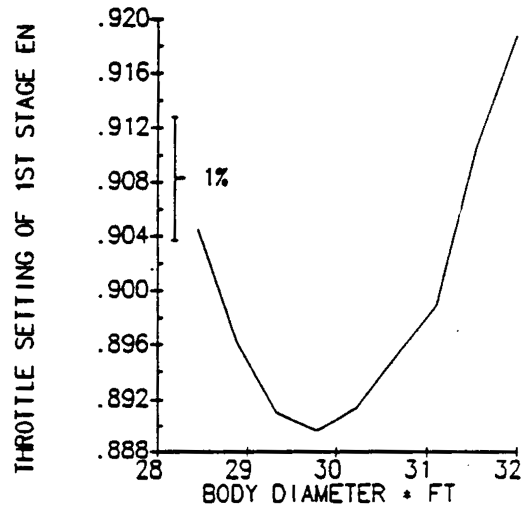


(c-8) **Engine Rated Vacuum Thrust Versus Body Diameter**

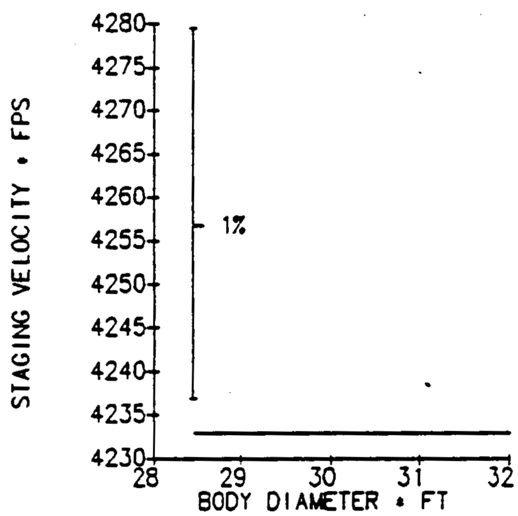
Configuration 2.C Sensitivity Studies (Continued)



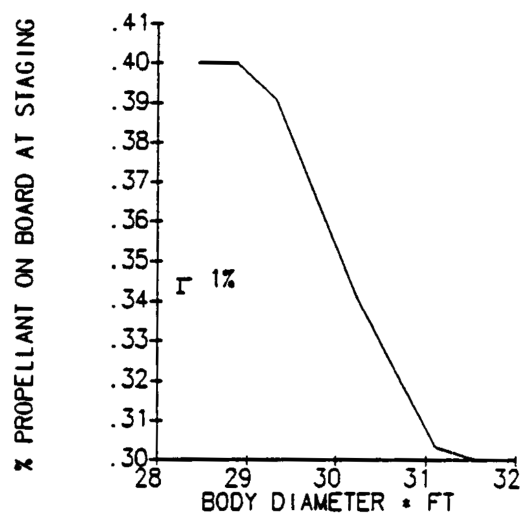
(c-9) Propellant Mixture Ratio Versus Body Diameter



(c-10) Initial Booster Throttle Setting Versus Body Diameter

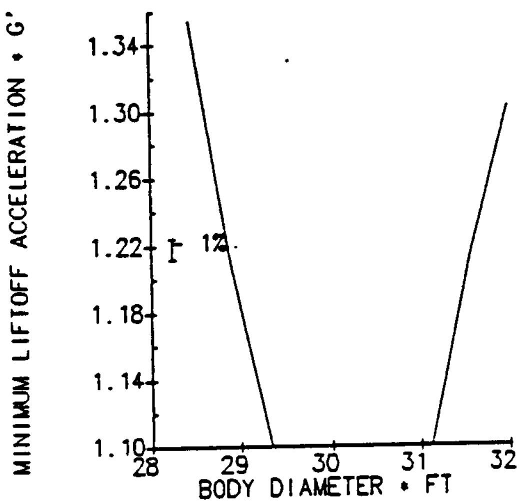


(c-11) Staging Velocity Versus Body Diameter

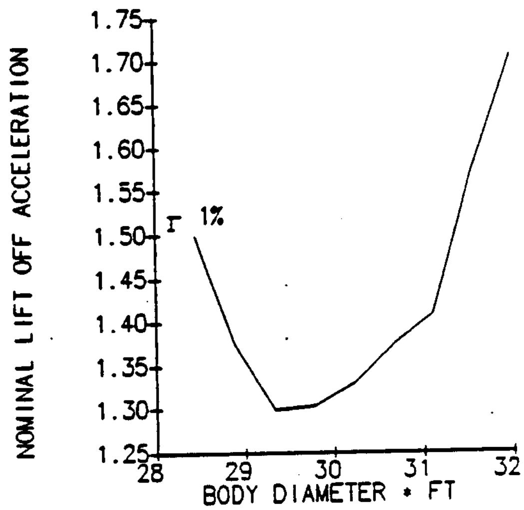


(c-12) Orbiter Propellant at Staging Versus Body Diameter

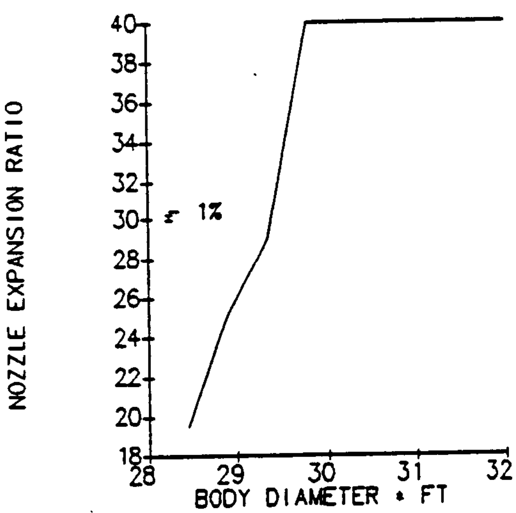
Configuration 2.C Sensitivity Studies (Continued)



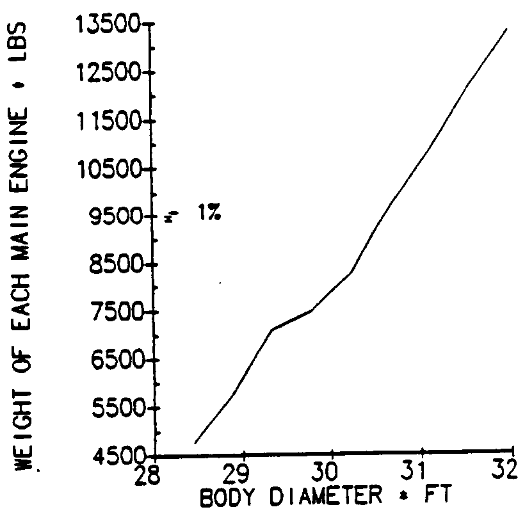
(c-13) Engine-out Lift Off Acceleration Versus Body Diameter



(c-14) Nominal Lift Off Acceleration Versus Body Diameter

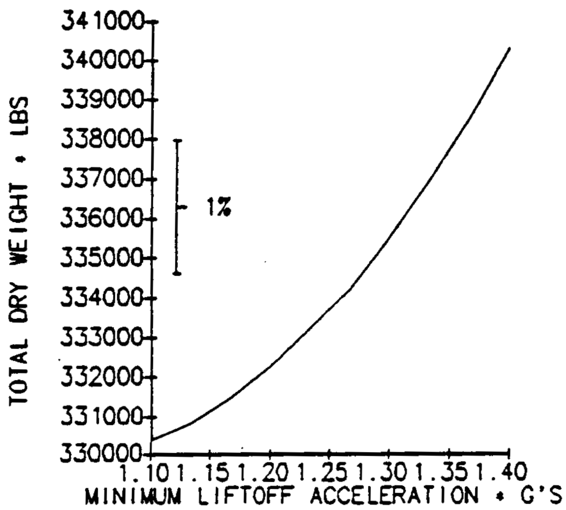


(c-15) Nozzle Expansion Ratio Versus Body Diameter

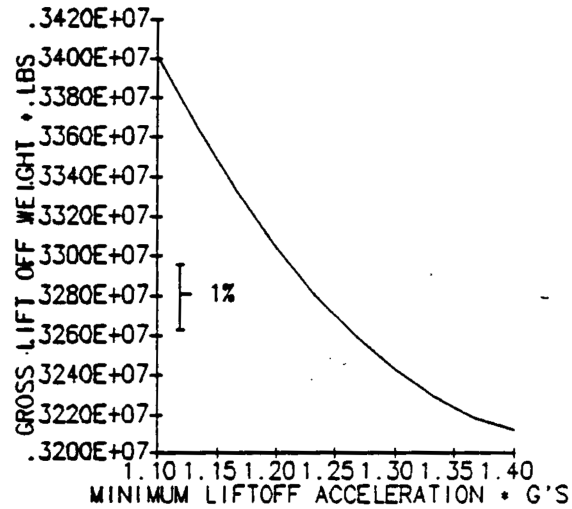


(c-16) Booster Engine Weight Versus Body Diameter

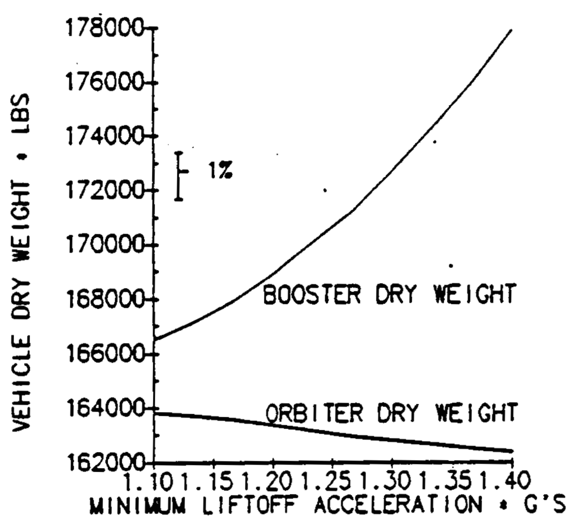
Configuration 2.C Sensitivity Studies (Continued)



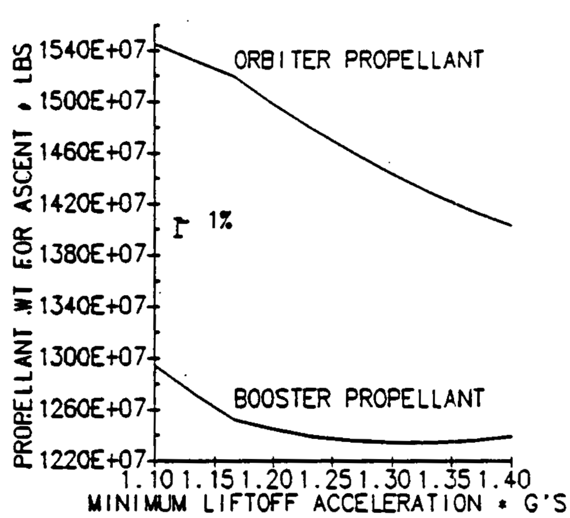
(c-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(c-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

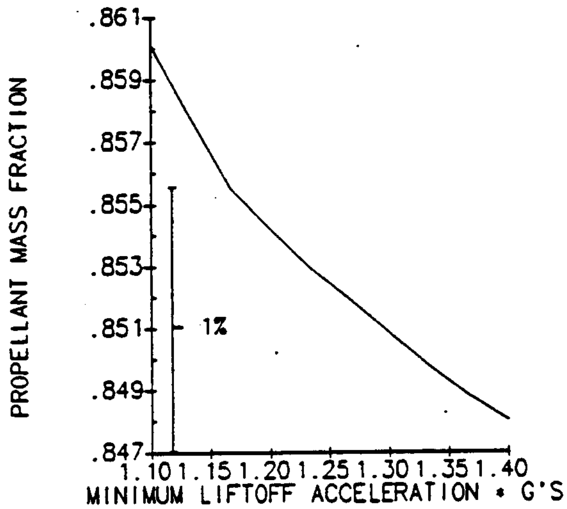


(c-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

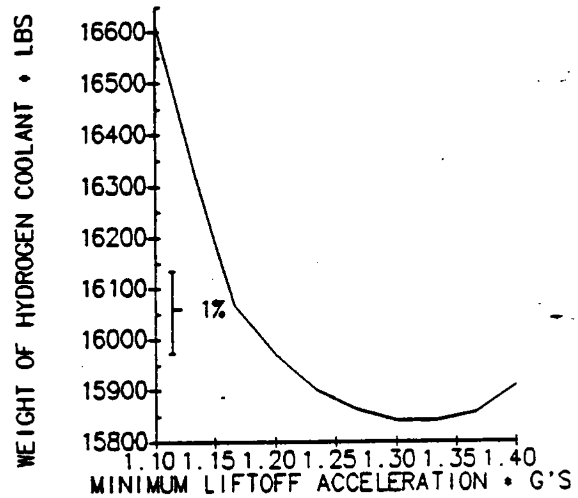


(c-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

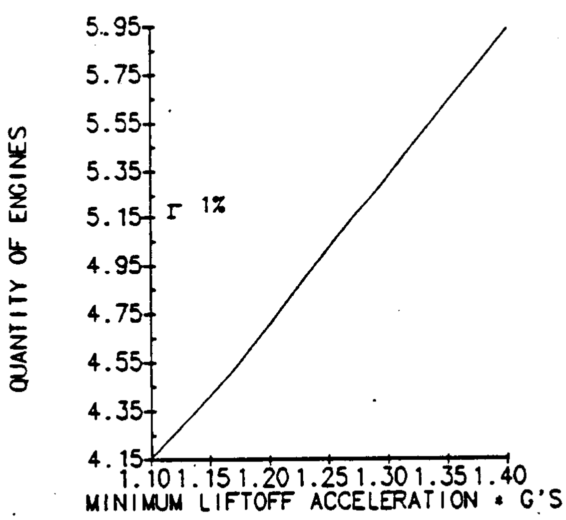
Configuration 2.C Sensitivity Studies (Continued)



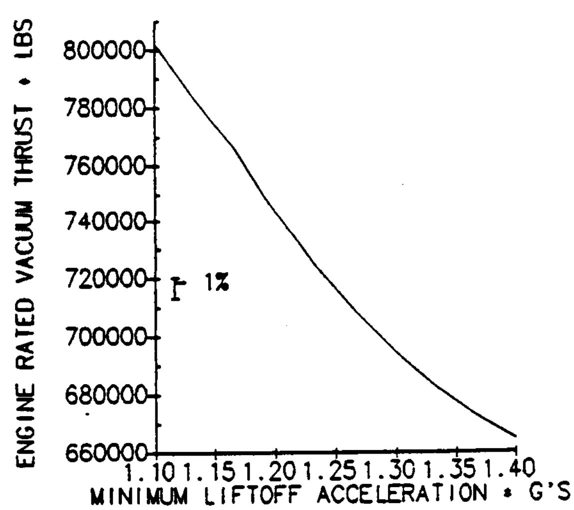
(c-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(c-22) Weight of Hydrogen Coolant Versus Engine-out Lift Off Acceleration

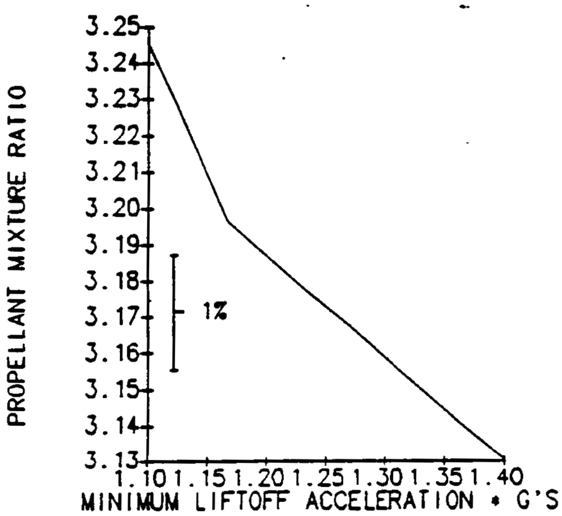


(c-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

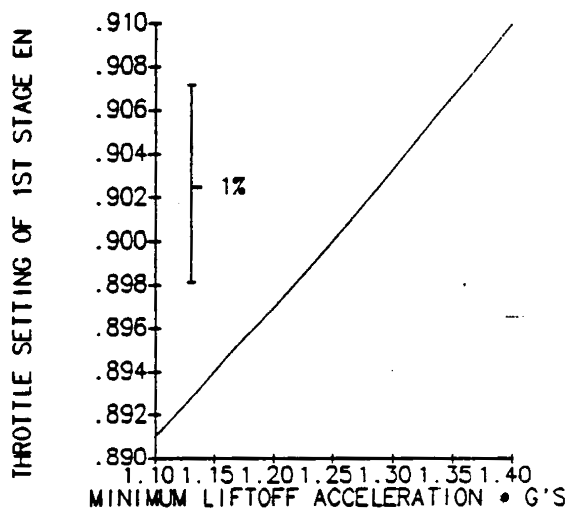


(c-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

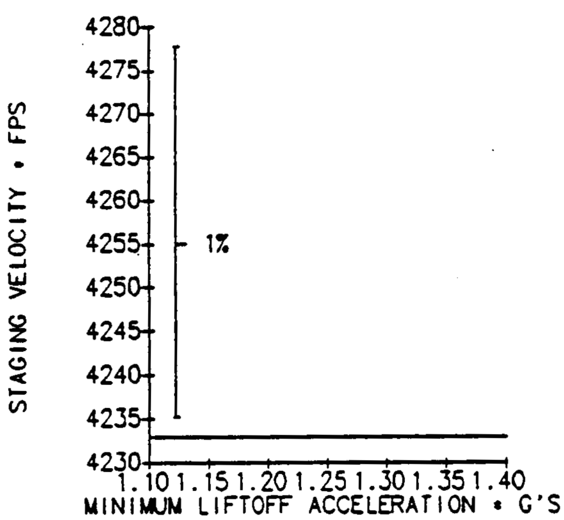
Configuration 2.C Sensitivity Studies (Continued)



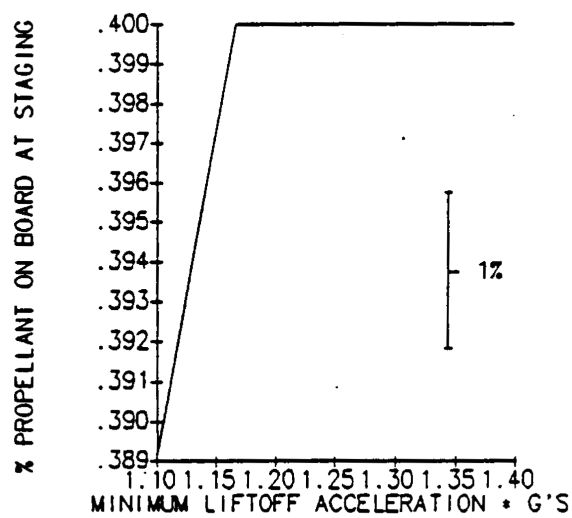
(c-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(c-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

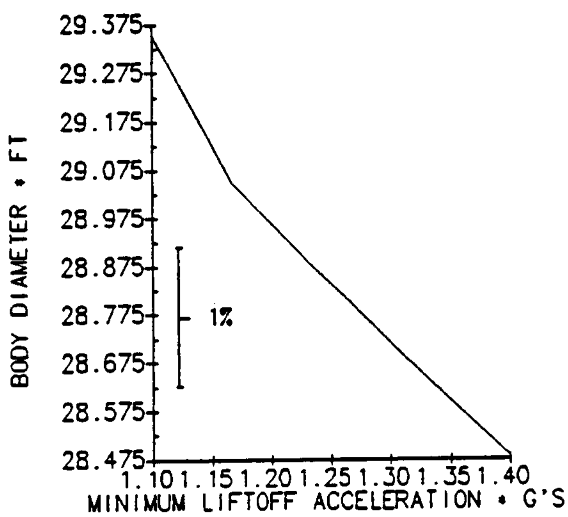


(c-27) Staging Velocity Versus Engine-out Lift Off Acceleration

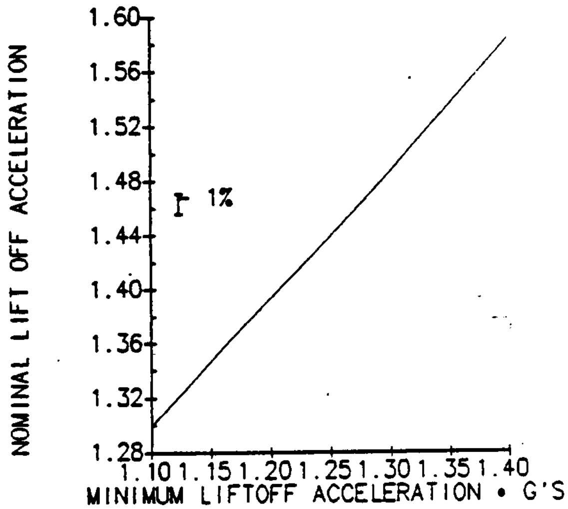


(c-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

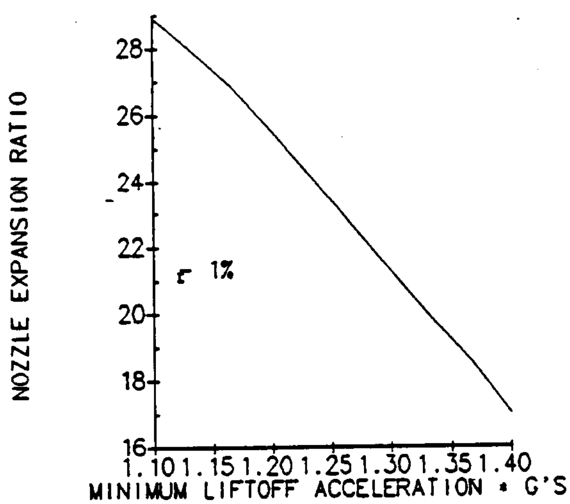
Configuration 2.C Sensitivity Studies (Continued)



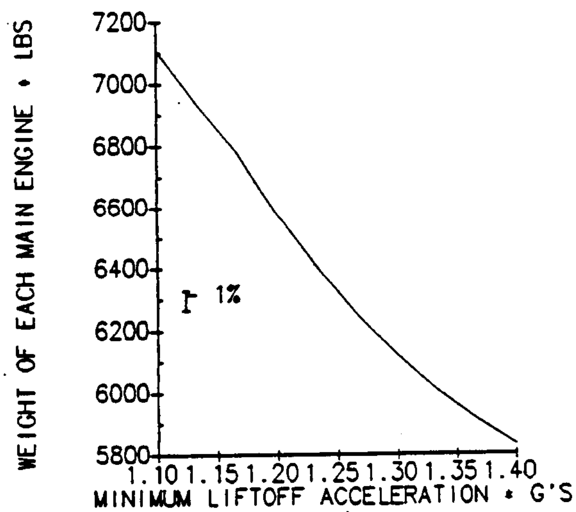
(c-29) Body Diameter Versus Engine-out Lift Off Acceleration



(c-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

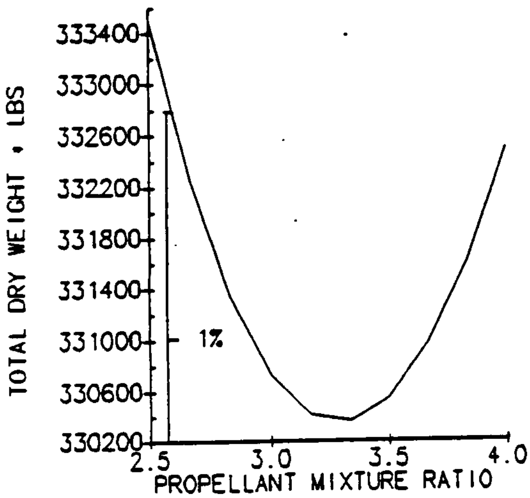


(c-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

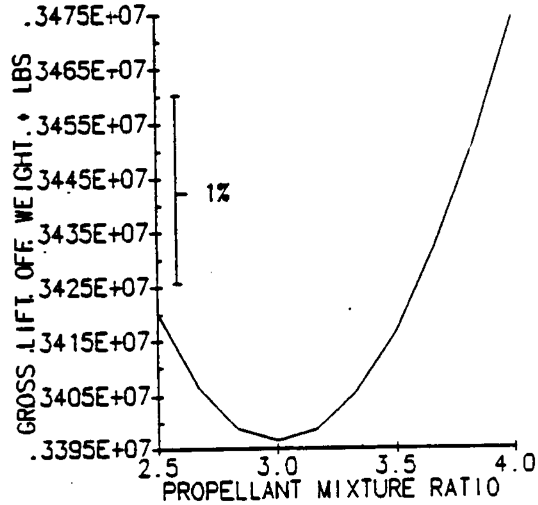


(c-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

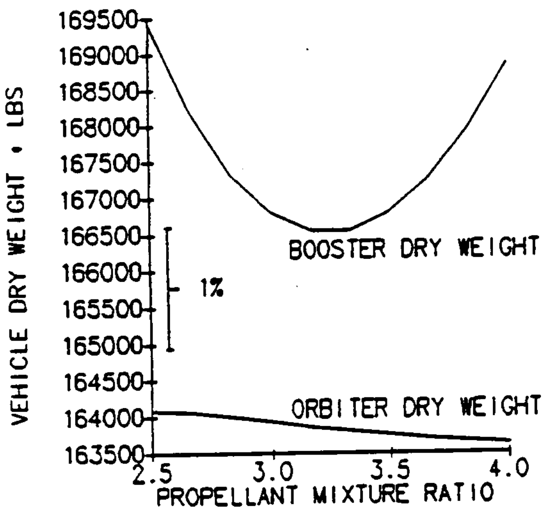
Configuration 2.C Sensitivity Studies (Continued)



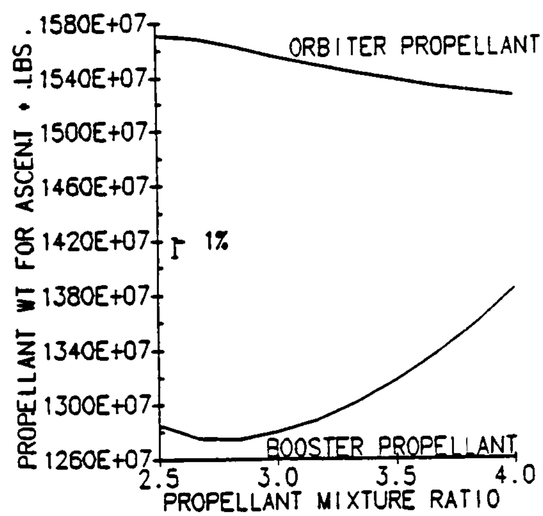
(c-33) Total Dry Weight Versus Propellant Mixture Ratio



(c-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

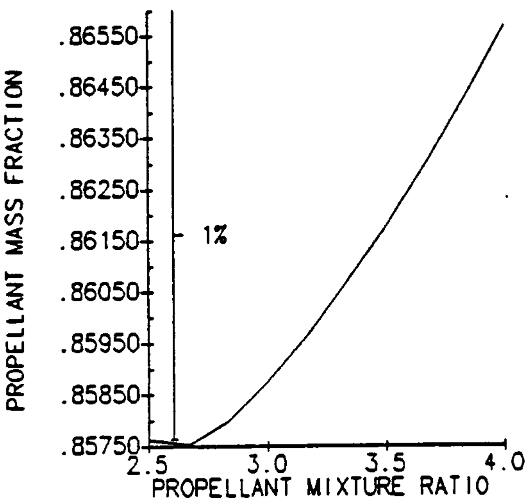


(c-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

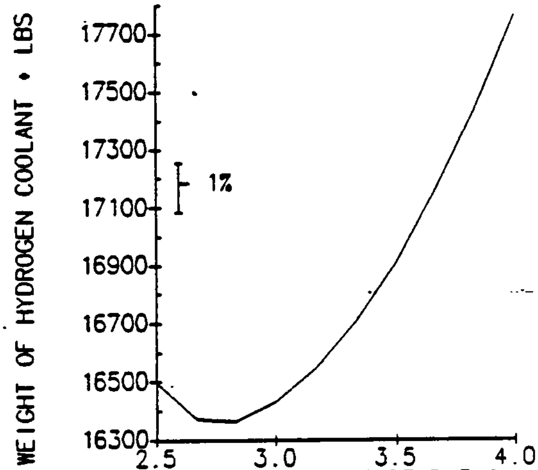


(c-36) Propellant Consumed Versus Propellant Mixture Ratio

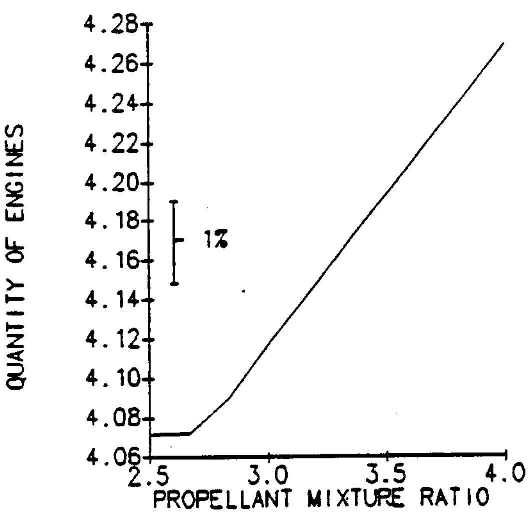
Configuration 2.C Sensitivity Studies (Continued)



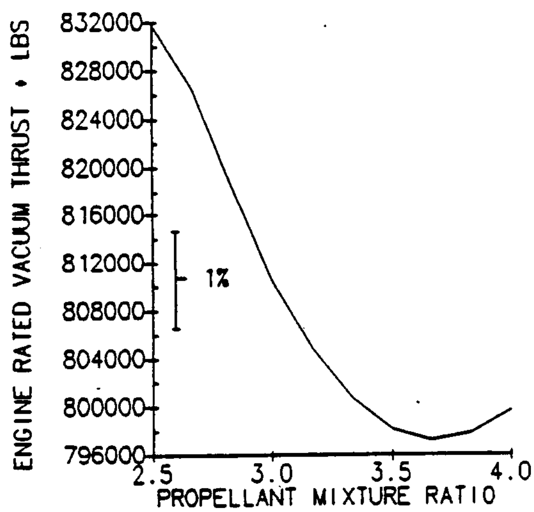
(c-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(c-38) Weight of Hydrogen Coolant Versus Propellant Mixture Ratio

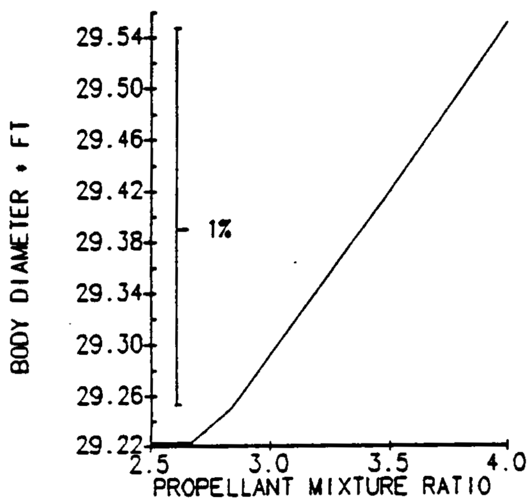


(c-39) Number of Booster Engines Versus Propellant Mixture Ratio

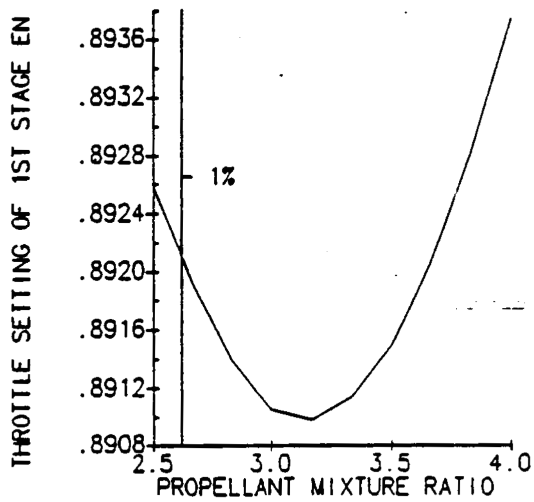


(c-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

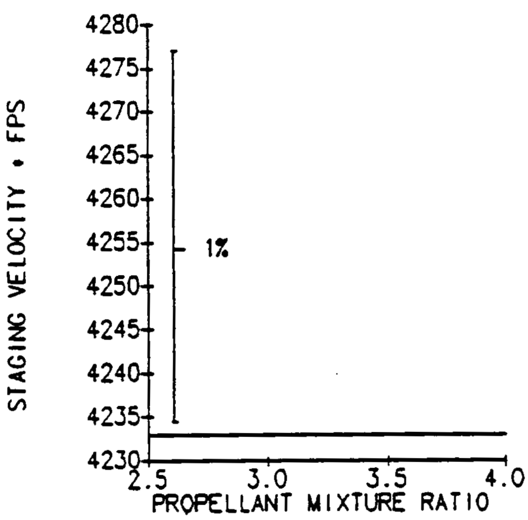
Configuration 2.C Sensitivity Studies (Continued)



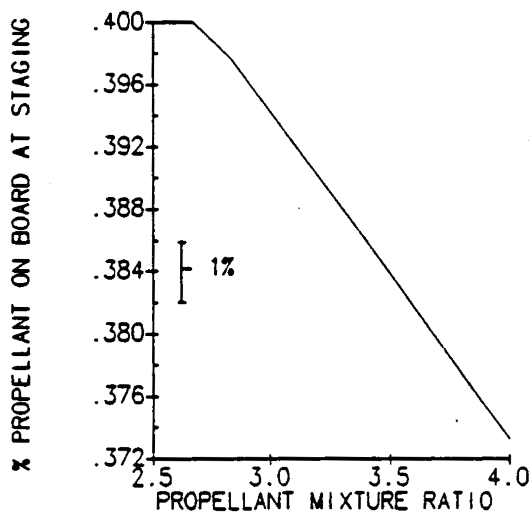
(c-41) Body Diameter Versus Prupellant Mixture Ratio



(c-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

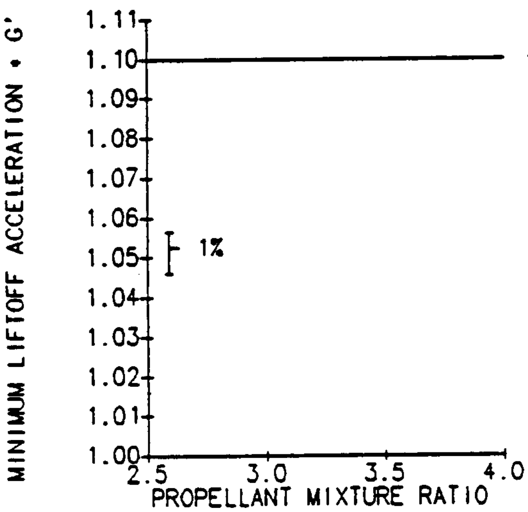


(c-43) Staging Velocity Versus Propellant Mixture Ratio

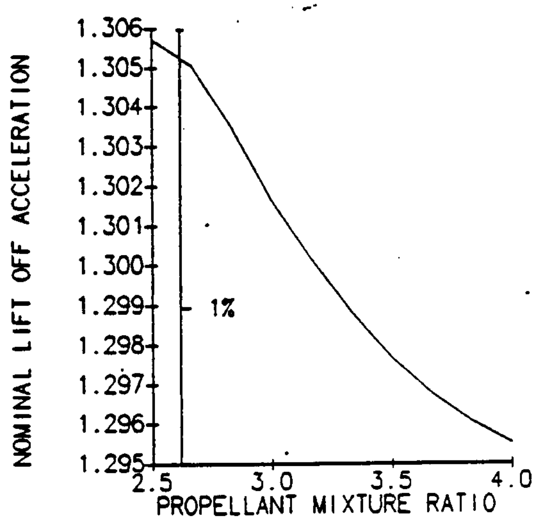


(.-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

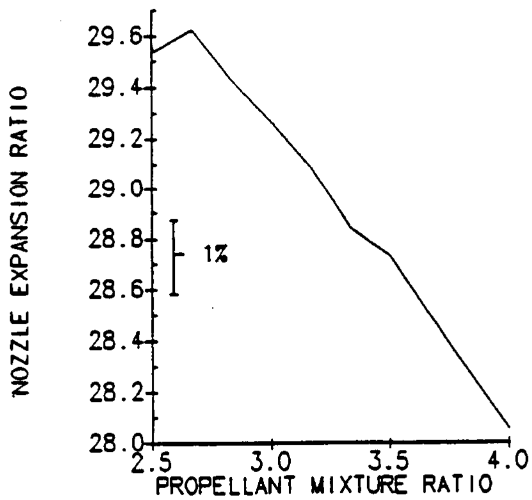
Configuration 2.C Sensitivity Studies (Continued)



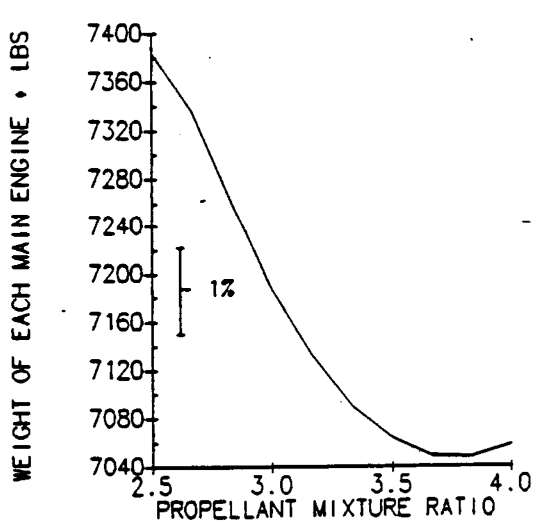
(c-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(c-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

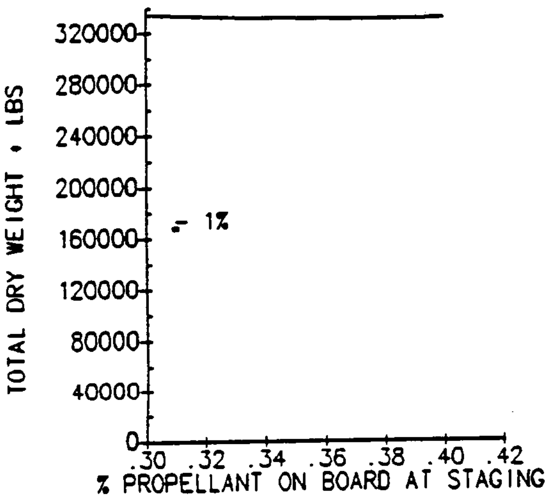


(c-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

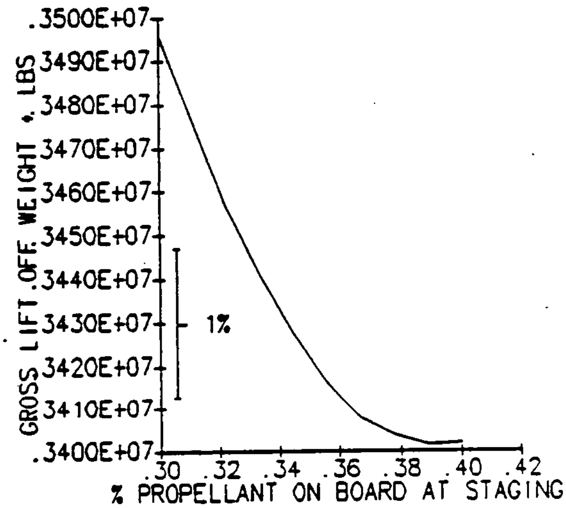


(c-48) Booster Engine Weight Versus Propellant Mixture Ratio

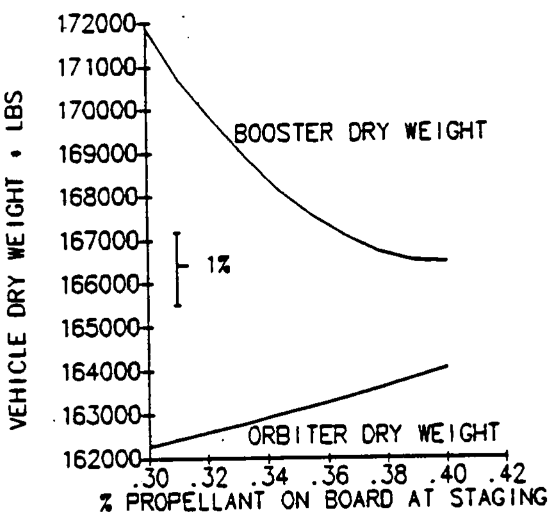
Configuration 2.C Sensitivity Studies (Continued)



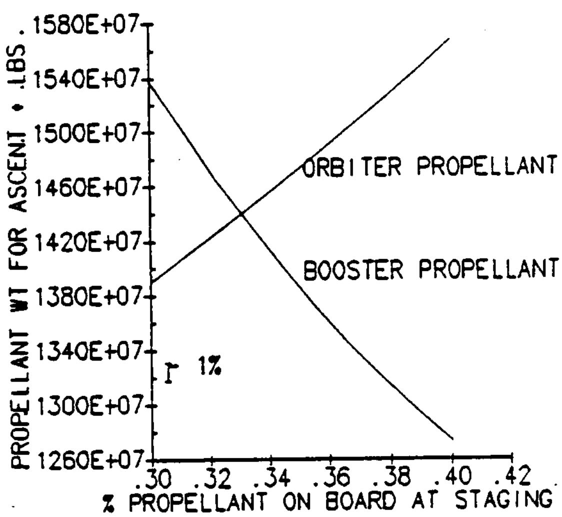
(c-49) Total Dry Weight Versus Orbiter Propellant at Staging



(c-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

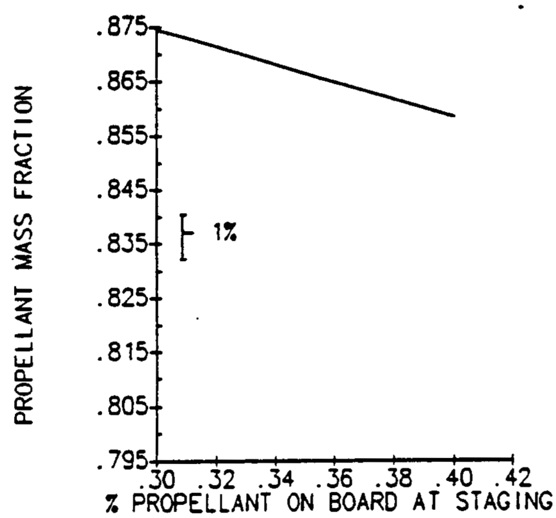


(c-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

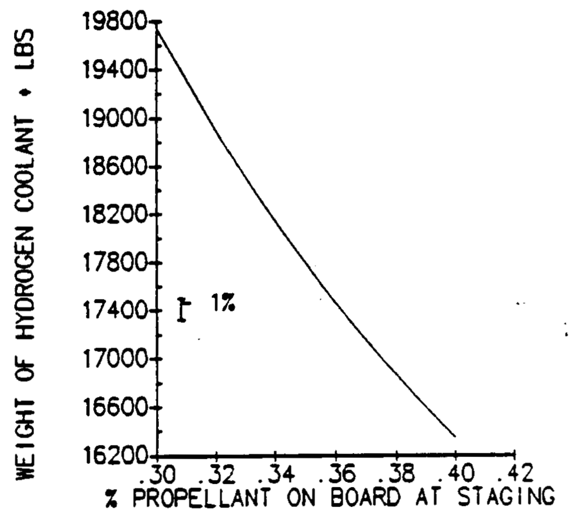


(c-52) Propellant Consumed Versus Orbiter Propellant at Staging

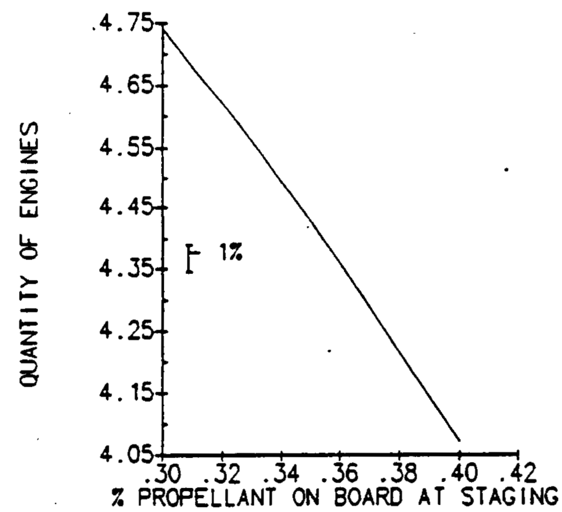
Configuration 2.C Sensitivity Studies (Continued)



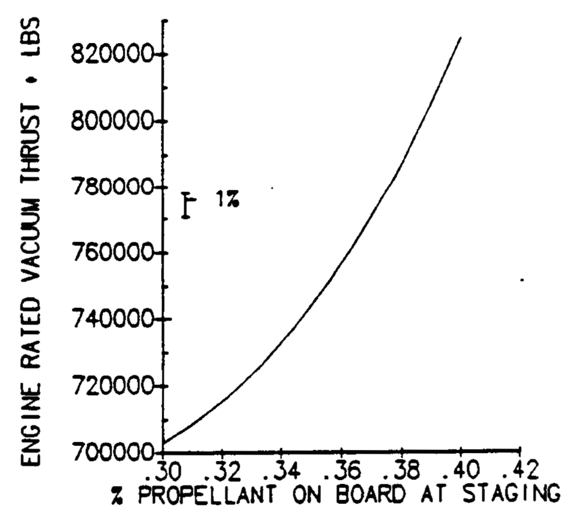
(c-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(c-54) Weight of Hydrogen Coolant Versus Orbiter Propellant at Staging

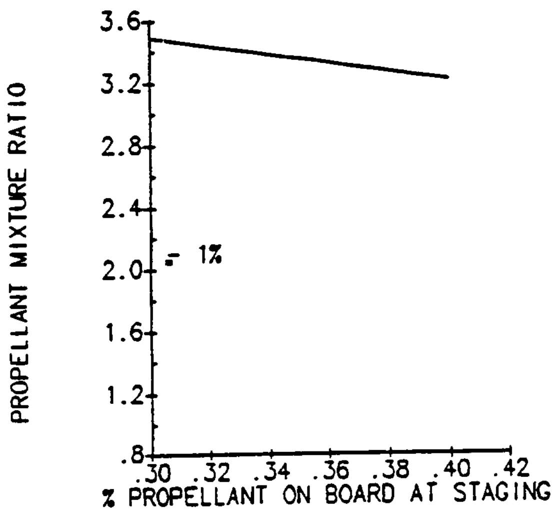


(c-55) Numbar of Booster Engines Versus Orbiter Propellant at Staging

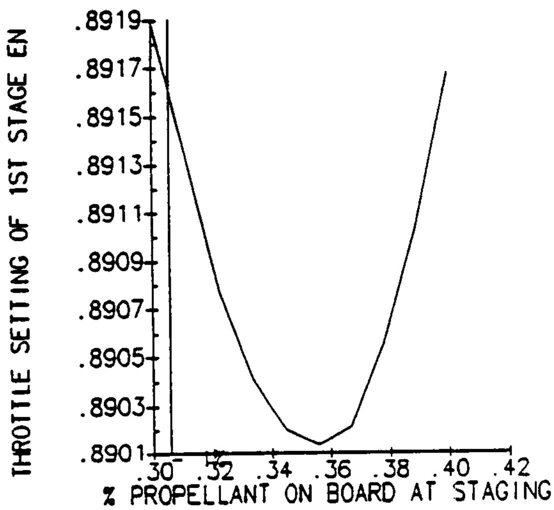


(c-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

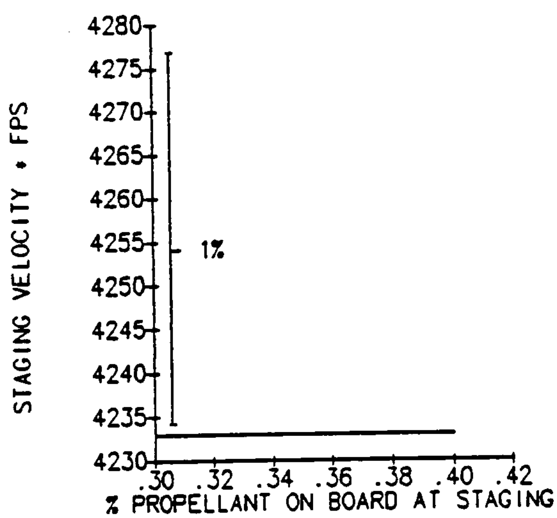
Configuration 2.C Sensitivity Studies (Continued)



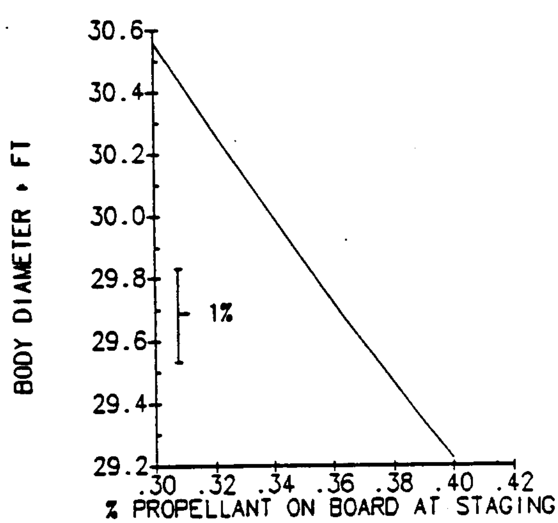
(c-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(c-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

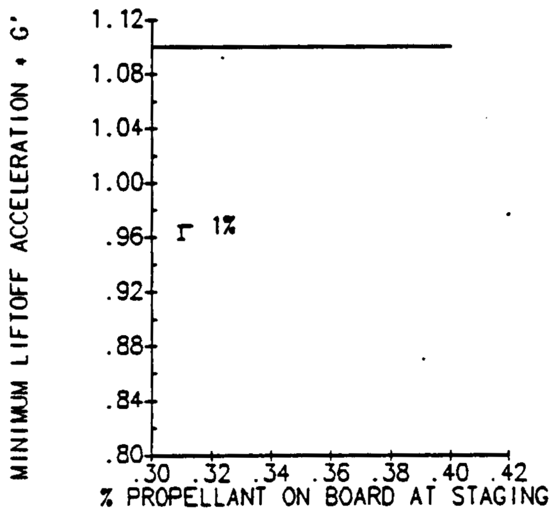


(c-59) Staging Velocity Versus Orbiter Propellant at Staging

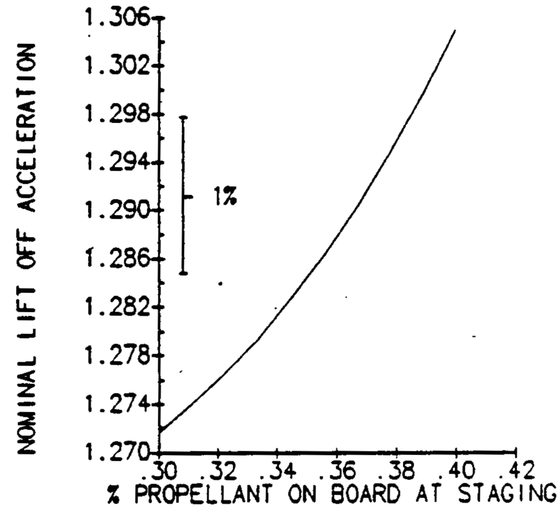


(c-60) Body Diameter Versus Orbiter Propellant at Staging

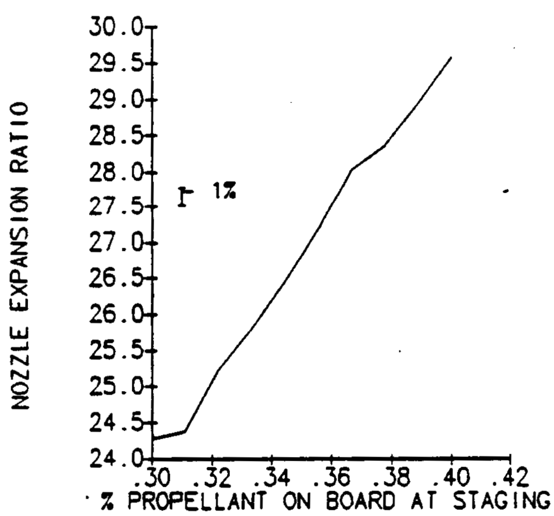
Configuration 2.C Sensitivity Studies (Continued)



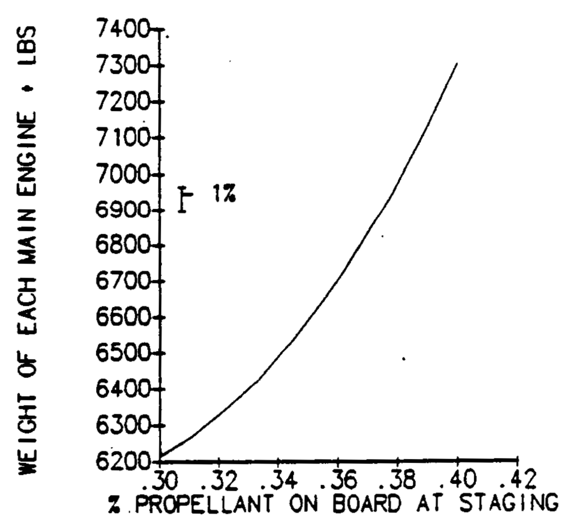
(c-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(c-62) Nominal Lift Off Acceleration Versus Propellant on Boad at Staging

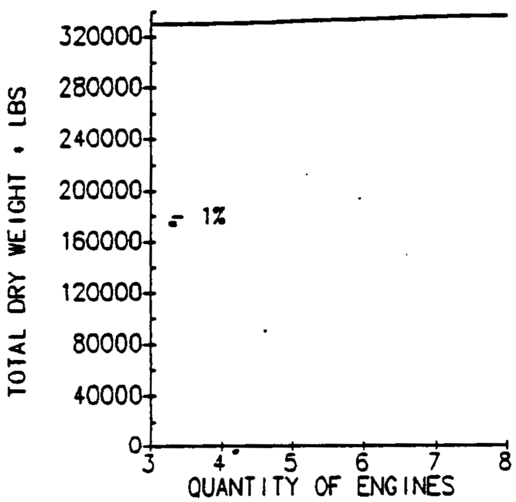


(c-63) Nozzle Expansion Ratio Versus Propellant at Staging

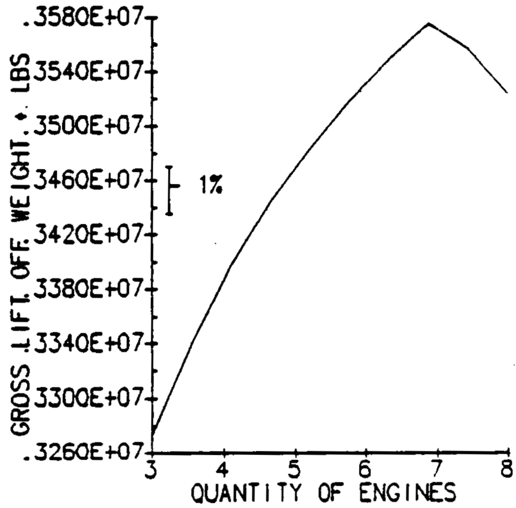


(c-64) Booster E.igine Weight Versus Propellant at Staging

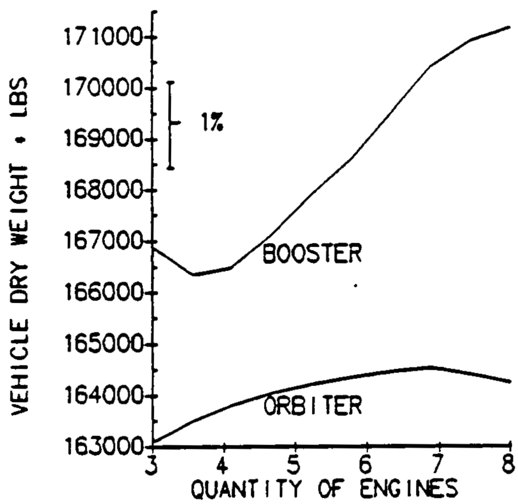
Configuration 2.C Sensitivity Studies (Continued)



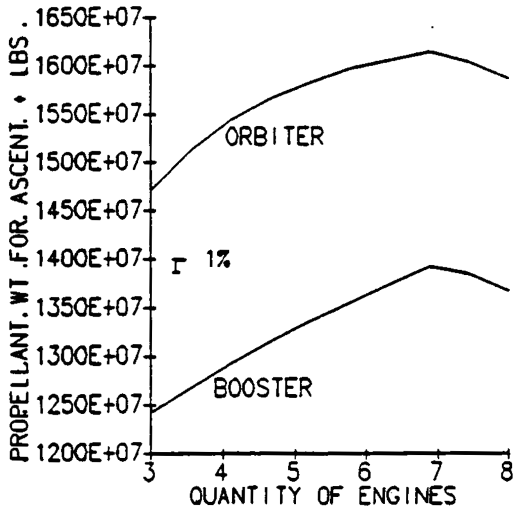
(c-65) Total Dry Weight Versus Number of Booster Engines



(c-66) Gross Lift Off Weight Versus Number of Booster Engines

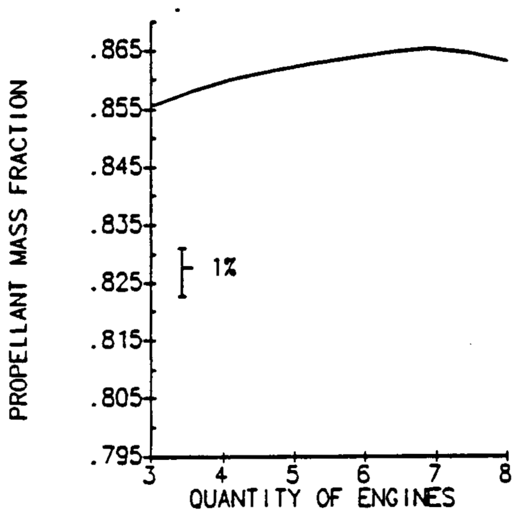


(c-67) Vehicle Dry Weight Versus Number of Booster Engines

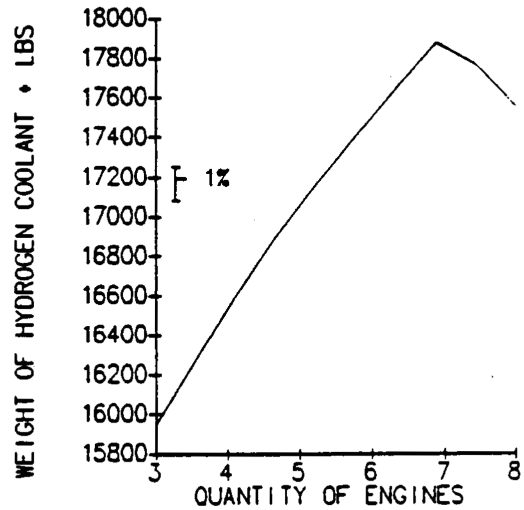


(c-68) Propellant Consumed Versus Number of Booster Engines

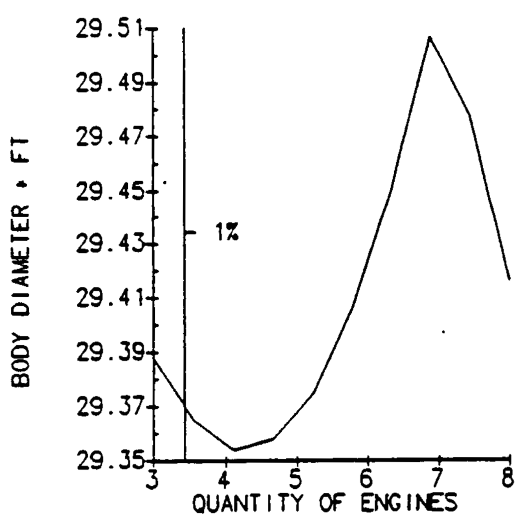
Configuration 2.C Sensitivity Studies (Continued)



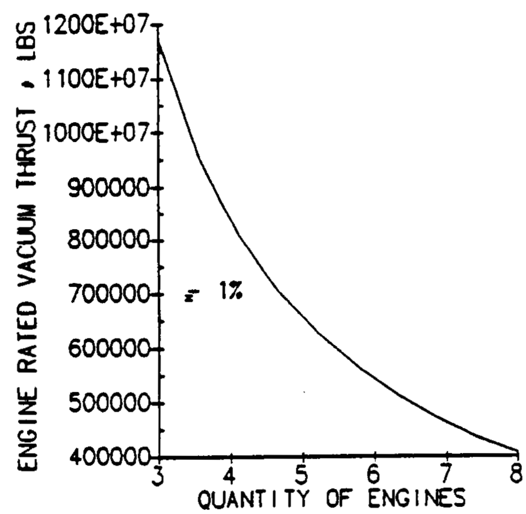
(c-69) Propellant Mass Fraction Versus Number of Booster Engines



(c-70) Weight of Hydrogen Coolant Versus Number of Booster Engines

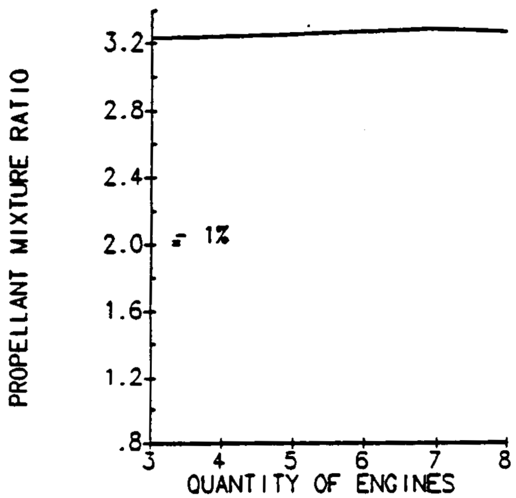


(c-71) Body Diameter Versus Number of Booster Engines

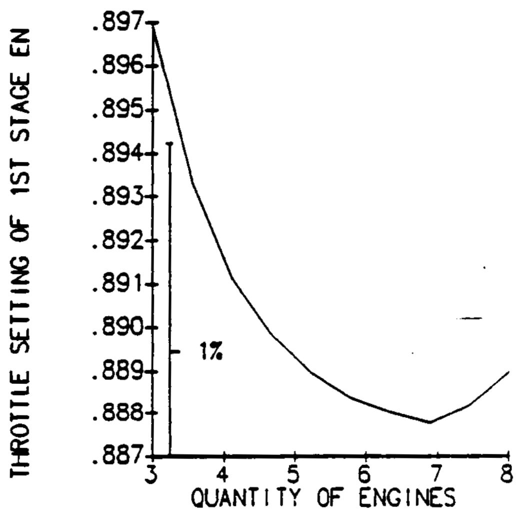


(c-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

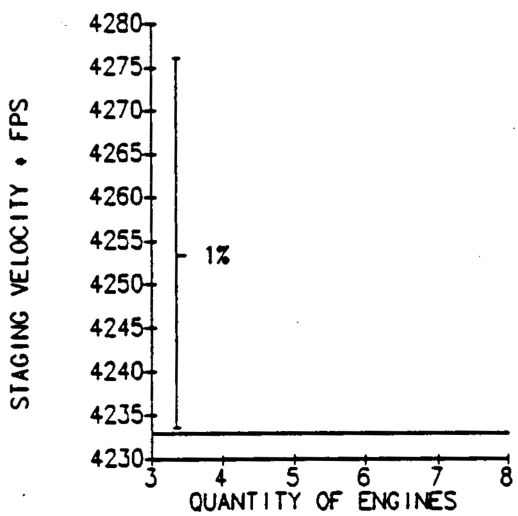
Configuration 2.C Sensitivity Studies (Continued)



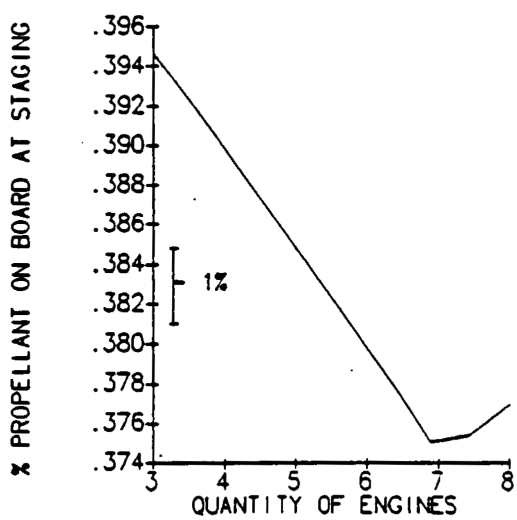
(c-73) Propellant Mixture Ratio Versus Number of Booster Engines



(c-74) Initial Booster Throttle Setting Versus Number of Booster Engines



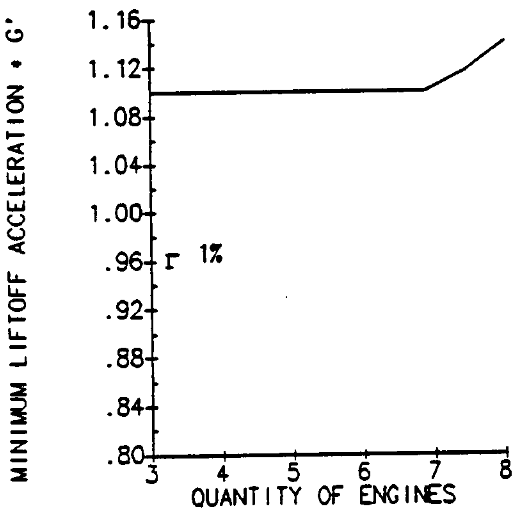
(c-75) Staging Velocity Versus Number of Booster Engines



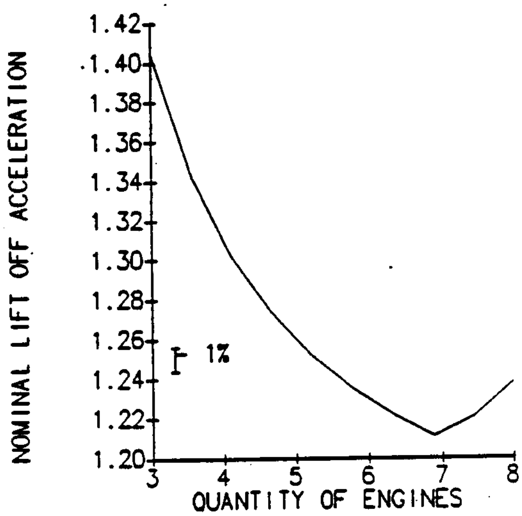
(c-76) Orbiter Propellant at Staging Versus Number of Booster Engines

Configuration 2.C Sensitivity Studies (Continued)

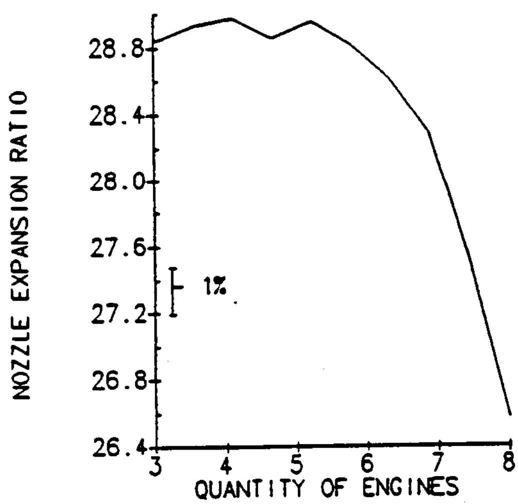
C-4



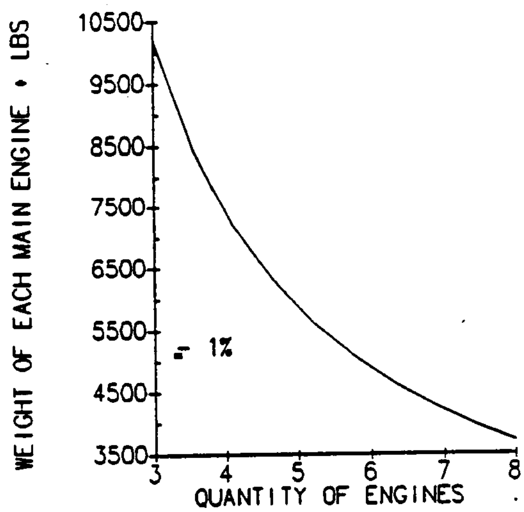
(c-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(c-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

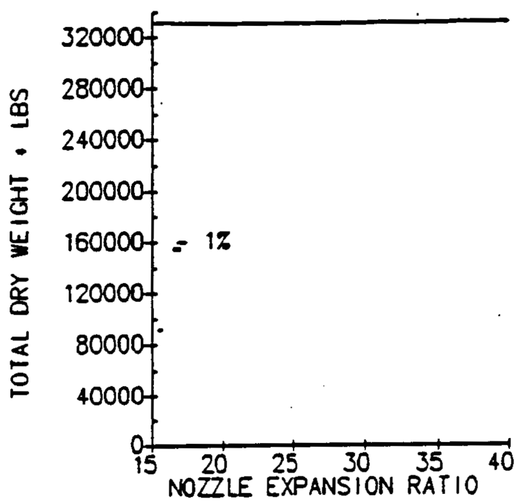


(c-79) Nozzle Expansion Ratic Versus Number of Booster Engines

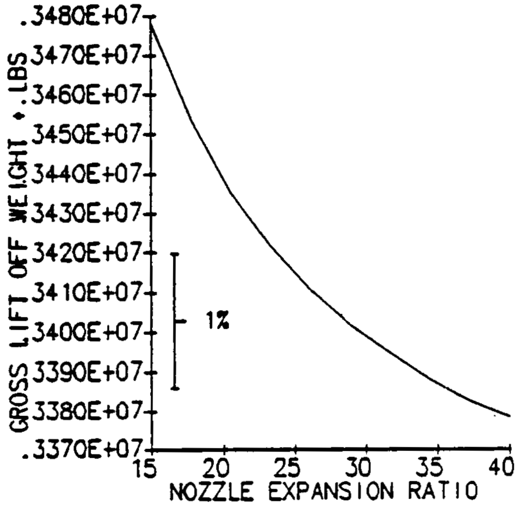


(c-80) Booster Engine Weight Versus Number of Booster Engines

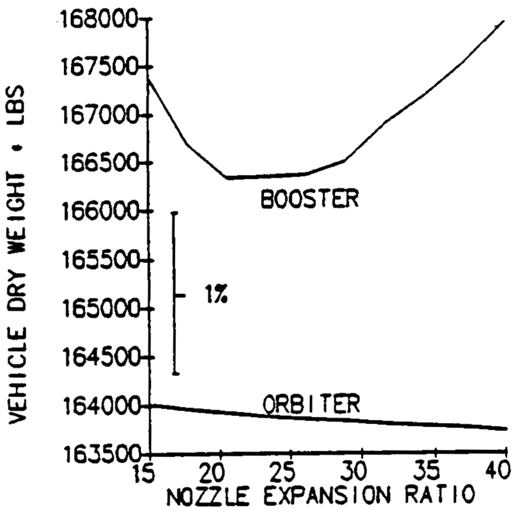
Configuration 2.C Sensitivity Studies (Continued)



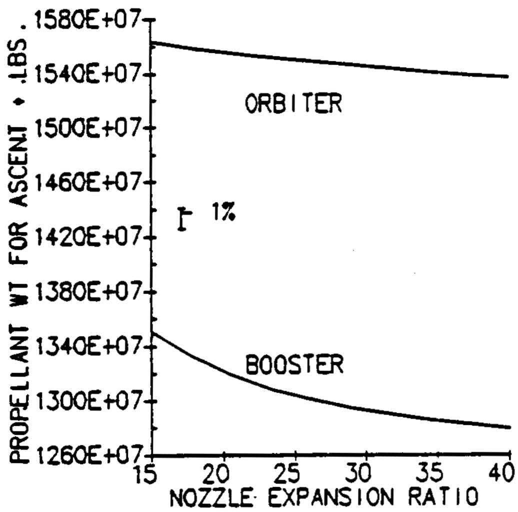
(c-81) Total Dry Weight Versus Nozzle Expansion Ratio



(c-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

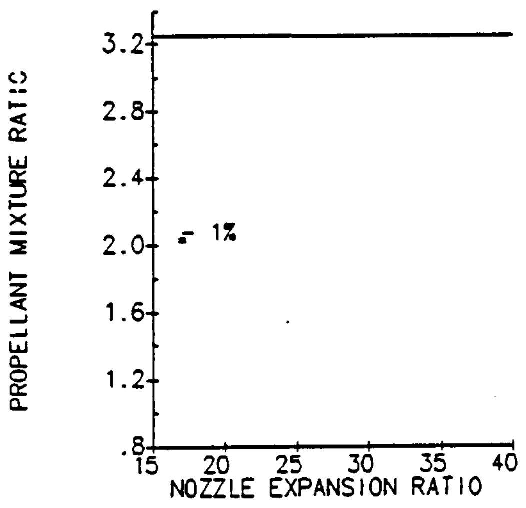


(c-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

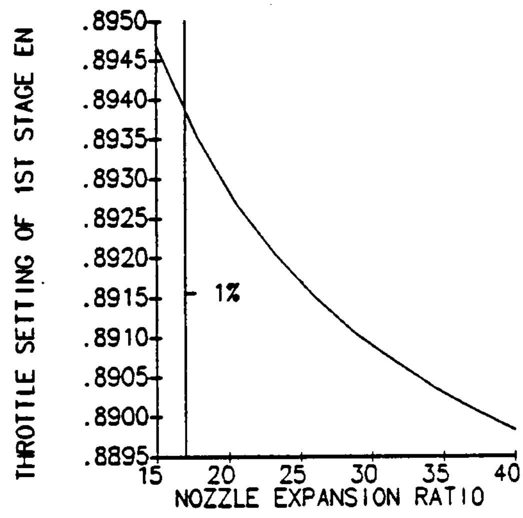


(c-84) Propellant Consumed Versus Nozzle Expansion Ratio

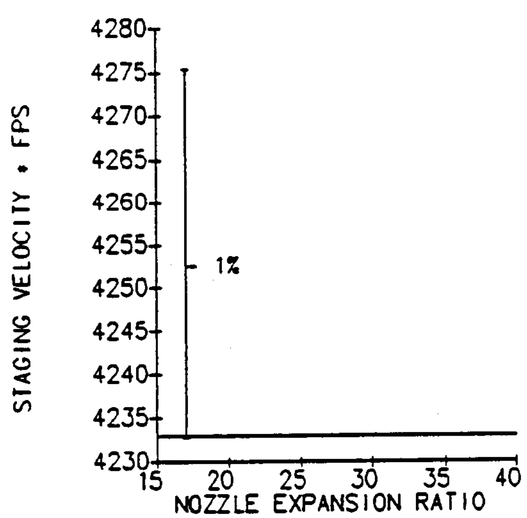
Configuration 2.C Sensitivity Studies (Continued)



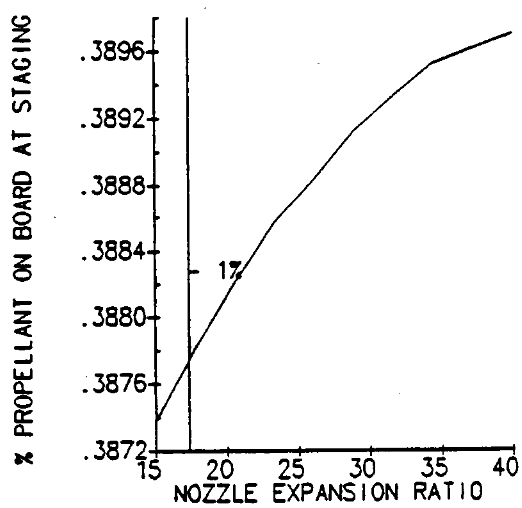
(c-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(c-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

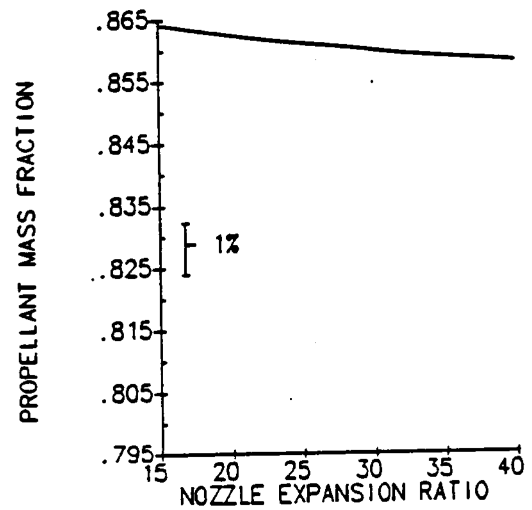


(c-91) Staging Velocity Versus Nozzle Expansion Ratio

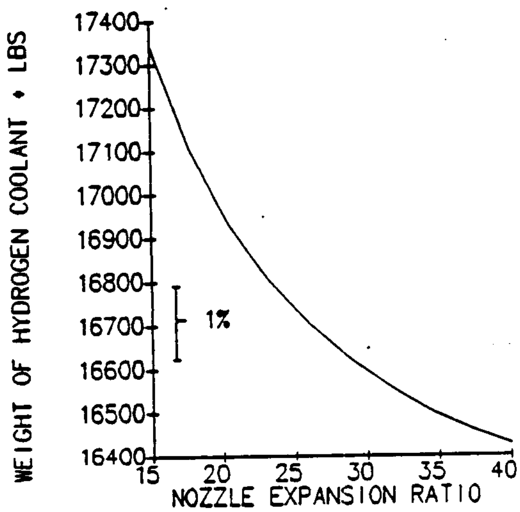


(c-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

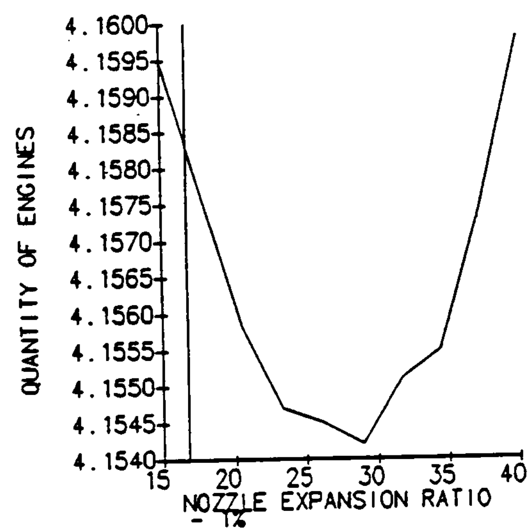
Configuration 2.C Sensitivity Studies (Continued)



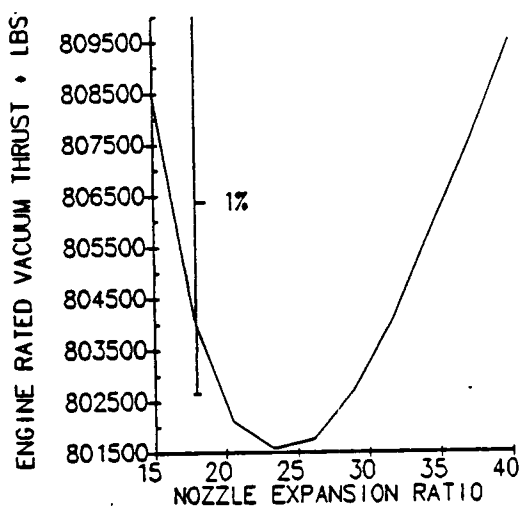
(c-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(c-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

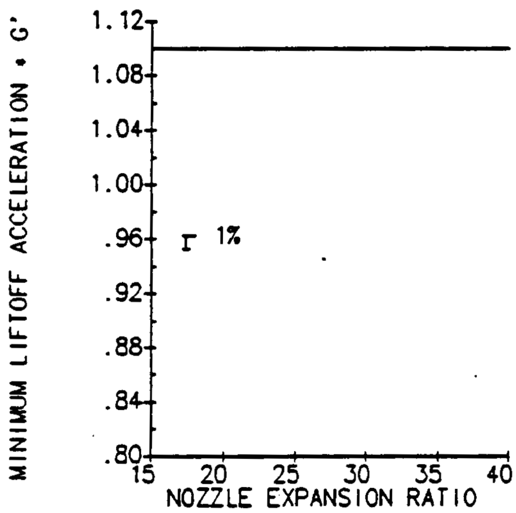


(c-87) Number of Booster Engines Versus Nozzle Expansion Ratio

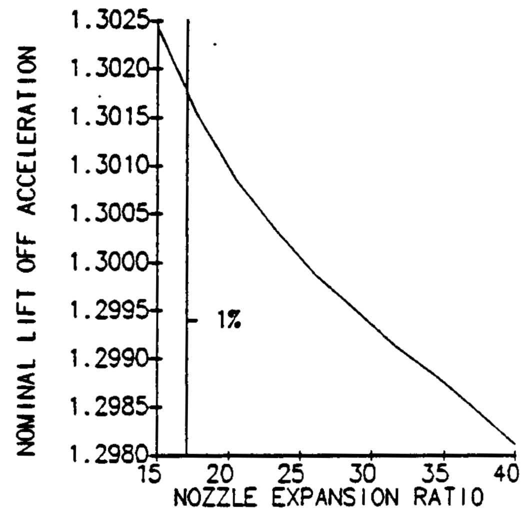


(c-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

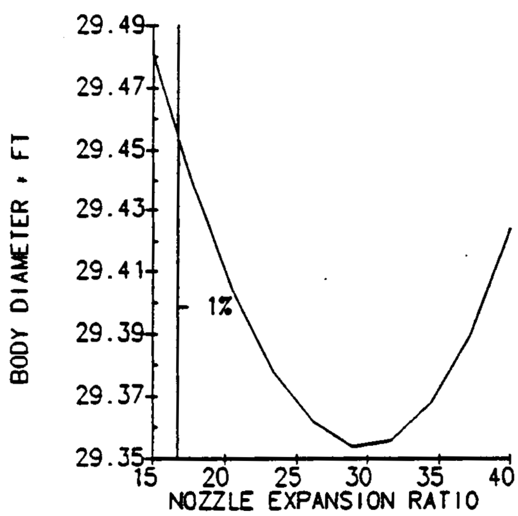
Configuration 2.C Sensitivity Studies (Continued)



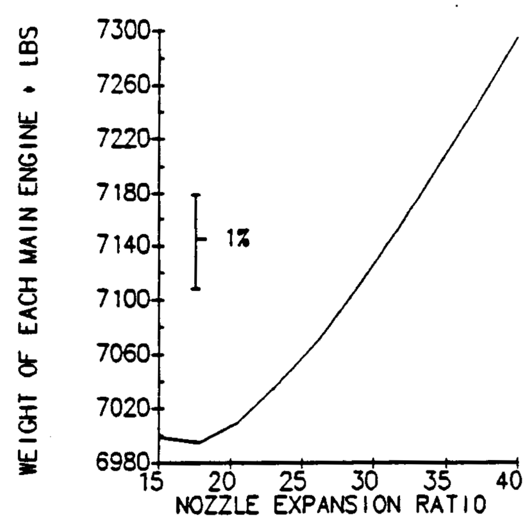
(c-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(c-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

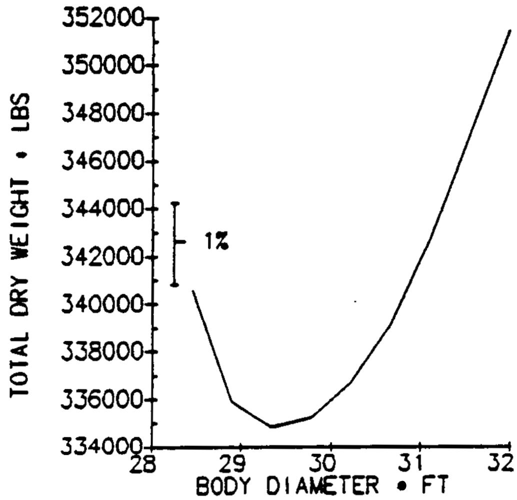


(c-95) Body Diameter Versus Nozzle Expansion Ratio

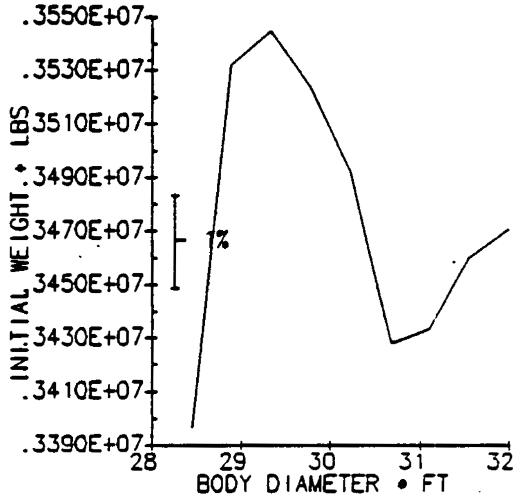


(c-96) Booster Engine Weight Versus Nozzle Expansion Ratio

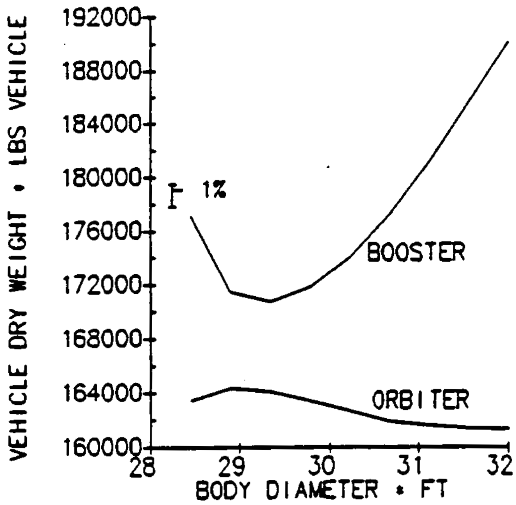
Configuration 2.C Sensitivity Studies (Continued)



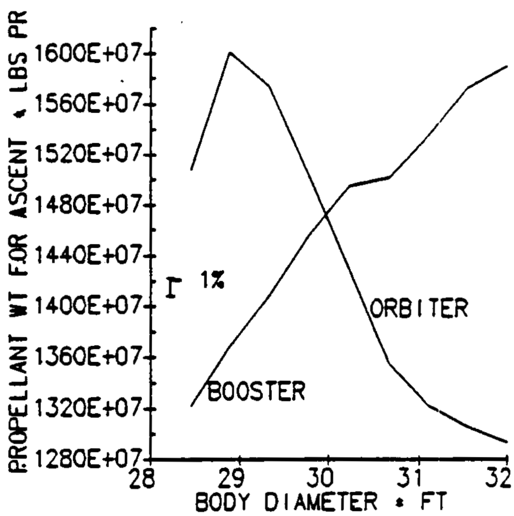
(d-1) Total Dry Weight Versus Body Diameter



(d-2) Gross Lift Off Weight Versus Body Diameter

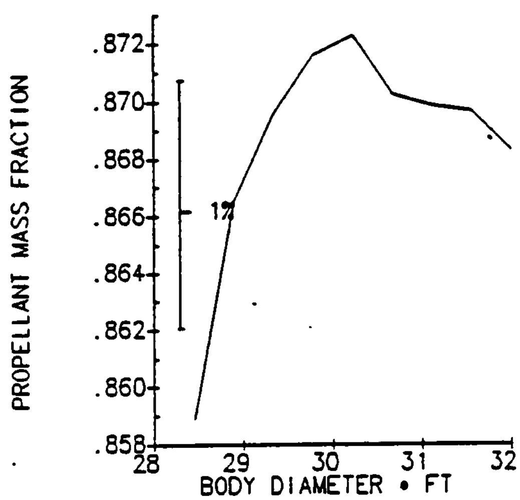


(d-3) Vehicle Dry Weight Versus Body Diameter

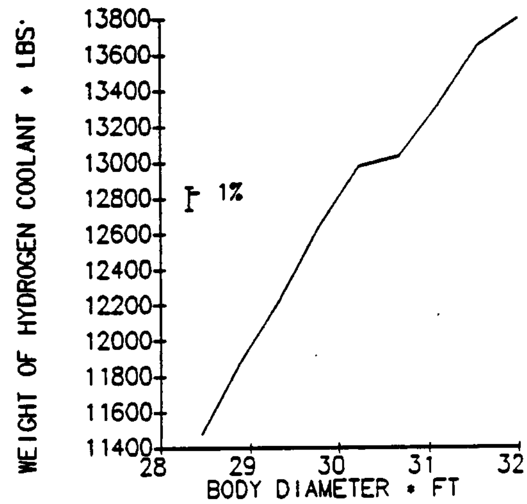


(d-4) Propellant Consumed Versus Body Diameter

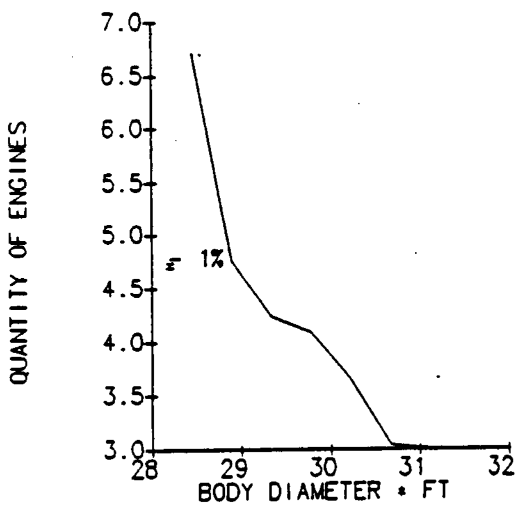
Configuration 2.D Sensitivity Studies



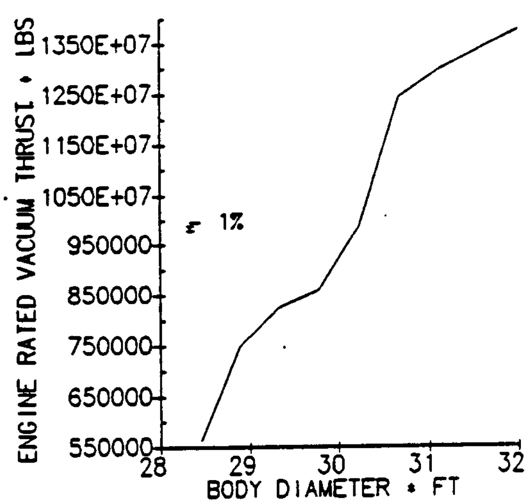
(d-5) Propellant Mass Fraction Versus Body Diameter



(d-6) Weight of Hydrogen Coolant Versus Body Diameter

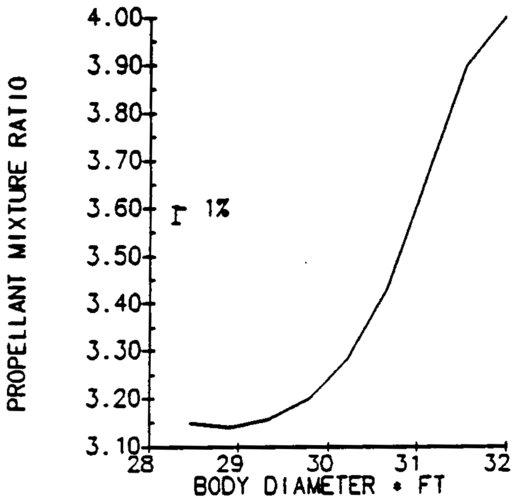


(d-7) Number of Booster Engines Versus Body Diameter

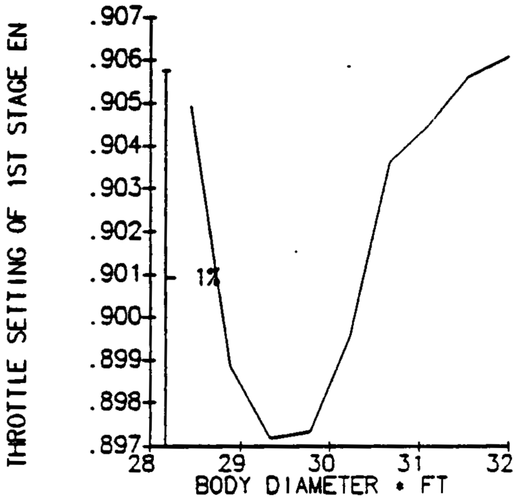


(d-8) Engine Rated Vacuum Thrust Versus Body Diameter

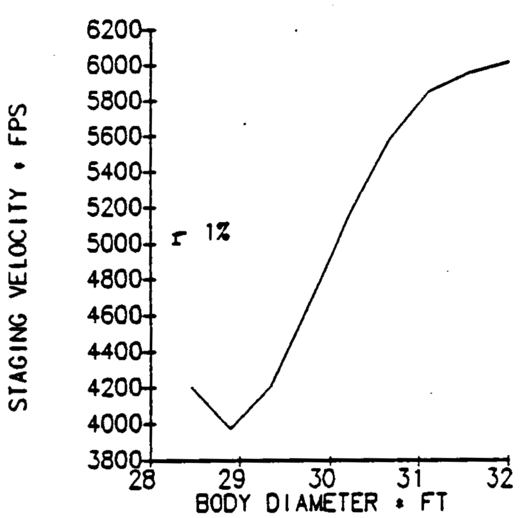
Configuration 2.D Sensitivity Studies (Continued)



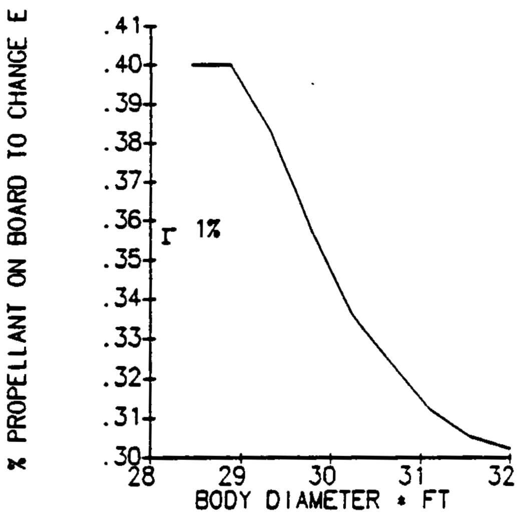
(d-9) Propellant Mixture Ratio Versus Body Diameter



(d -10)Initial Booster Throttle Setting Versus Body Diameter

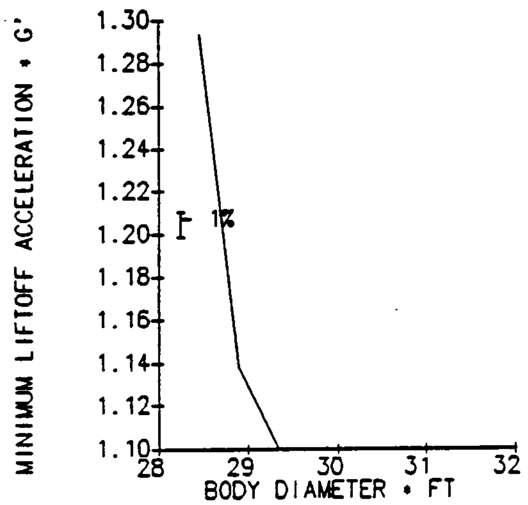


(d-11) Staging Velocity Versus Body Diameter

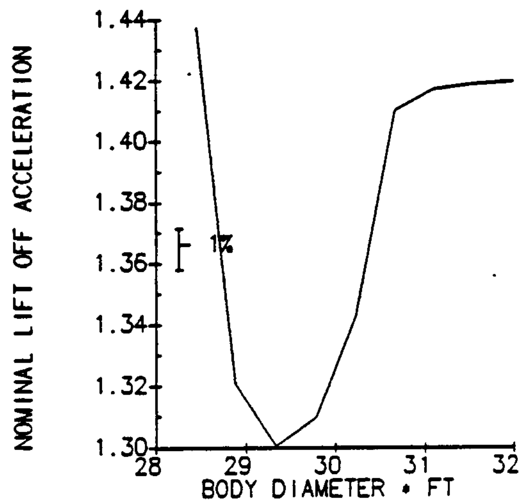


(d-12) Orbiter Propellant at Staging Versus Body Diameter

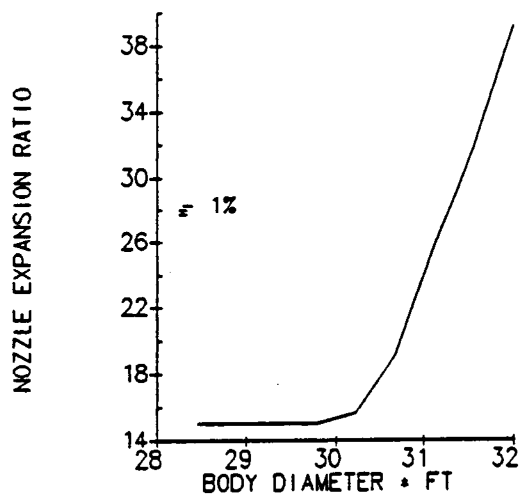
Configuration 2.D Sensitivity Studies (Continued)



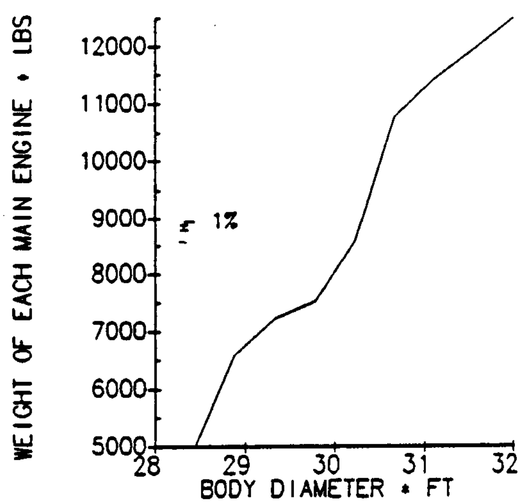
(d-13) Engine-out Lift Off Acceleration Versus Body Diameter



(d-14) Nominal Lift Off Acceleration Versus Body Diameter

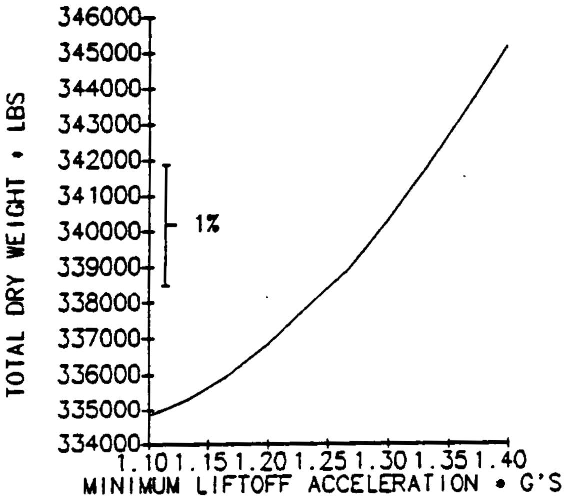


(d-15) Nozzle Expansion Ratio Versus Body Diameter

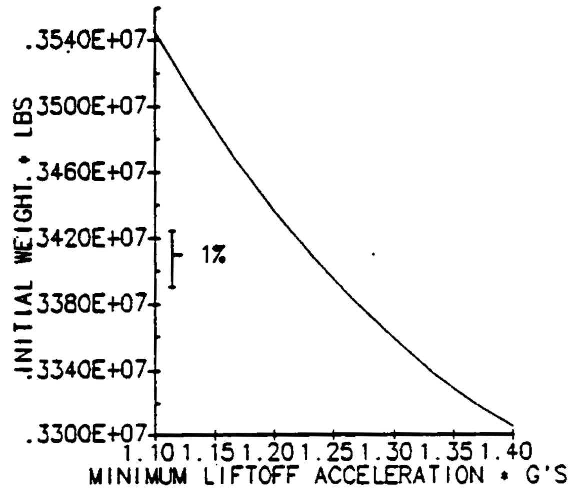


(d-16) Booster Engine Weight Versus Body Diameter

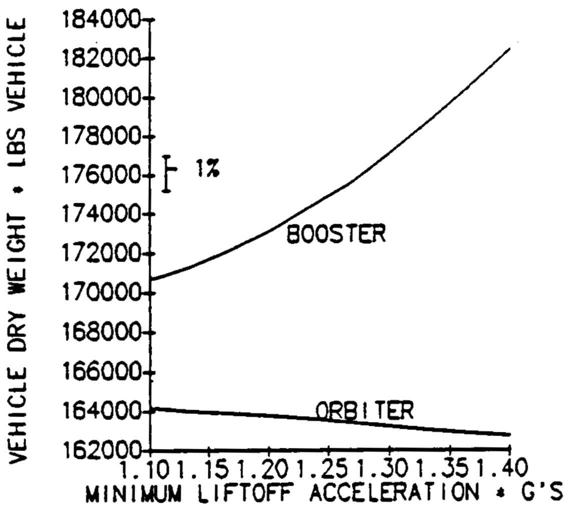
Configuration 2.D Sensitivity Studies (Continued)



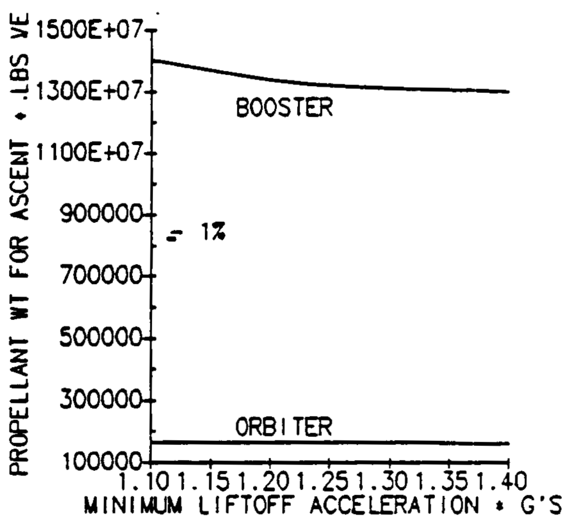
(d-17) **Total Dry Weight Versus Engine-out Lift Off Acceleration**



(d-18) **Gross Lift Off Weight Versus Engine-out Lift Off Acceleration**

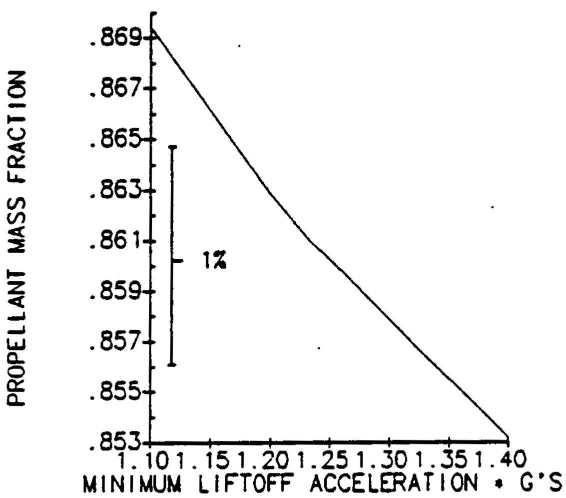


(d-19) **Vehicle Dry Weight Versus Engine-out Lift Off Acceleration**

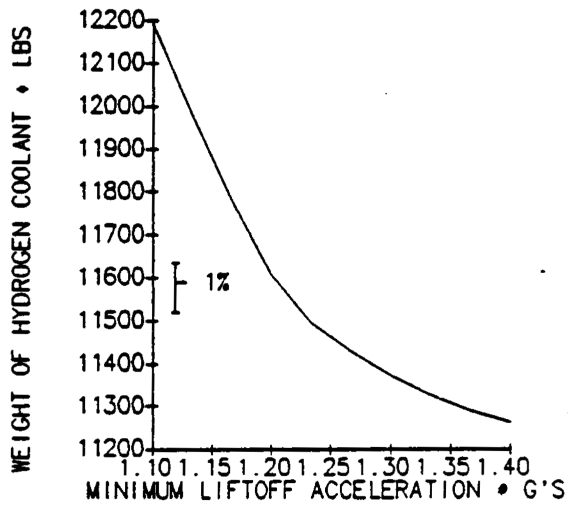


(d-20) **Propellant Consumed Versus Engine-out Lift Off Acceleration**

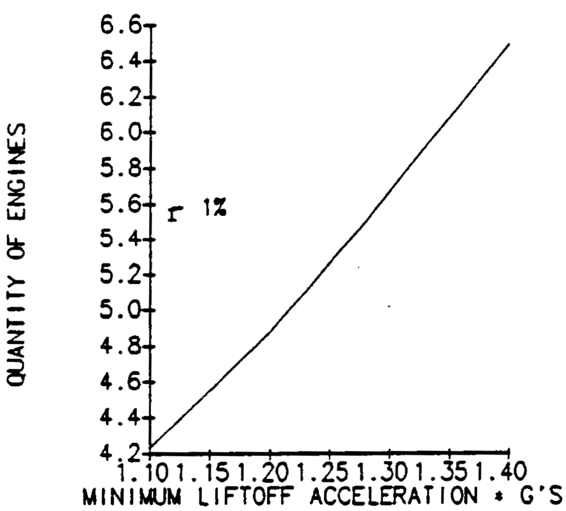
Configuration 2.D Sensitivity Studies (Continued)



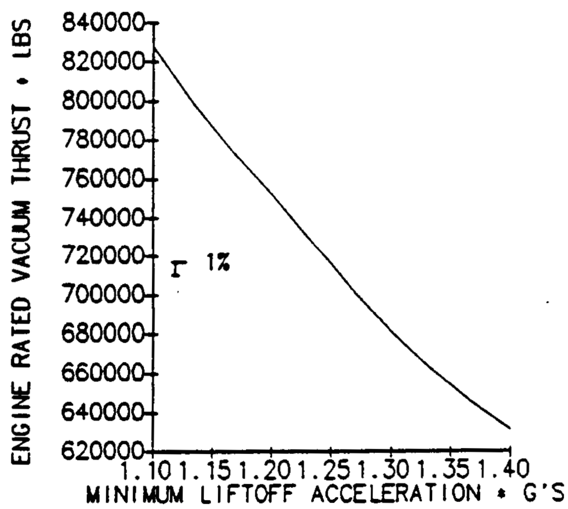
(d-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(d-22) Weight of Hydrogen Coolant Versus Engine-out Lift Off Acceleration

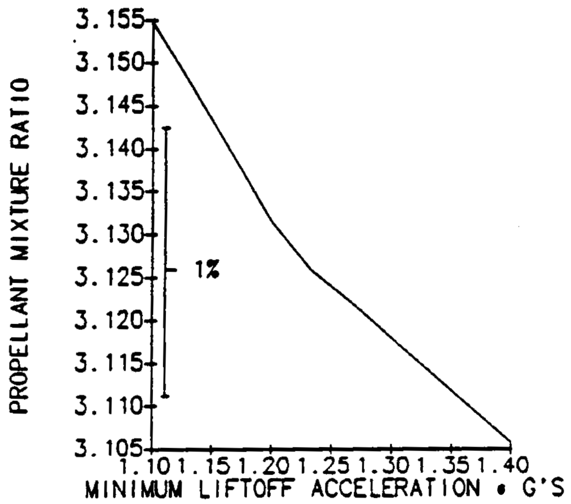


(d-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

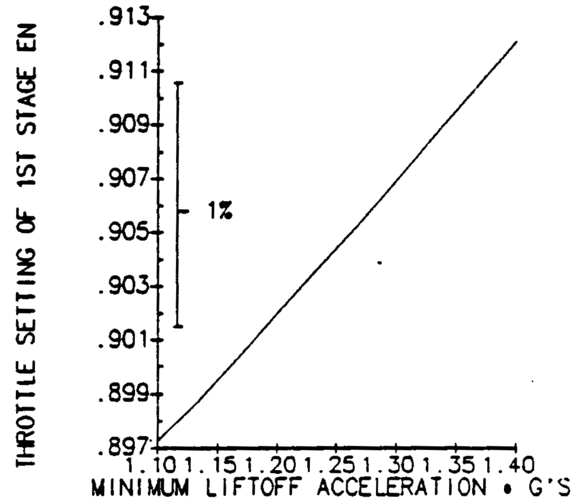


(d-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

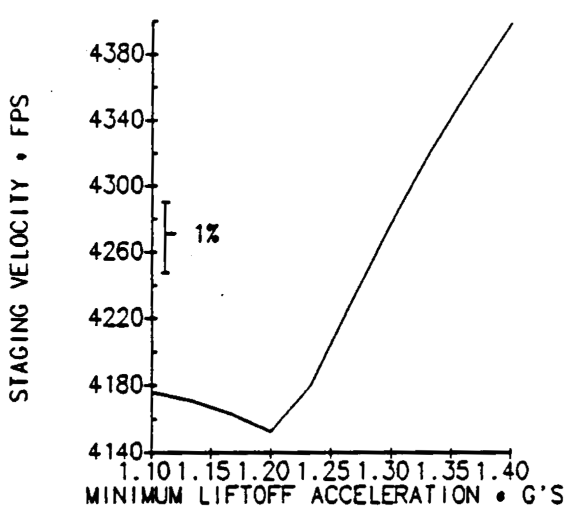
Configuration 2.D Sensitivity Studies (Continued)



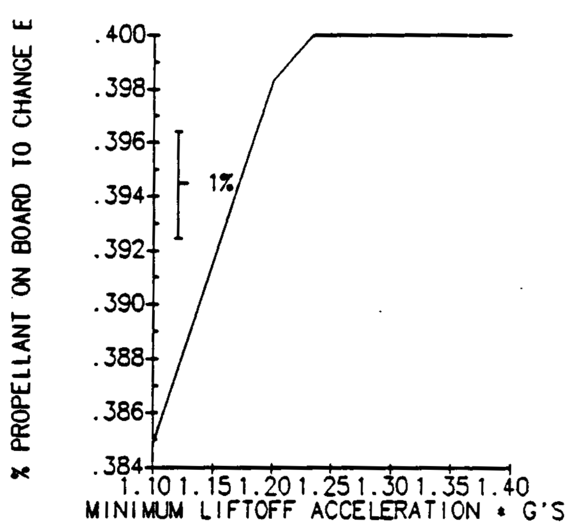
(d-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(d-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

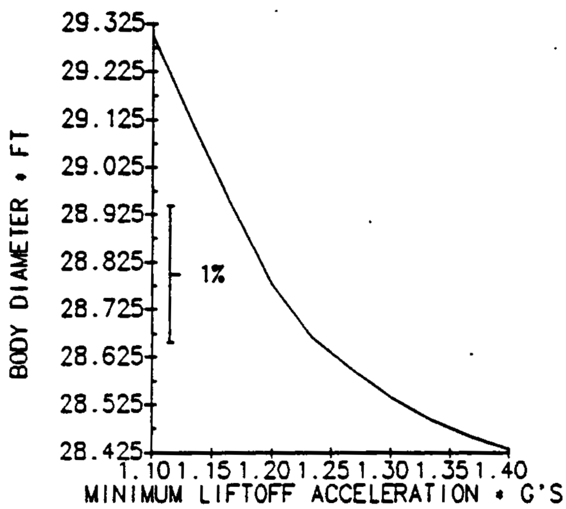


(d-27) Staging Velocity Versus Engine-out Lift Off Acceleration

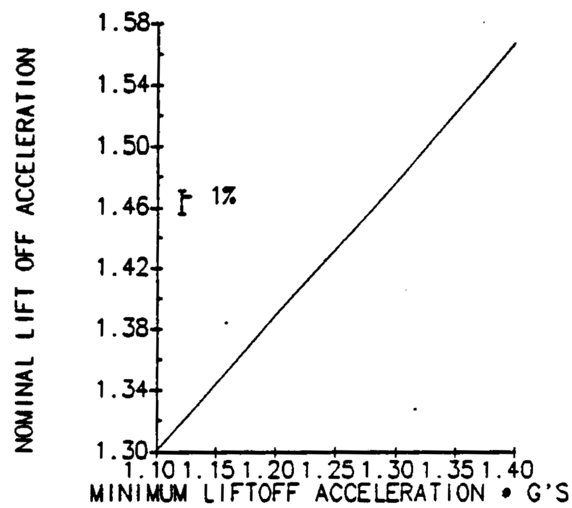


(d-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

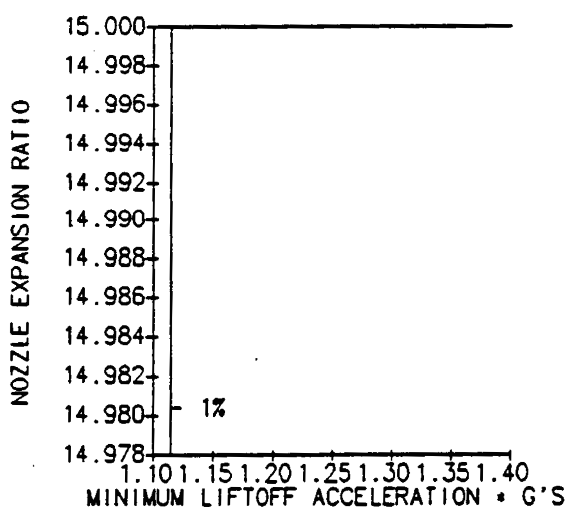
Configuration 2.D Sensitivity Studies (Continued)



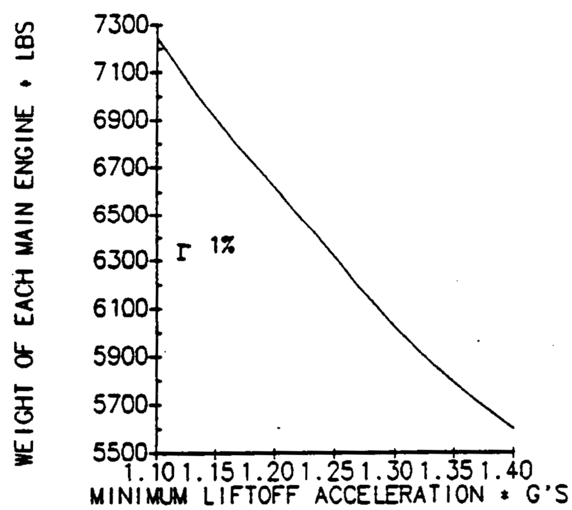
(d-29) Body Diameter Versus Engine-out Lift Off Acceleration



(d-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

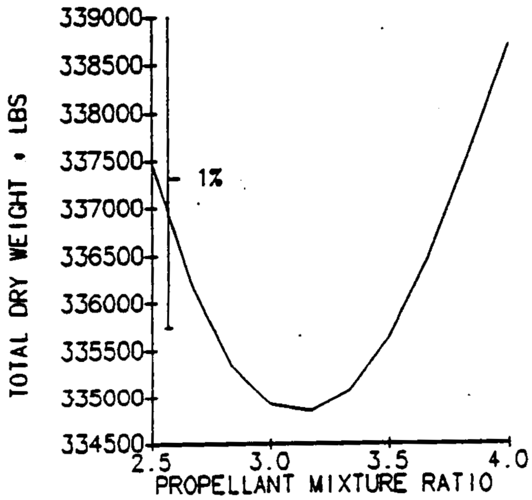


(d-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

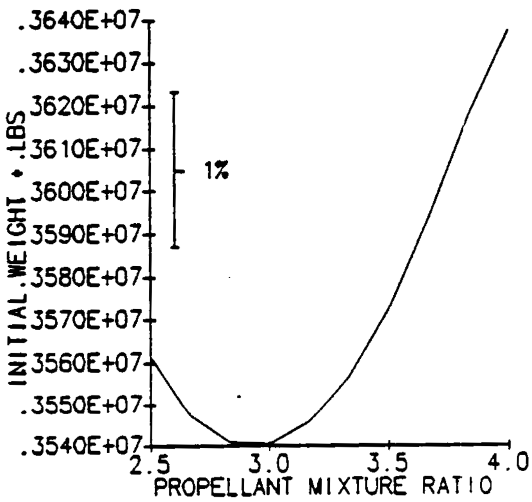


(d-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

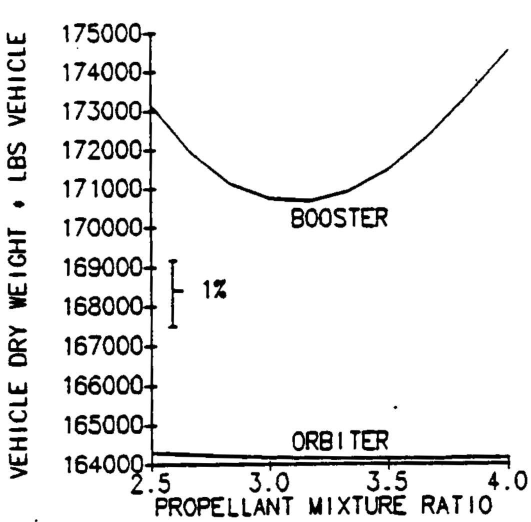
Configuration 2.D Sensitivity Studies (Continued)



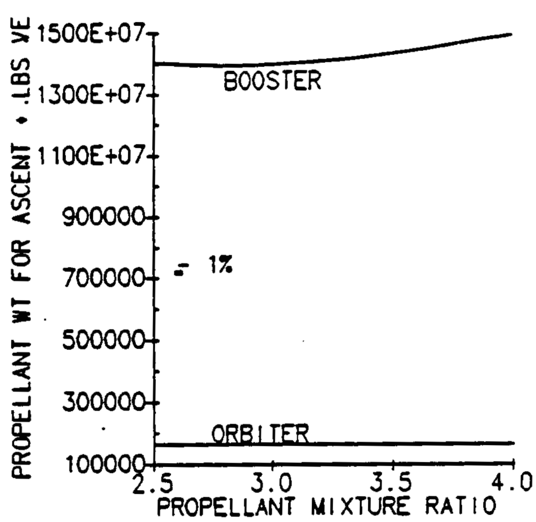
(d-33) Total Dry Weight Versus Propellant Mixture Ratio



(d-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

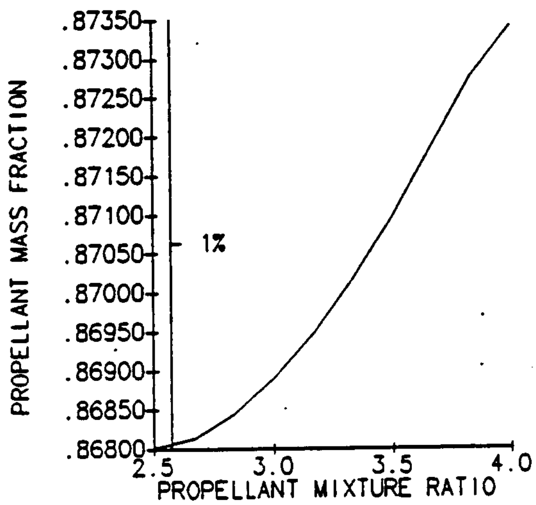


(d-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

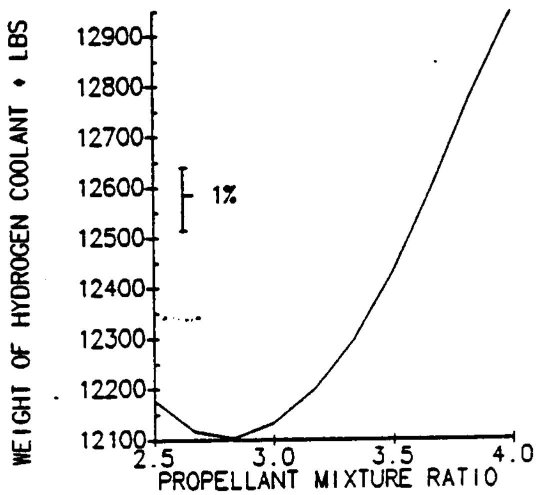


(d-36) Propellant Consumed Versus Propellant Mixture Ratio

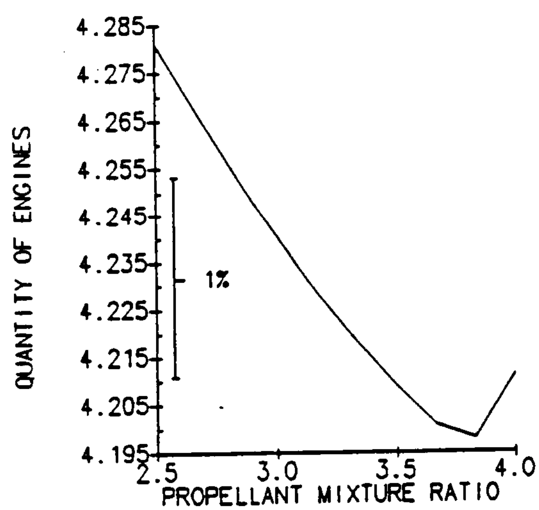
Configuration 2.D Sensitivity Studies (Continued)



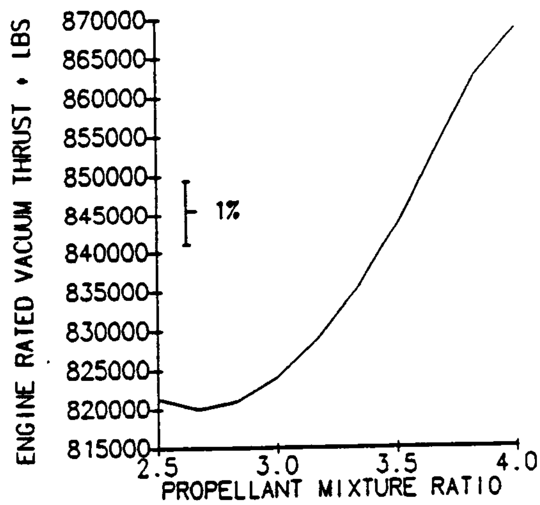
(d-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(d-38) Weight of Hydrogen Coolant Versus Propellant Mixture Ratio

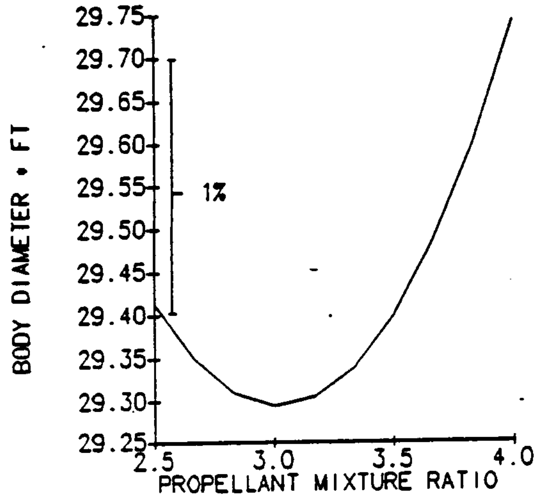


(d-39) Number of Booster Engines Versus Propellant Mixture Ratio

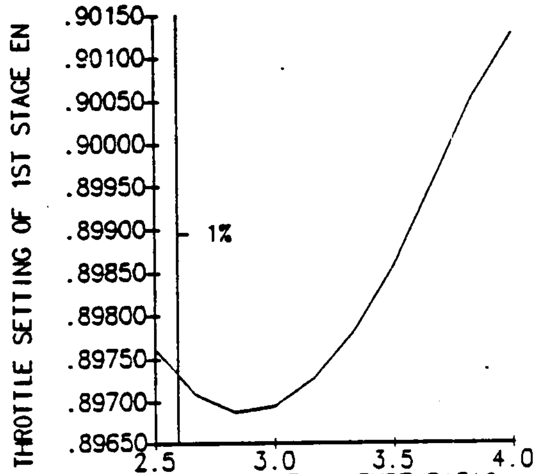


(d-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

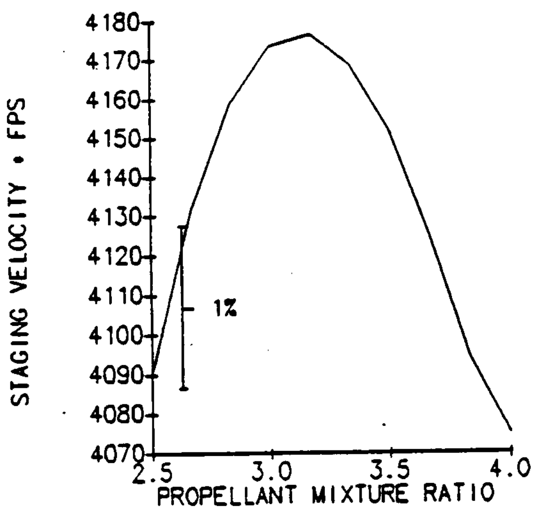
Configuration 2.D Sensitivity Studies (Continued)



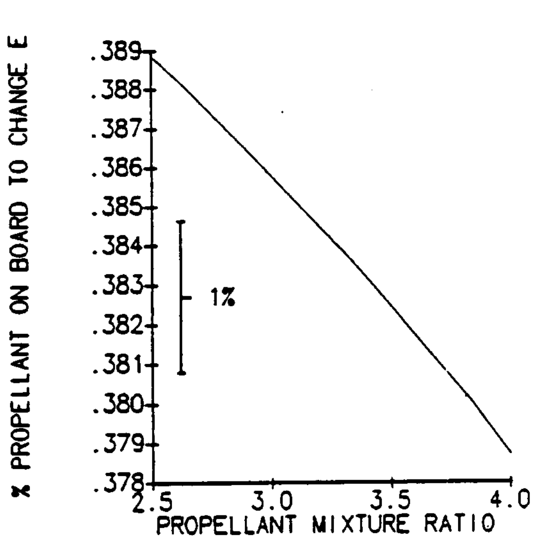
(d-41) Body Diameter Versus Propellant Mixture Ratio



(d-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

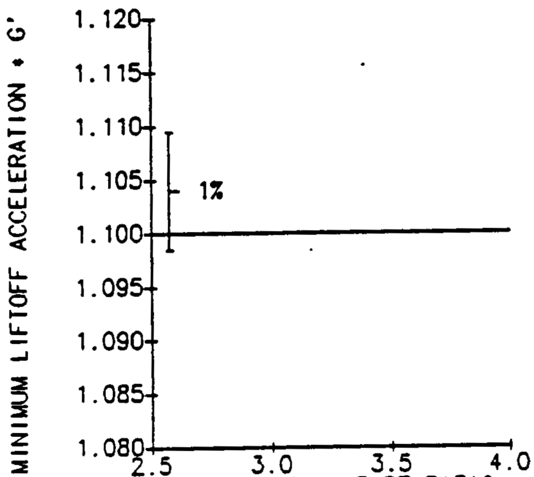


(d-43) Staging Velocity Versus Propellant Mixture Ratio

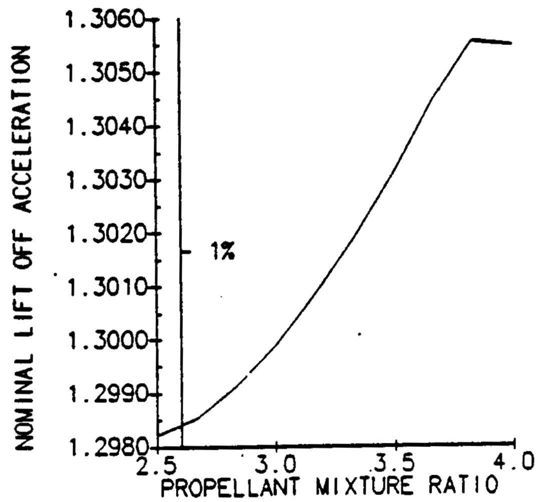


(d-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

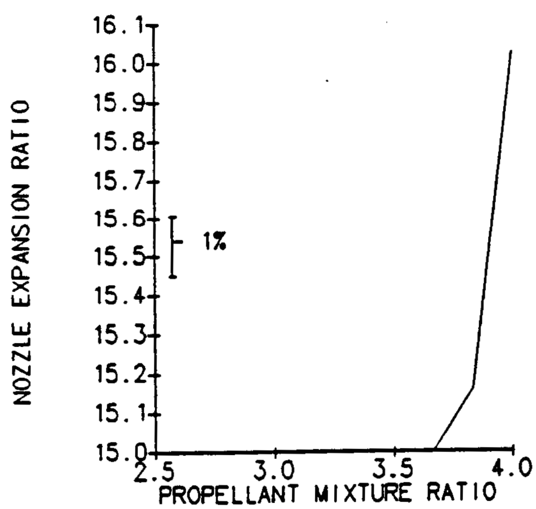
Configuration 2.D Sensitivity Studies (Continued)



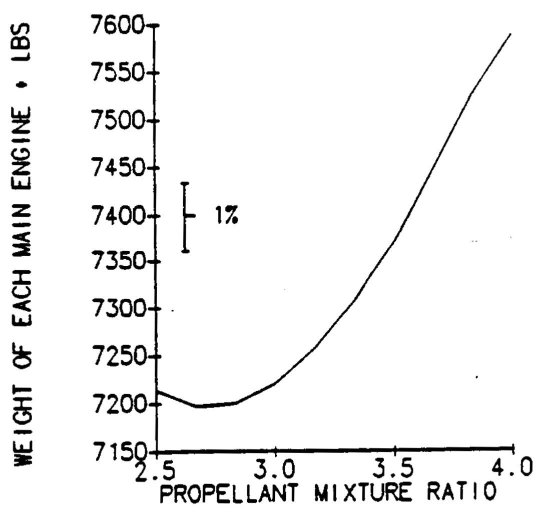
(d-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(d-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

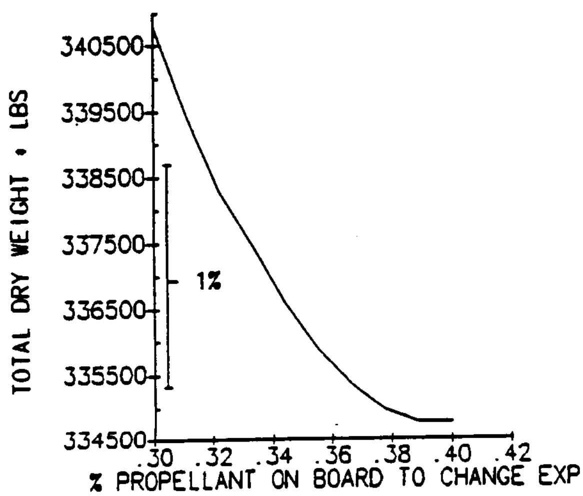


(d-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

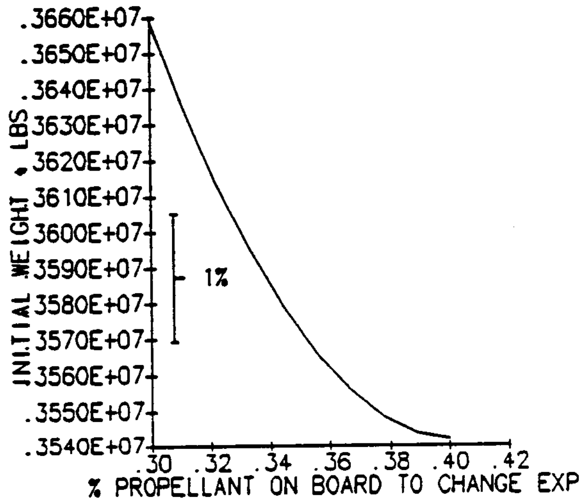


(d-48) Booster Engine Weight Versus Propellant Mixture Ratio

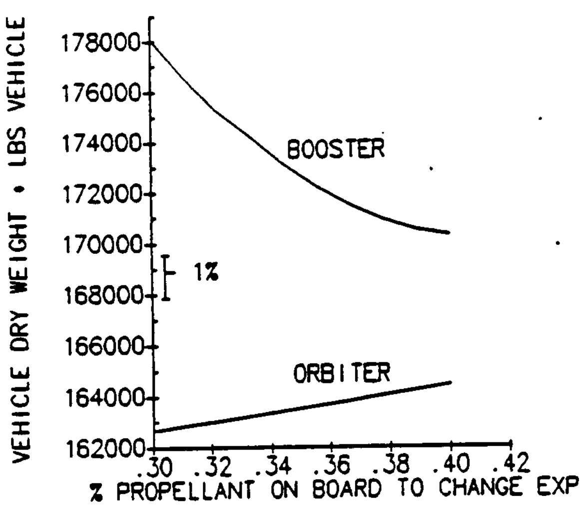
Configuration 2.D Sensitivity Studies (Continued)



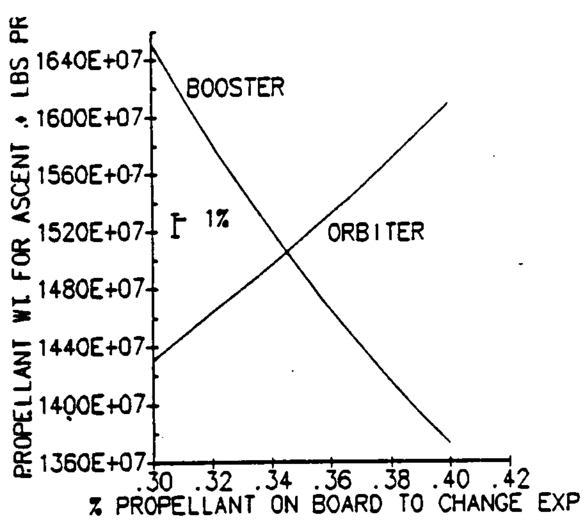
(d-49) **Total Dry Weight Versus Orbiter Propellant at Staging**



(d-50) **Gross Lift Off Weight Versus Orbiter Propellant at Staging**

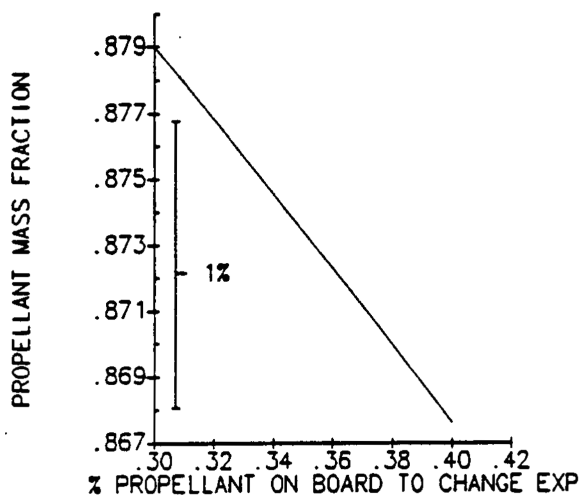


(d-51) **Vehicle Dry Weight Versus Orbiter Propellant at Staging**

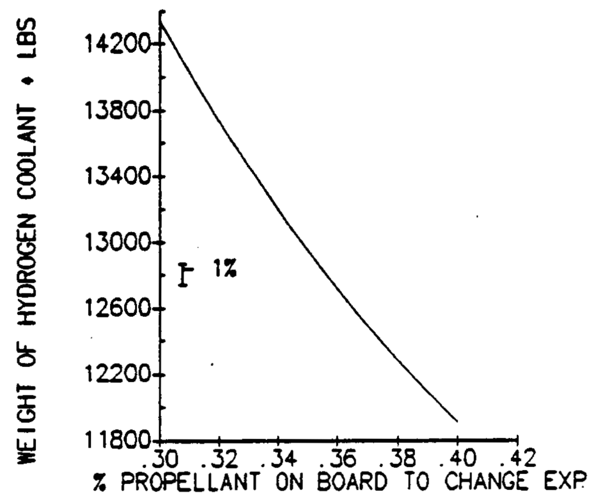


(d-52) **Propellant Consumed Versus Orbiter Propellant at Staging**

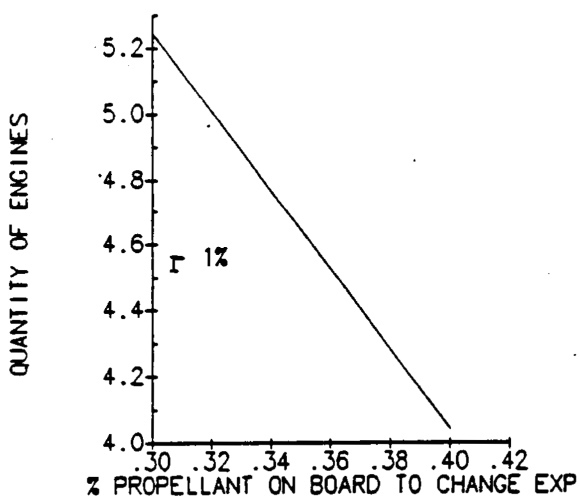
Configuration 2.D Sensitivity Studies (Continued)



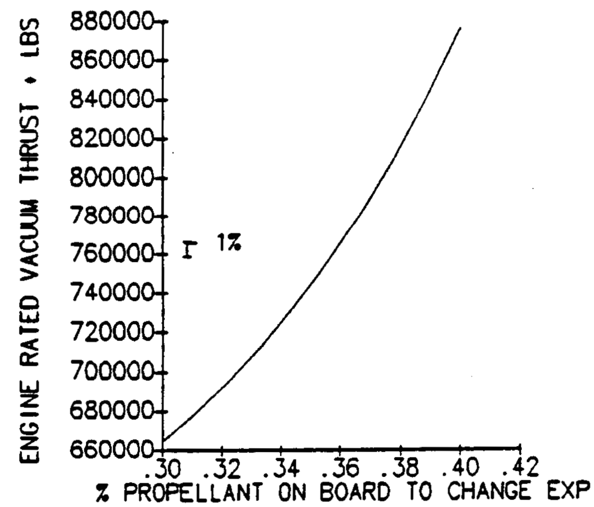
(d-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



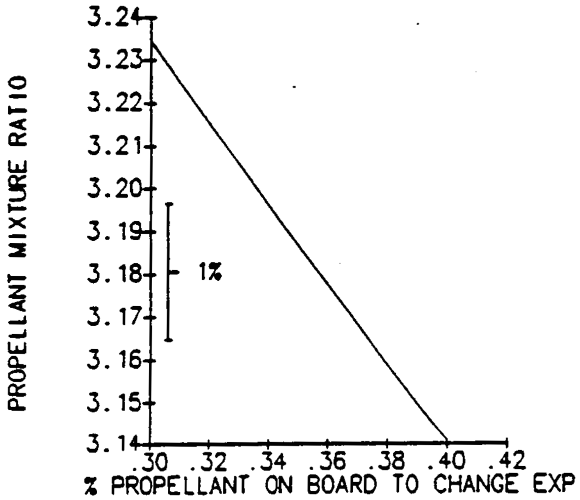
(d-54) Weight of Hydrogen Coolant Versus Orbiter Propellant at Staging



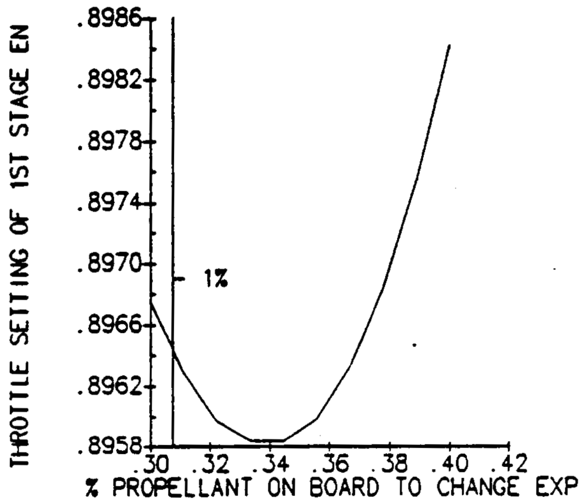
(d-55) Number of Booster Engines Versus Orbiter Propellant at Staging



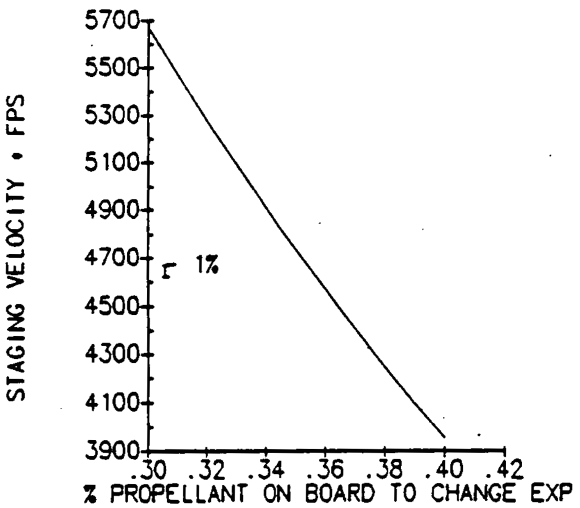
(d-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging



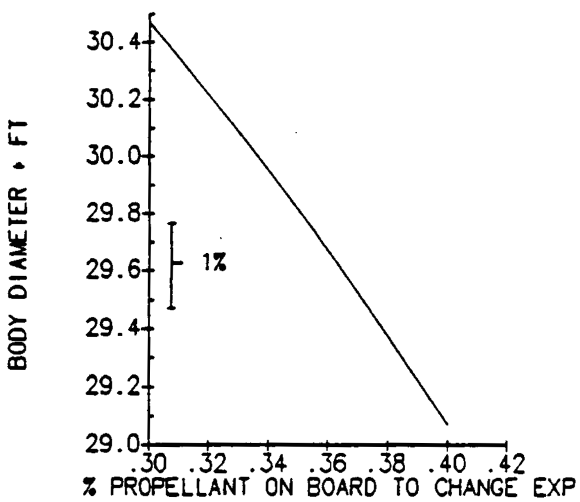
(d-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(d-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

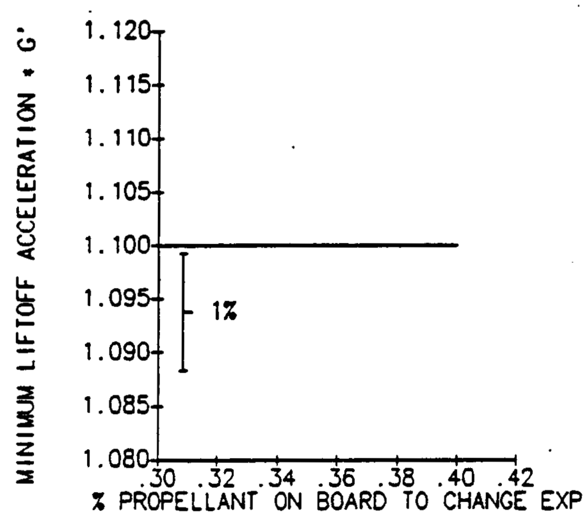


(d-59) Staging Velocity Versus Orbiter Propellant at Staging

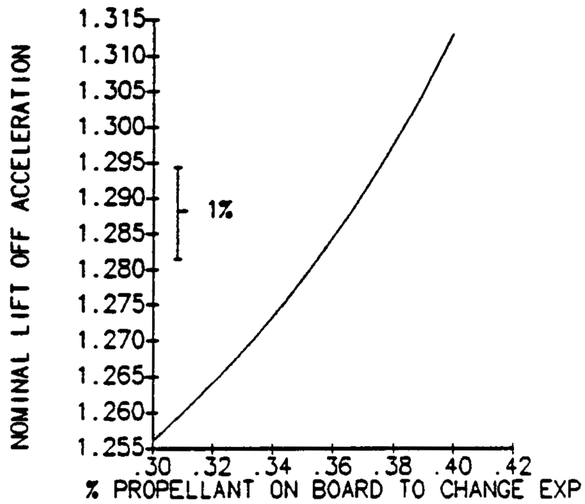


(d-60) Body Diameter Versus Orbiter Propellant at Staging

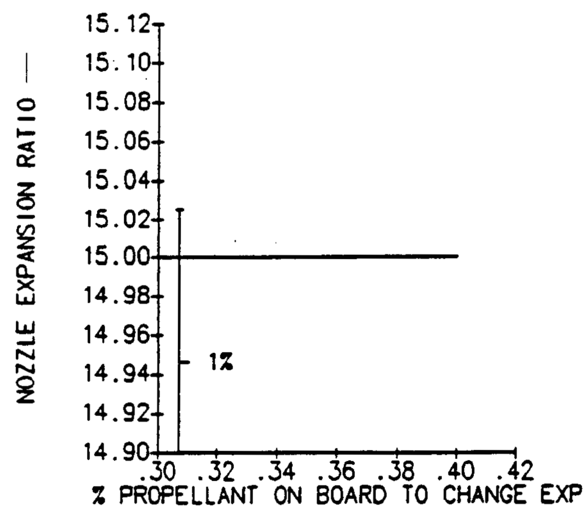
Configuration 2.D Sensitivity Studies (Continued)



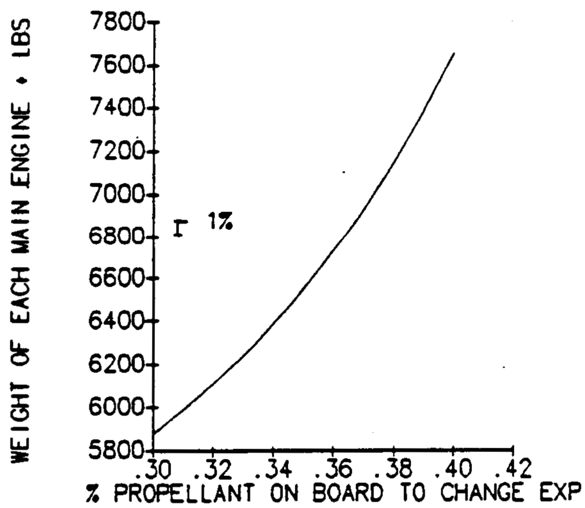
(d-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(d-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

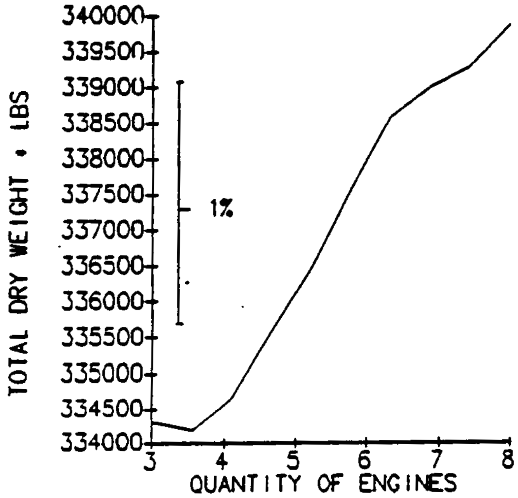


(d-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

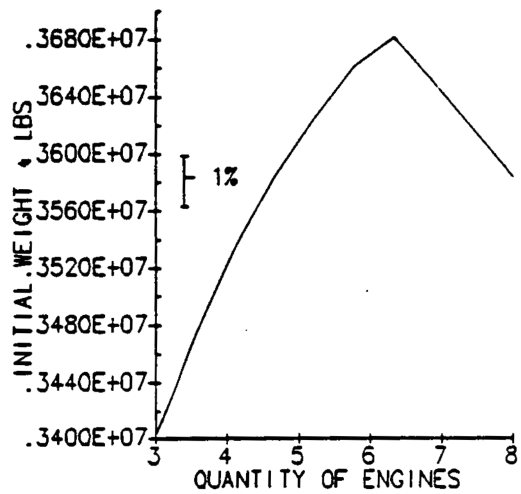


(d-64) Booster Engine Weight Versus Orbiter Propellant at Staging

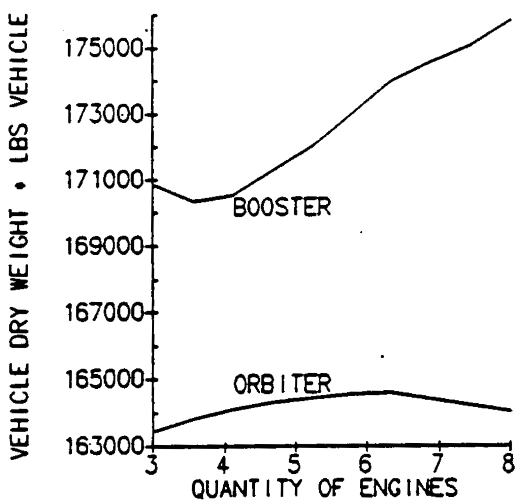
Configuration 2.D Sensitivity Studies (Continued)



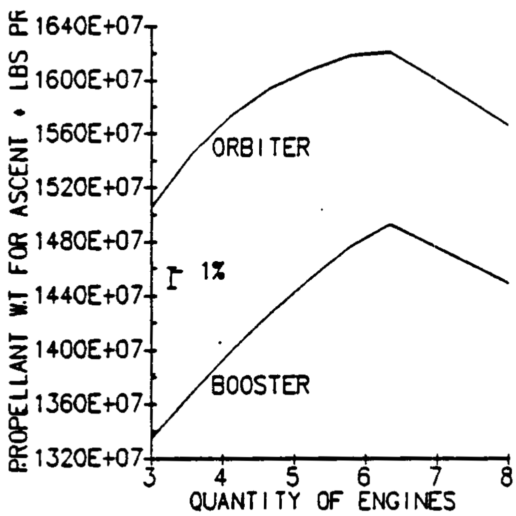
(d-65) Total Dry Weight Versus Number of Booster Engines



(d-66) Gross Lift Off Weight Versus Number of Booster Engines

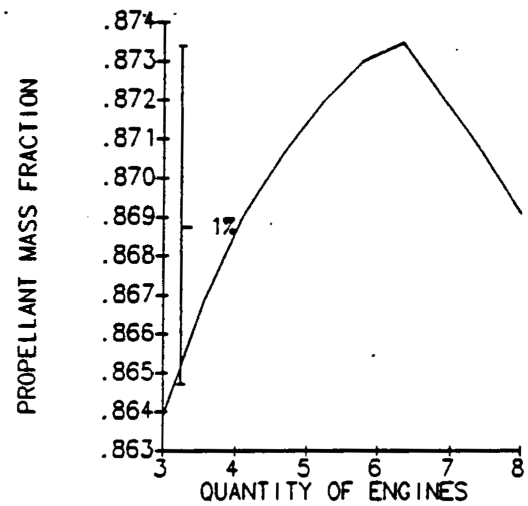


(d-67) Vehicle Dry Weight Versus Number of Booster Engines

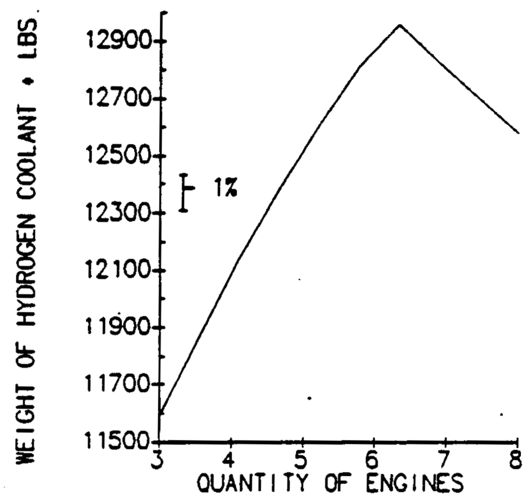


(d-68) Propellant Consumed Versus Number of Booster Engines

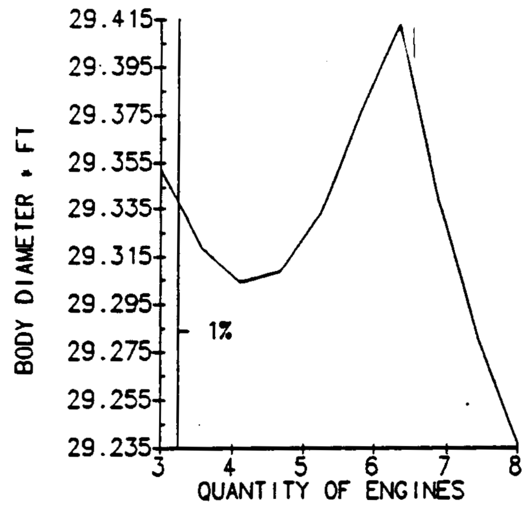
Configuration 2.D Sensitivity Studies (Continued)



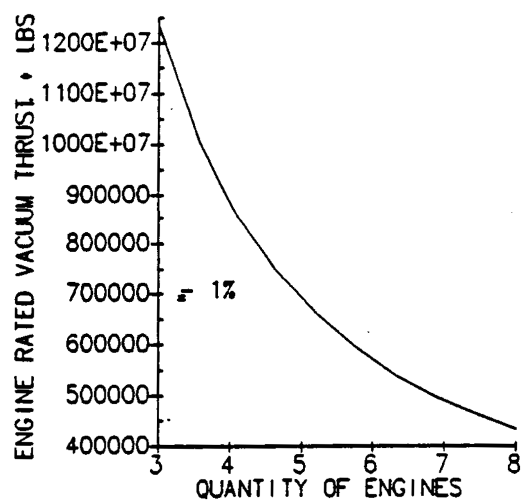
(d-69) Propellant Mass Fraction Versus Number of Booster Engines



(d-70) Weight of Hydrogen Coolant Versus Number of Booster Engines

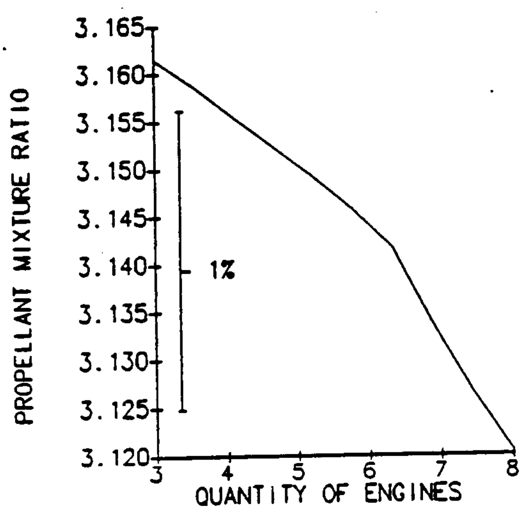


(d-71) Body Diameter Versus Number of Booster Engines

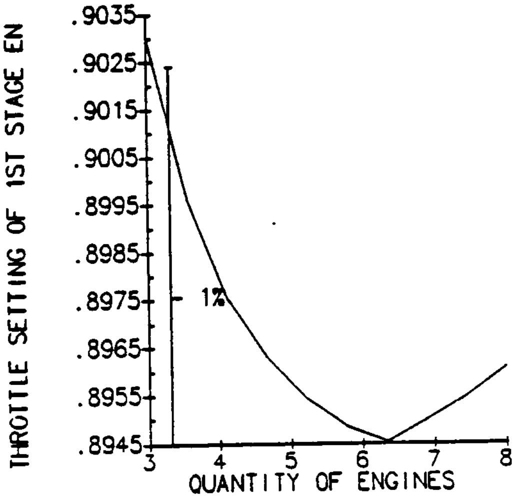


(d-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

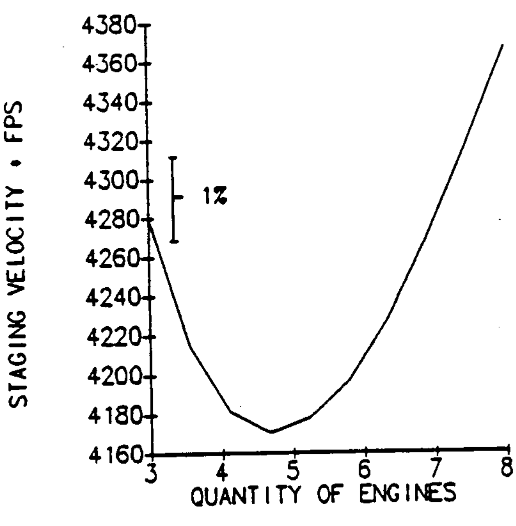
Configuration 2.D Sensitivity Studies (Continued)



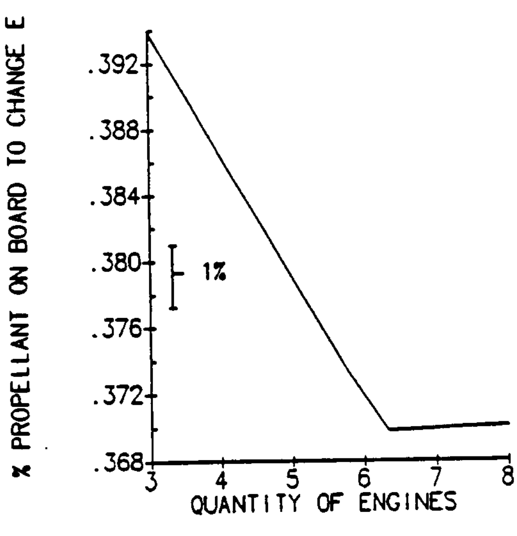
(d-73) Propellant Mixture Ratio Versus Number of Booster Engines



(d-74) Initial Booster Throttle Setting Versus Number of Booster Engines

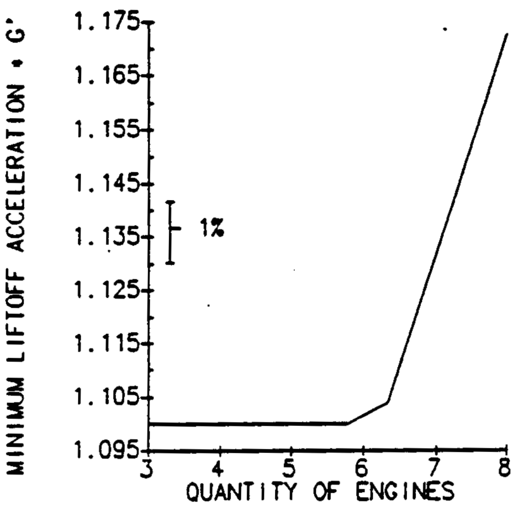


(d-75) Staging Velocity Versus Number of Booster Engines

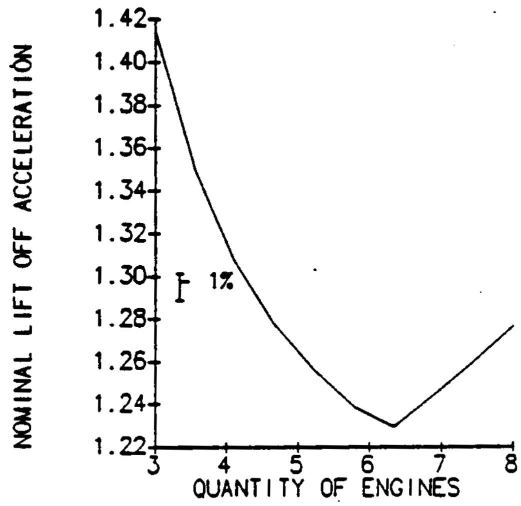


(d-76) Orbiter Propellant at Staging Versus Number of Booster Engines

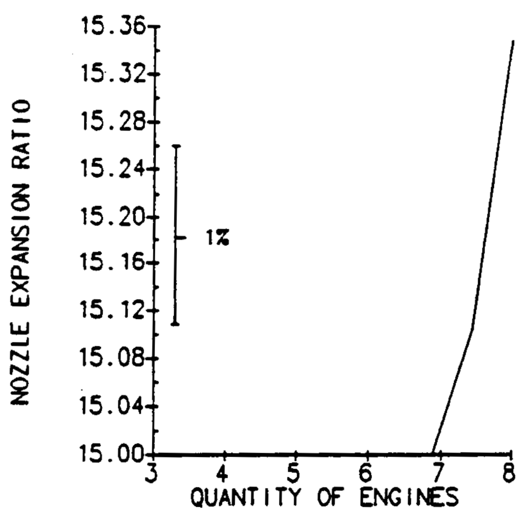
Configuration 2.D Sensitivity Studies (Continued)



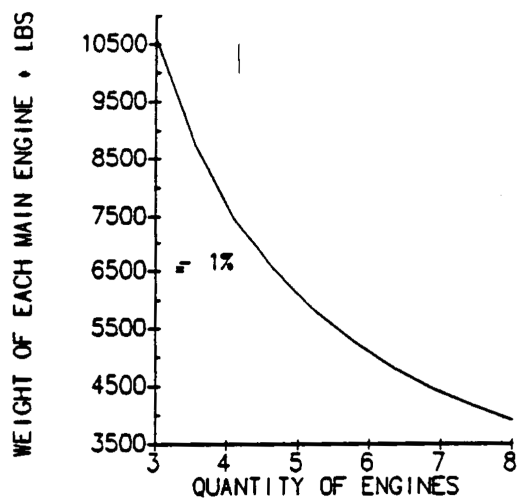
(d-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(d-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

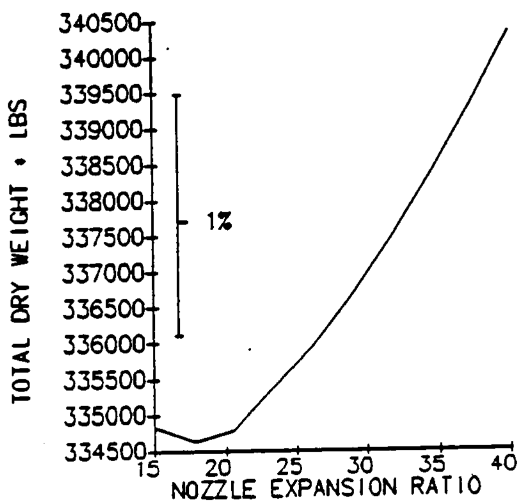


(d-79) Nozzle Expansion Ratio Versus Number of Booster Engines

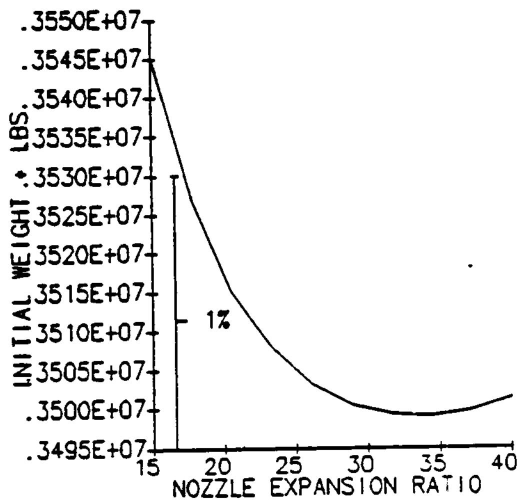


(d-80) Booster Engine Weight Versus Number of Booster Engines

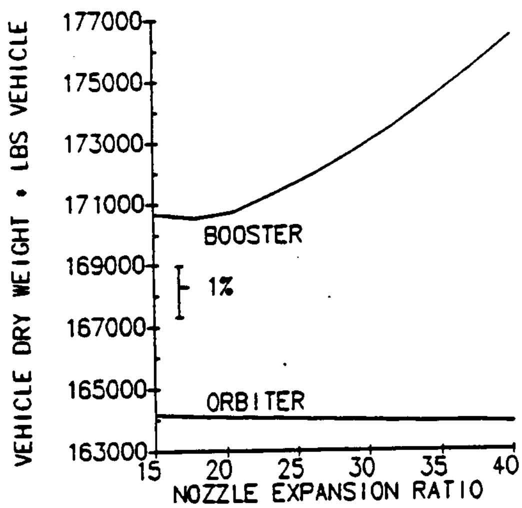
Configuration 2.D Sensitivity Studies (Continued)



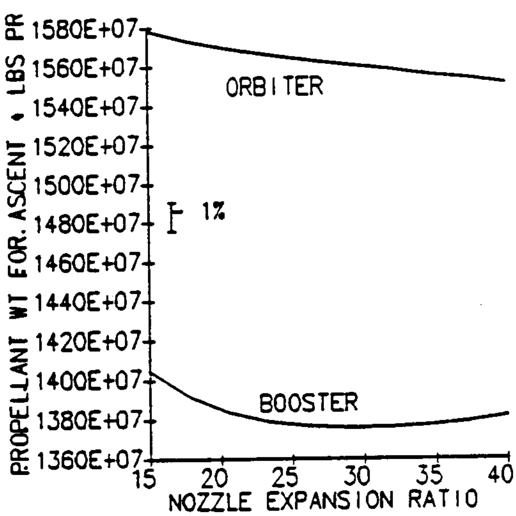
(d-81) Total Dry Weight Versus Nozzle Expansion Ratio



(d-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

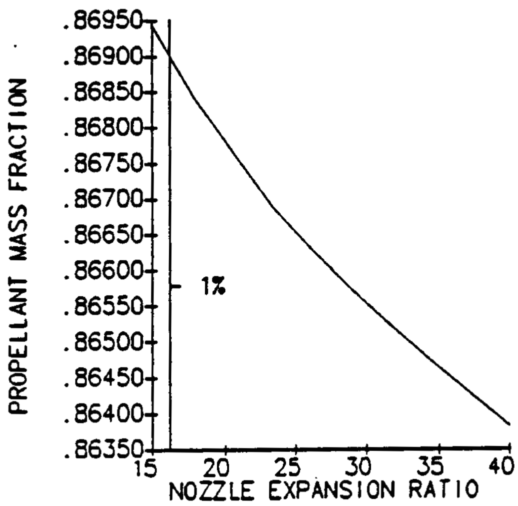


(d-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

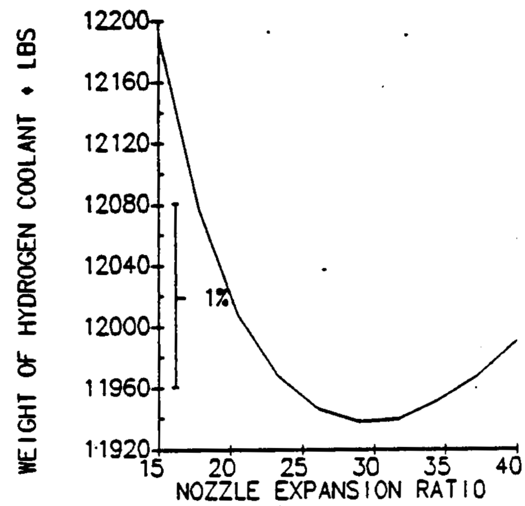


(d-84) Propellant Consumed Versus Nozzle Expansion Ratio

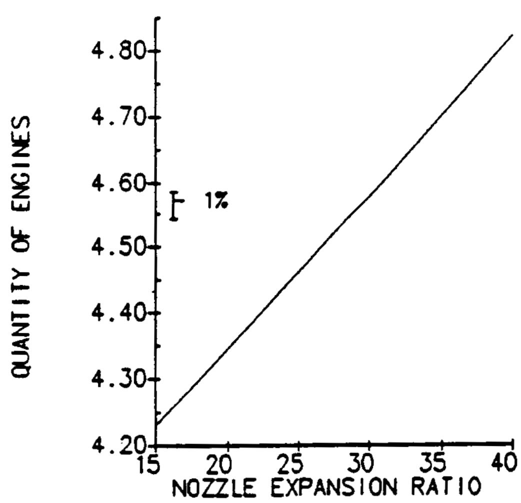
Configuration 2.D Sensitivity Studies (Continued)



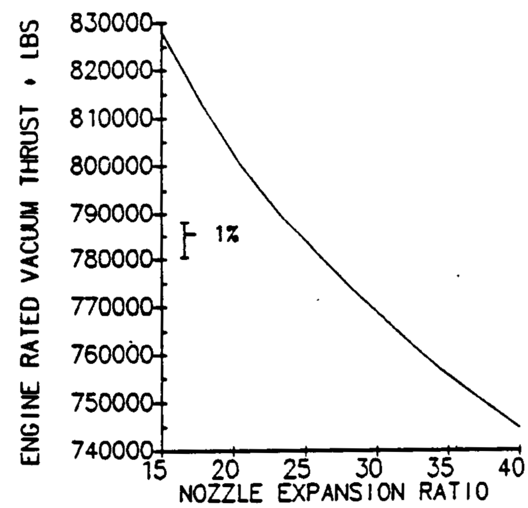
(d-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(d-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

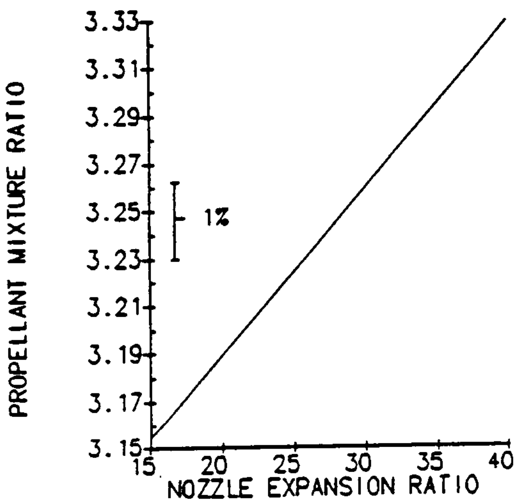


(d-87) Number of Booster Engines Versus Nozzle Expansion Ratio

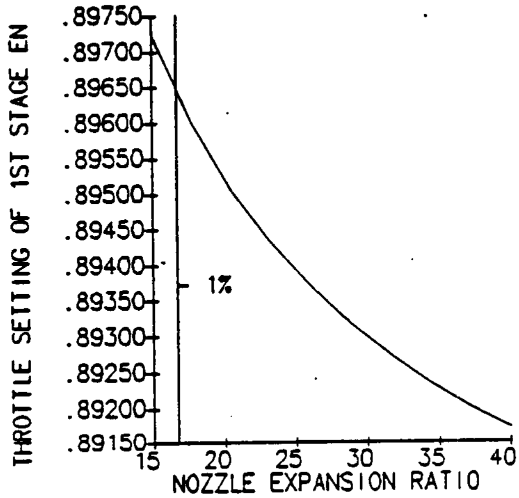


(d-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

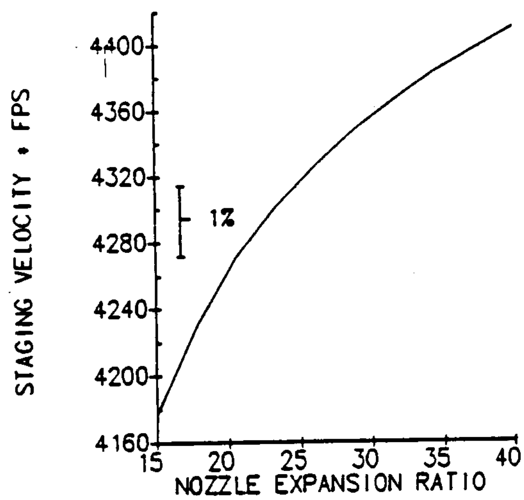
Configuration 2.D Sensitivity Studies (Continued)



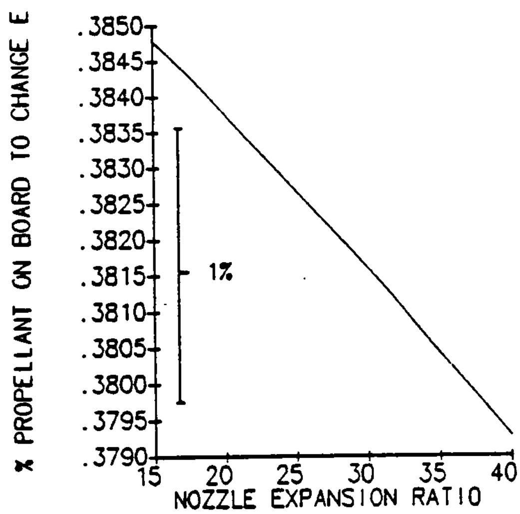
(d-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(d-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

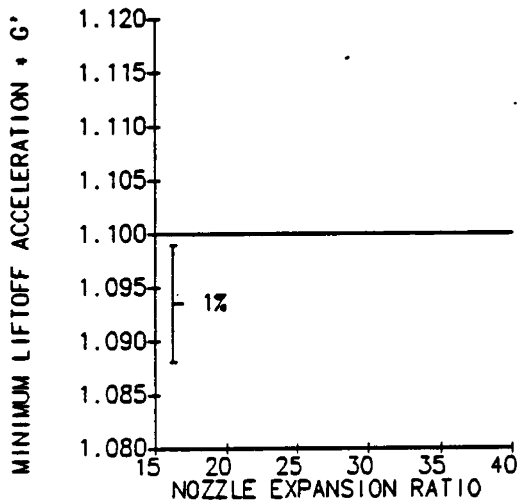


(d-91) Staging Velocity Versus Nozzle Expansion Ratio

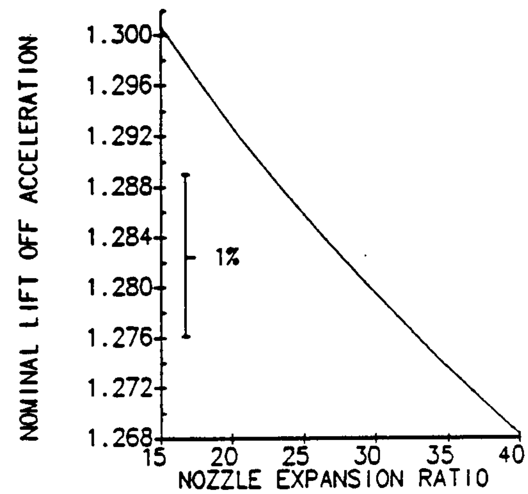


(d-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

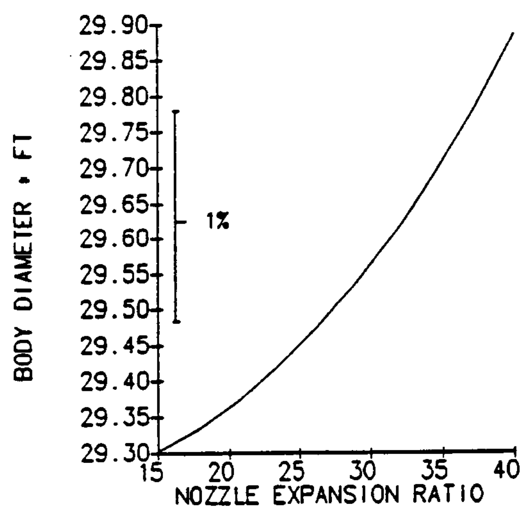
Configuration 2.D Sensitivity Studies (Continued)



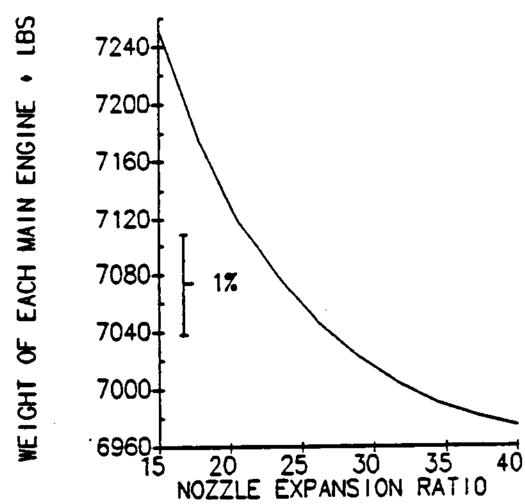
(d-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(d-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

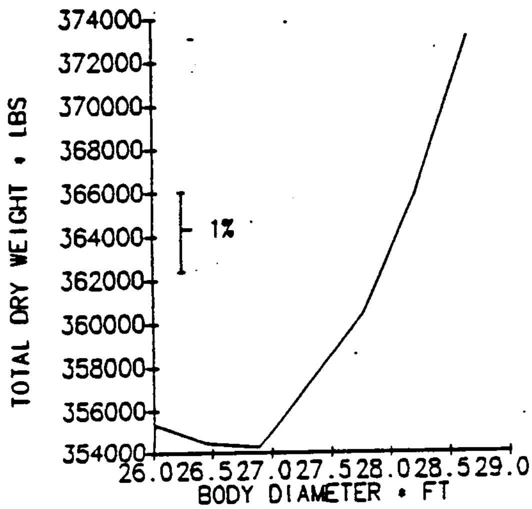


(d-95) Body Diameter Versus Nozzle Expansion Ratio

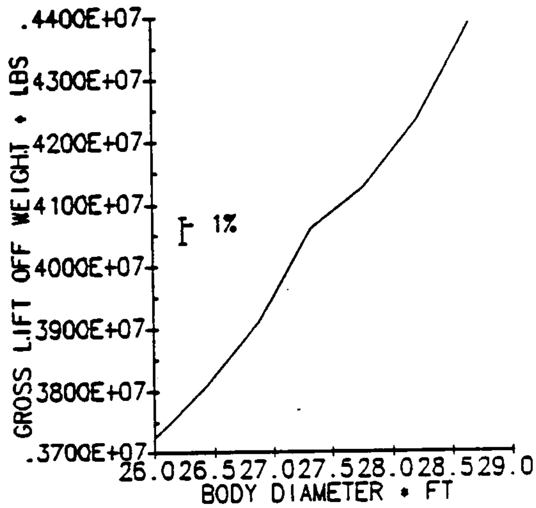


(d-96) Booster Engine Weight Versus Nozzle Expansion Ratio

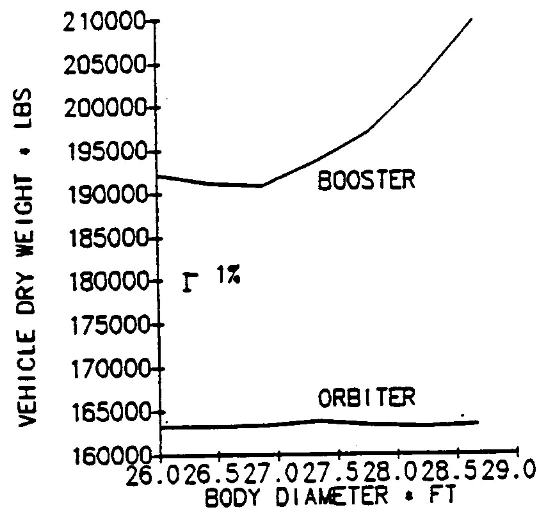
Configuration 2.D Sensitivity Studies (Continued)



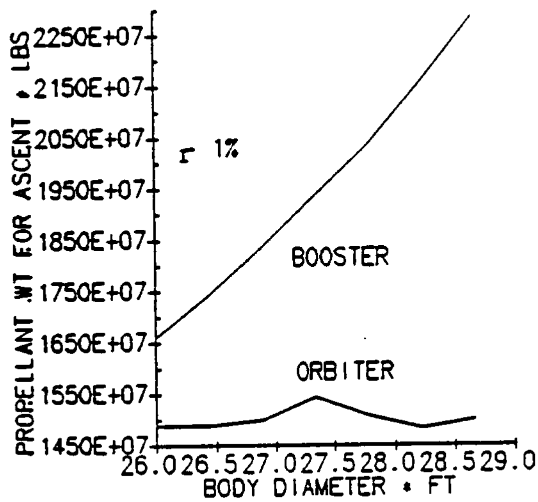
(e-1) Total Dry Weight Versus Body Diameter



(e-2) Gross Lift Off Weight Versus Body Diameter

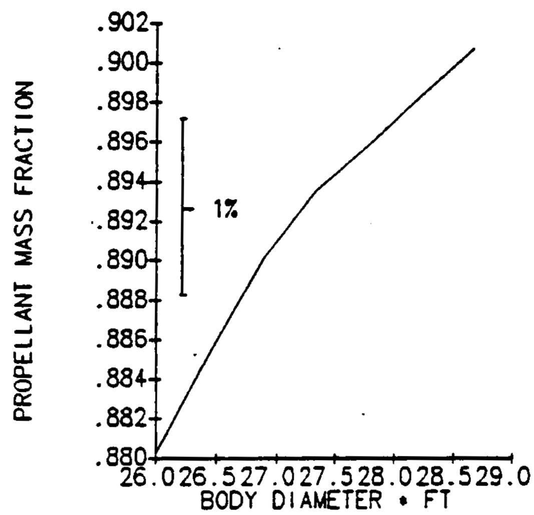


(e-3) Vehicle Dry Weight Versus Body Diameter

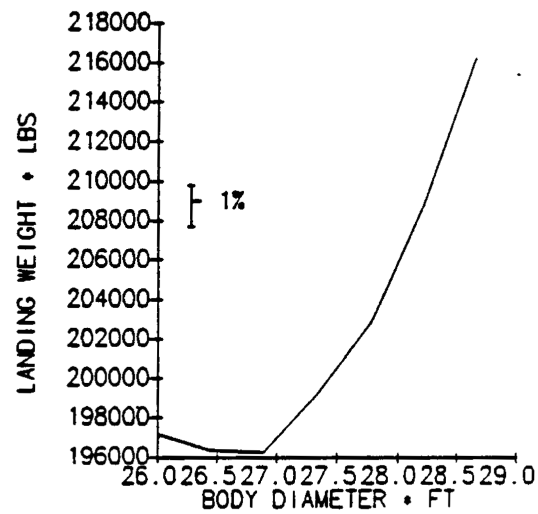


(e-4) Propellant Consumed Versus Body Diameter

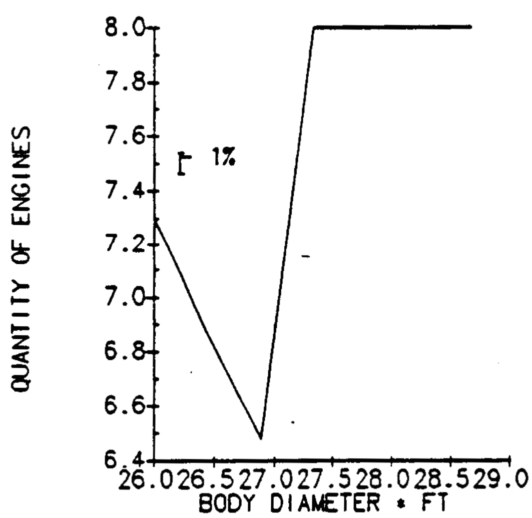
Configuration 2.E Sensitivity Studies



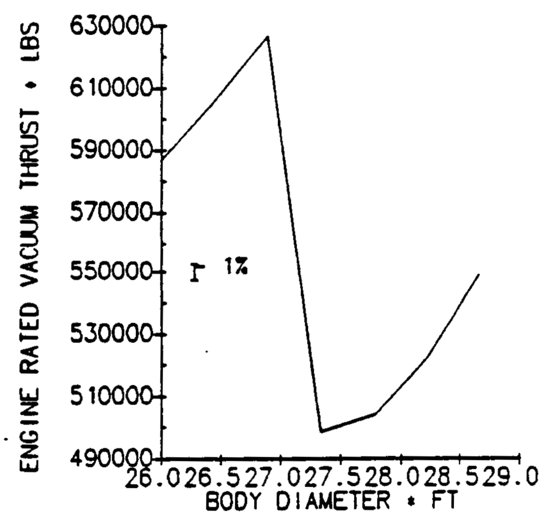
(e-5) **Propellant Mass Fraction Versus Body Diameter**



(e-6) **Landing Weight Versus Body Diameter**

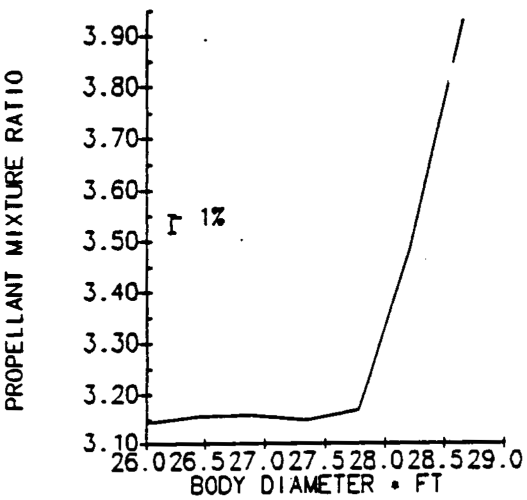


(e-7) **Number of Booster Engines Versus Body Diameter**

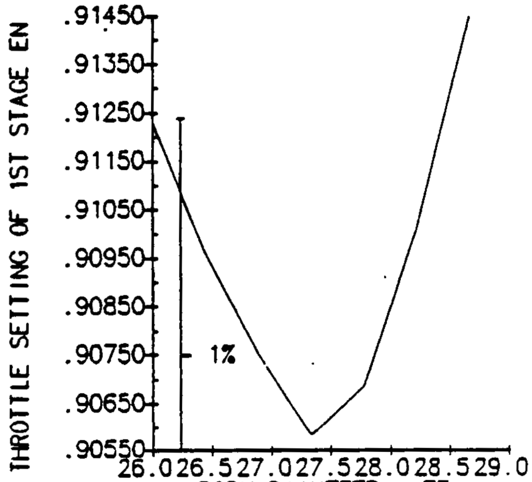


(e-8) **Engine Rated Vacuum Thrust Versus Body Diameter**

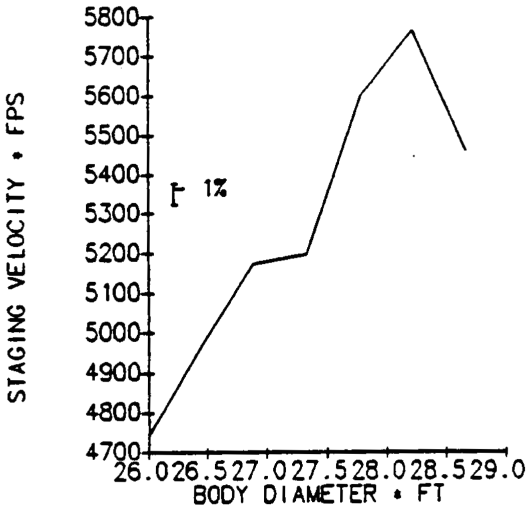
Configuration 2.E Sensitivity Studies (Continued)



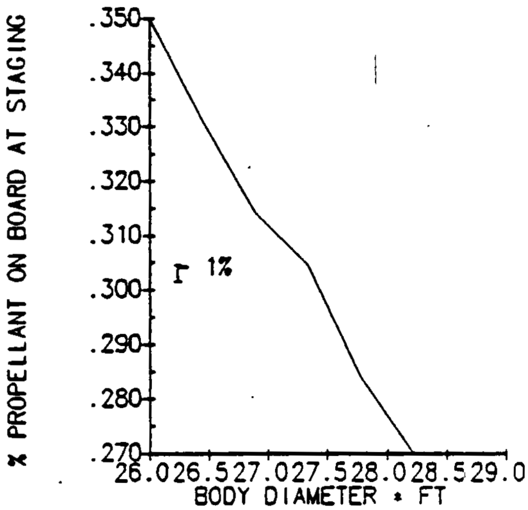
(e-9) Propellant Mixture Ratio Versus Body Diameter



(e-10) Initial Booster Throttle Setting Versus Body Diameter

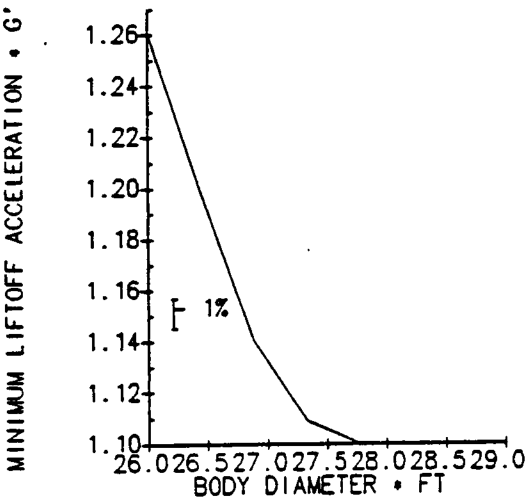


(e-11) Staging Velocity Versus Body Diameter

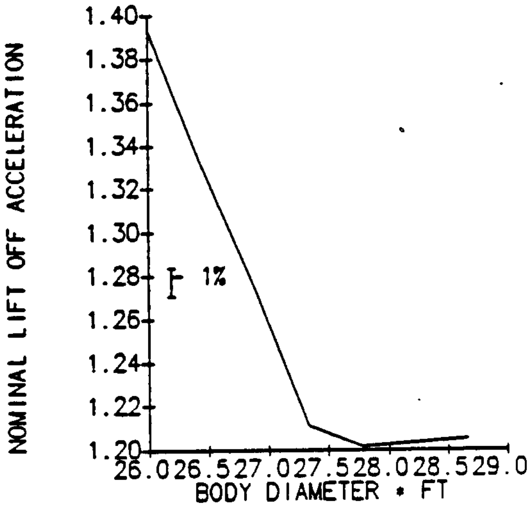


(e-12) Orbiter Propellant at Staging Versus Body Diameter

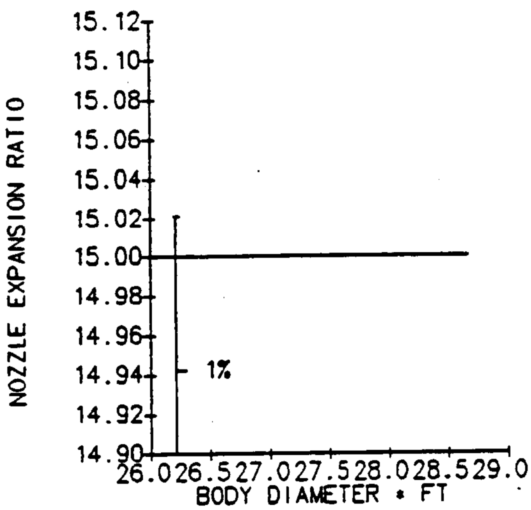
Configuration 2.E Sensitivity Studies (Continued)



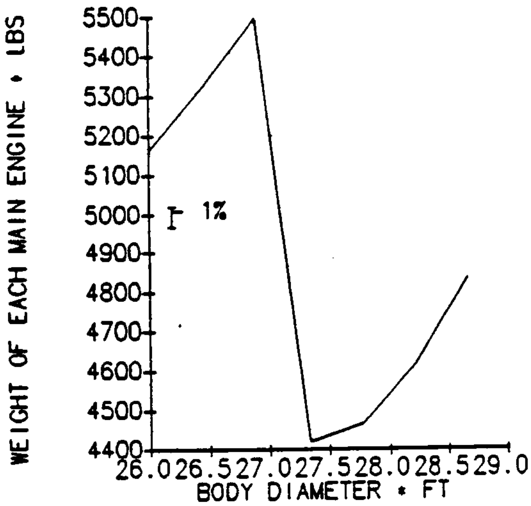
(e-13) Engine-out Lift Off Acceleration Versus Body Diameter



(e-14) Nominal Lift Off Acceleration Versus Body Diameter

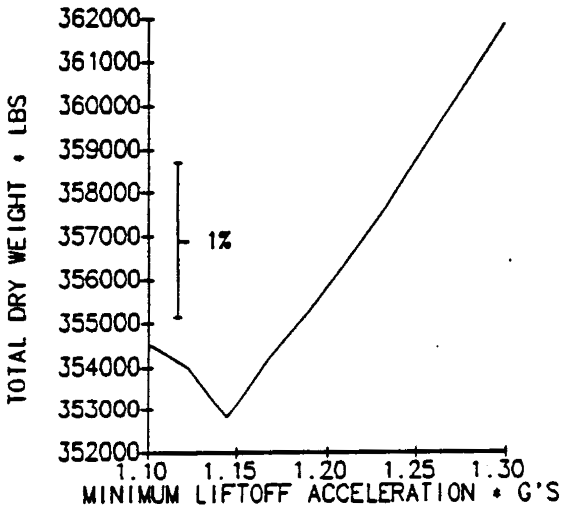


(e-15) Nozzle Expansion Ratio Versus Body Diameter

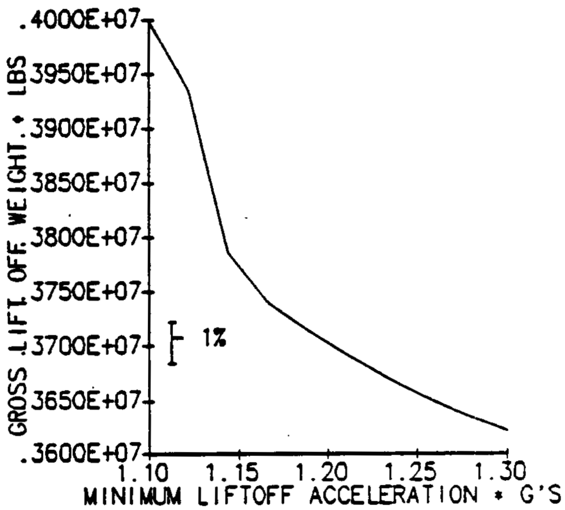


(e-16) Booster Engine Weight Versus Body Diameter

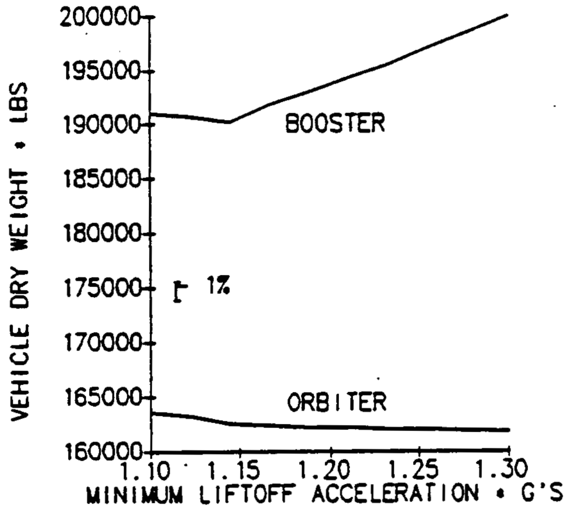
Configuration 2.E Sensitivity Studies (Continued)



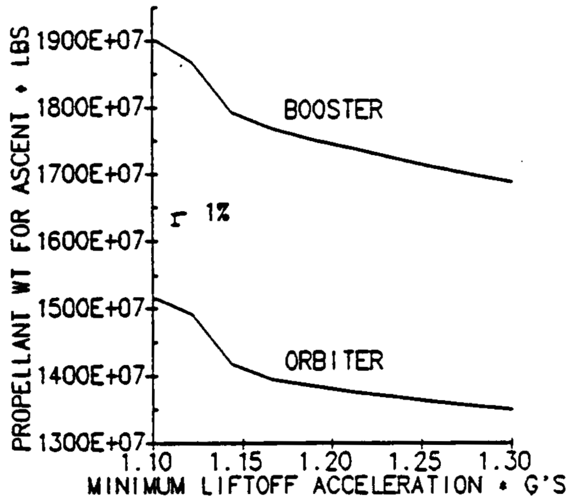
(e-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(e-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

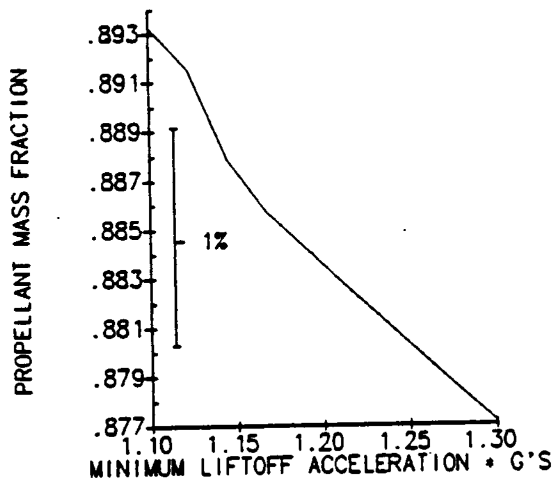


(e-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

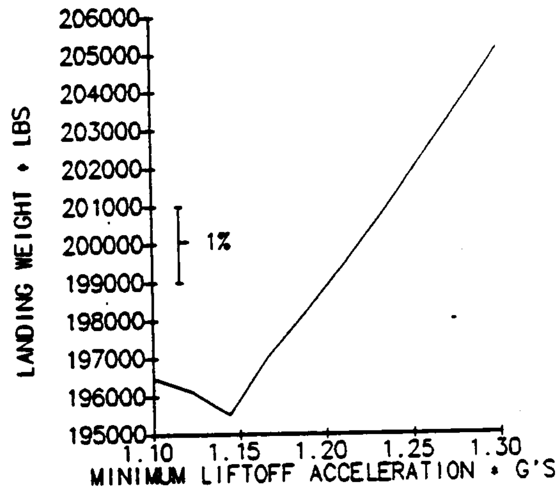


(e-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

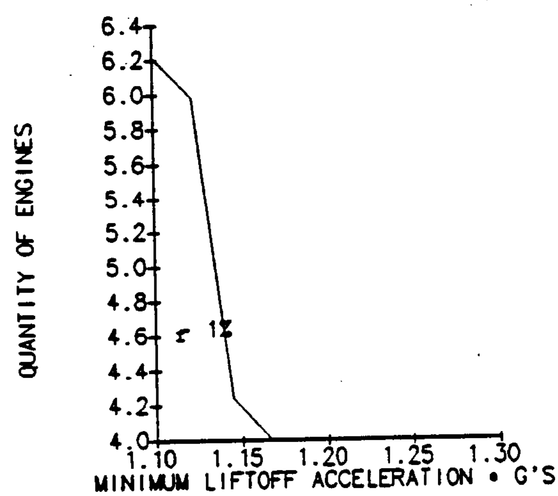
Configuration 2.E Sensitivity Studies (Continued)



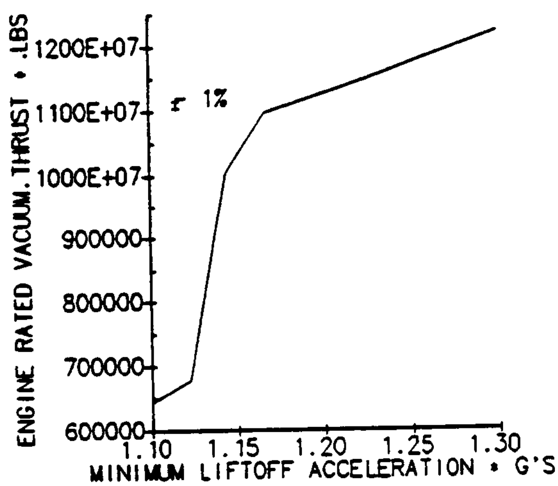
(e-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(e-22) Landing Weight Versus Engine-out Lift Off Acceleration

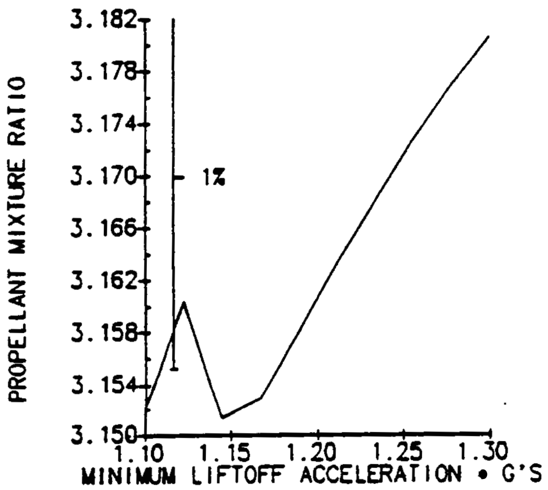


(e-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

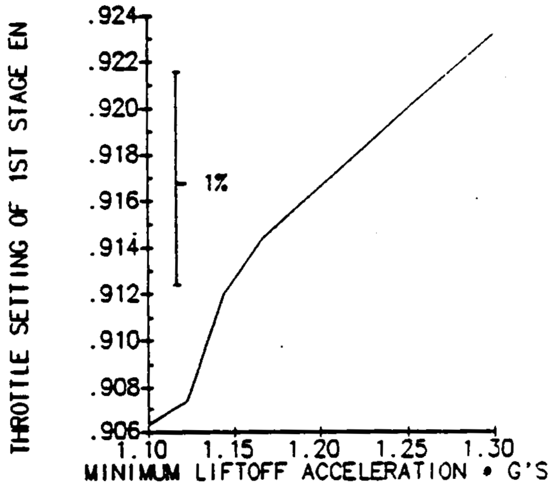


(e-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

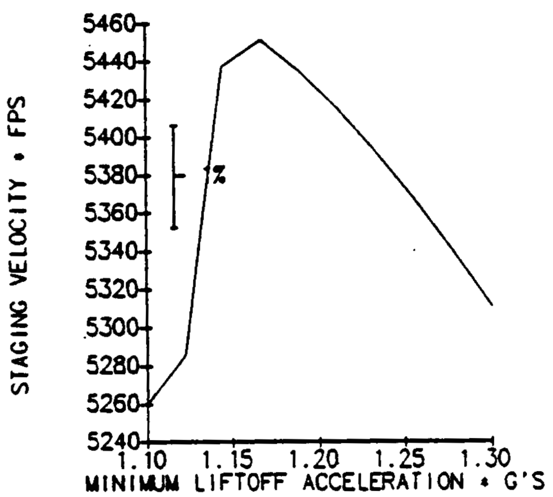
Configuration 2.E Sensitivity Studies (Continued)



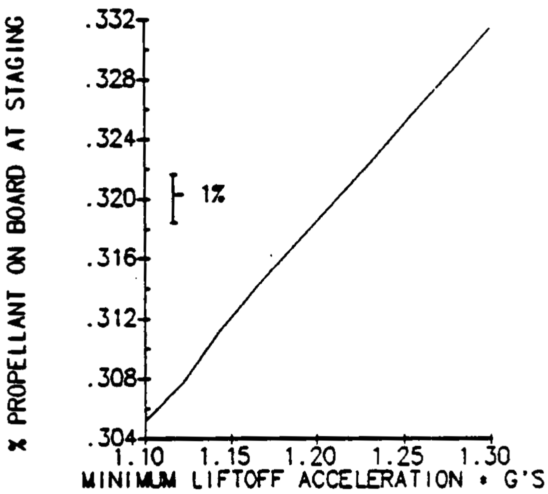
(e-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(e-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

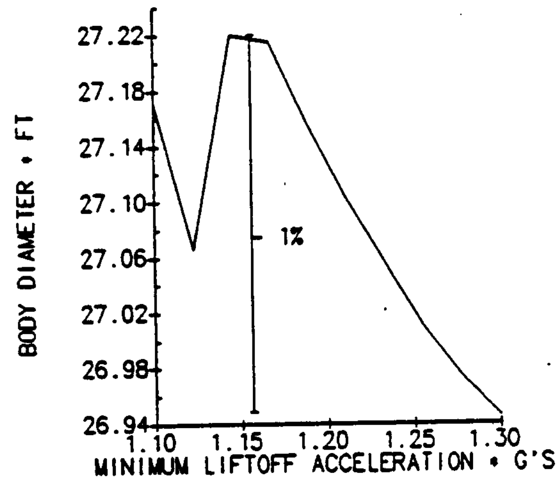


(e-27) Staging Velocity Versus Engine-out Lift Off Acceleration

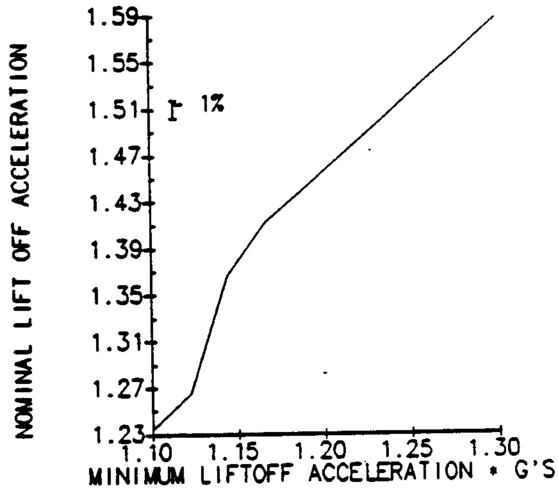


(e-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

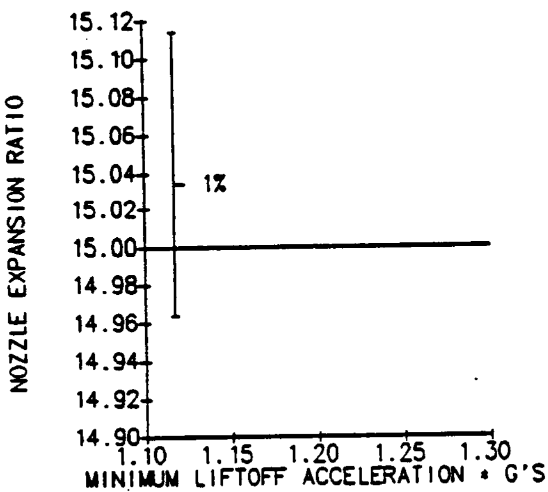
Configuration 2.E Sensitivity Studies (Continued)



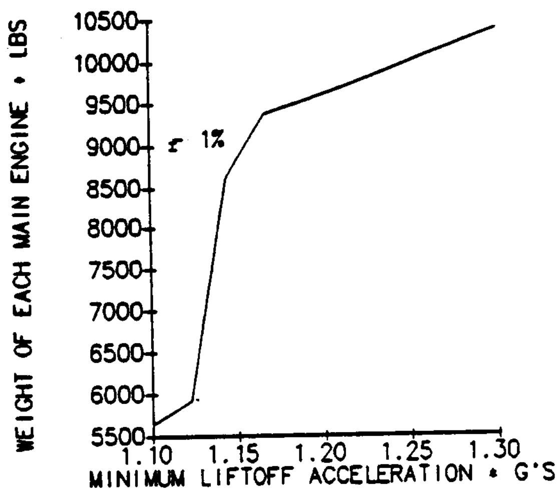
(e-29) Body Diameter Versus Engine-out Lift Off Acceleration



(e-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

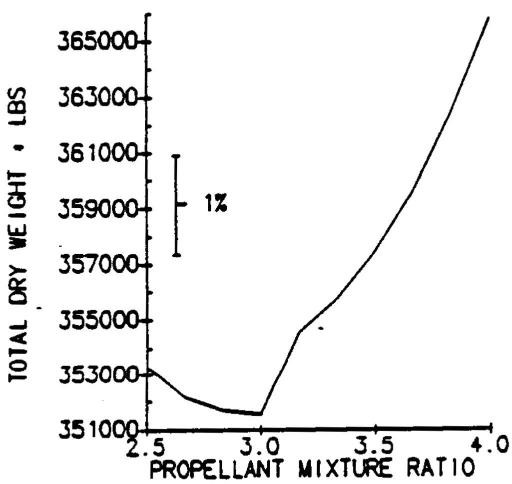


(e-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

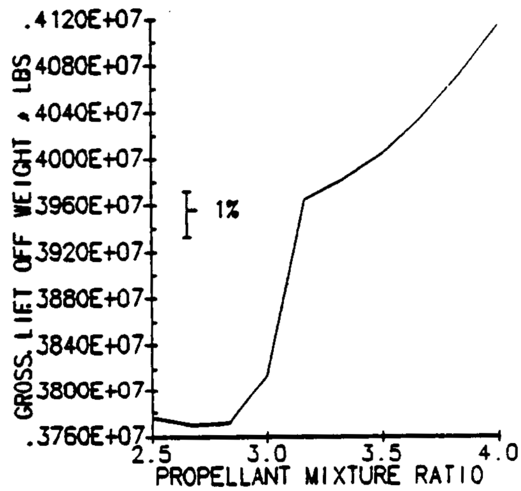


(e-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

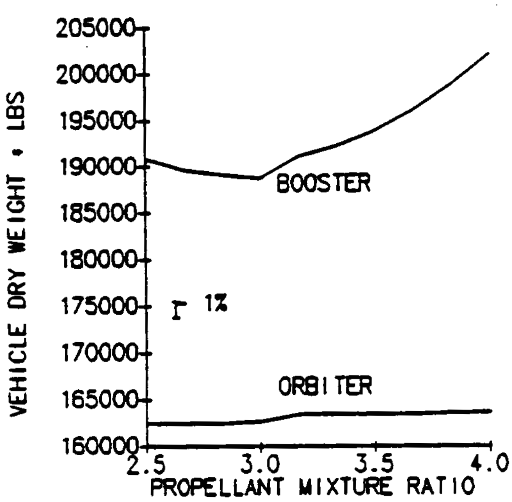
Configuration 2.E Sensitivity Studies (Continued)



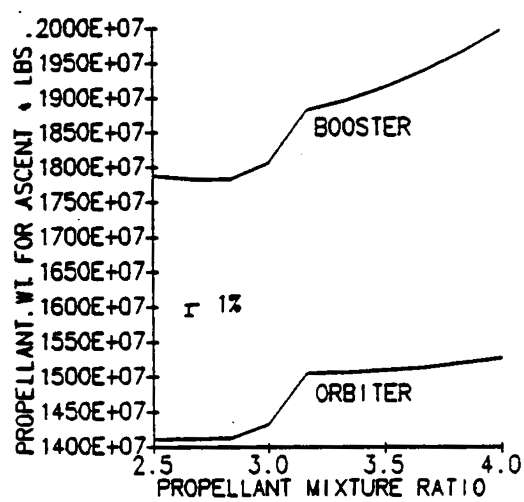
(e-33) Total Dry Weight Versus Propellant Mixture Ratio



(e-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

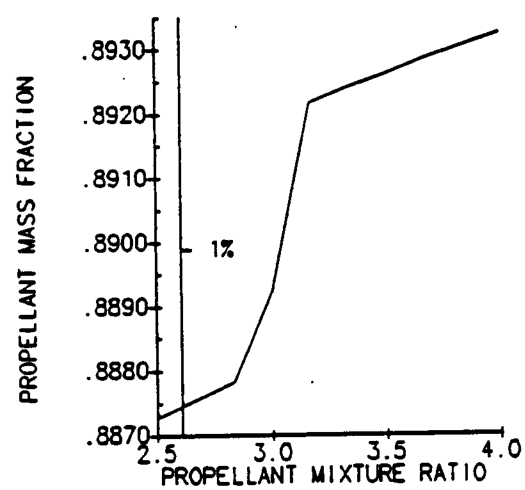


(e-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

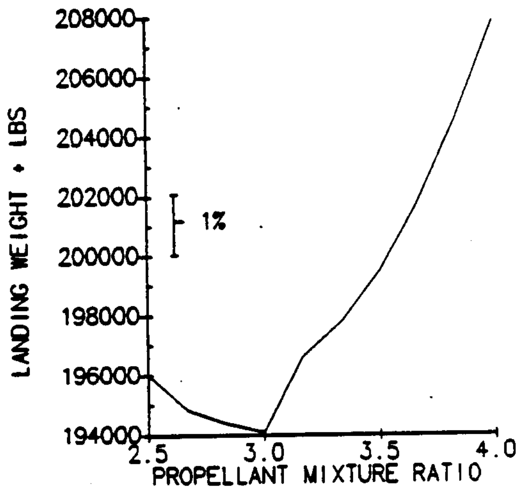


(e-36) Propellant Consumed Versus Propellant Mixture Ratio

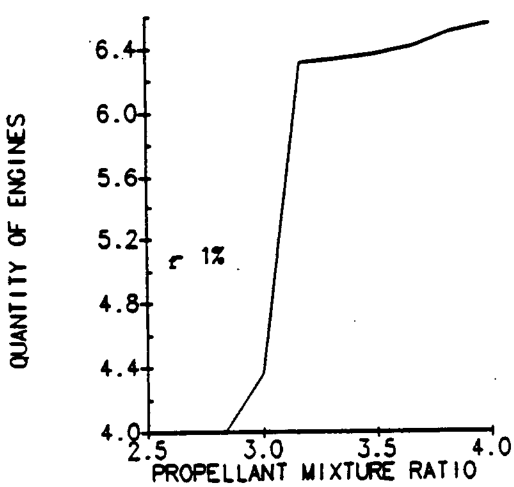
Configuration 2.E Sensitivity Studies (Continued)



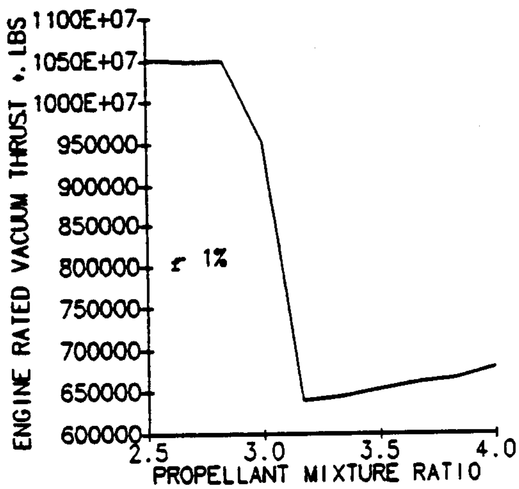
(e-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(e-38) Landing Weight Versus Propellant Mixture Ratio

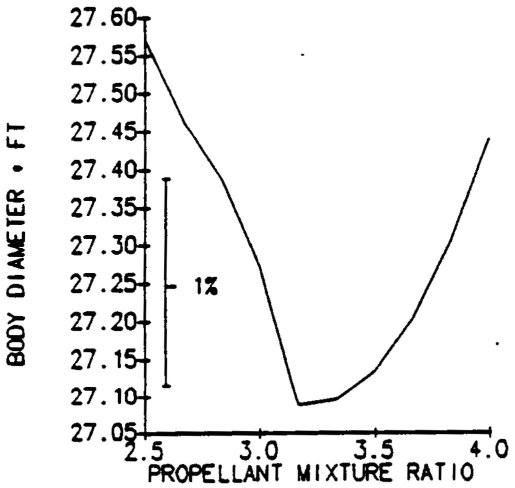


(e-39) Number of Booster Engines Versus Propellant Mixture Ratio

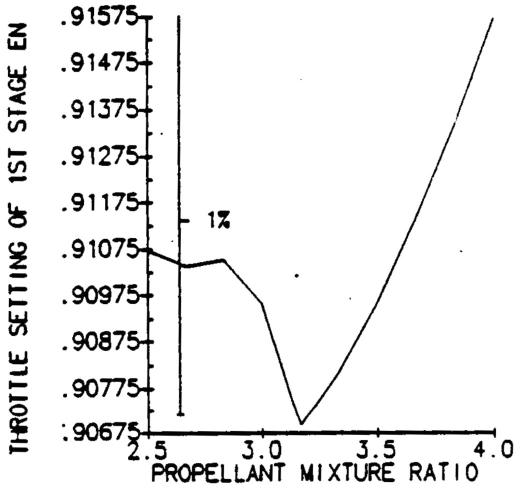


(e-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

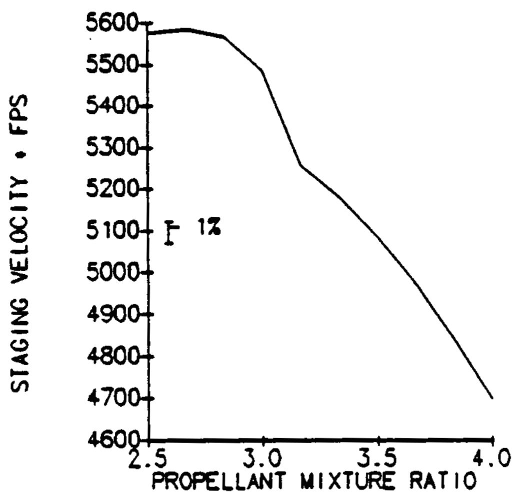
Configuration 2.E Sensitivity Studies (Continued)



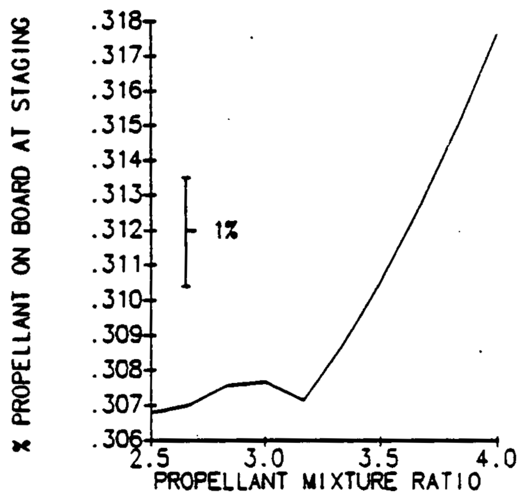
(e-41) Body Diameter Versus Propellant Mixture Ratio



(e-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

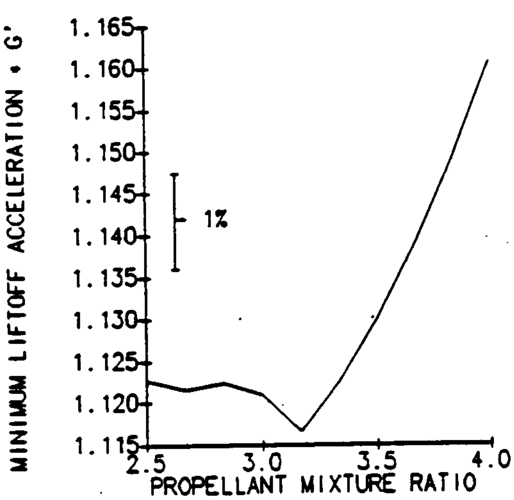


(e-43) Staging Velocity Versus Propellant Mixture Ratio

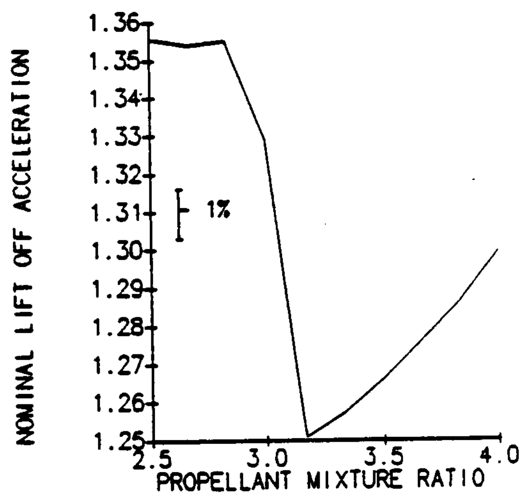


(e-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

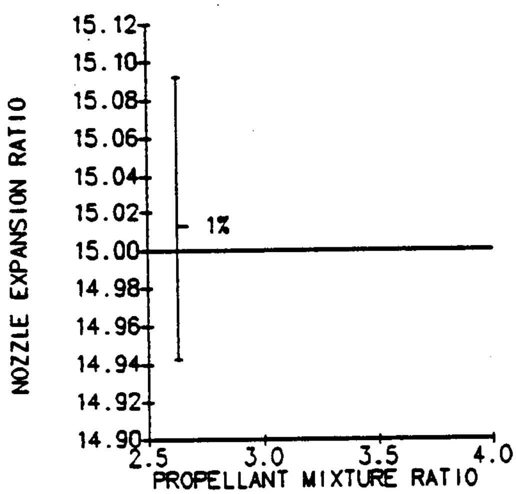
Configuration 2.E Sensitivity Studies (Continued)



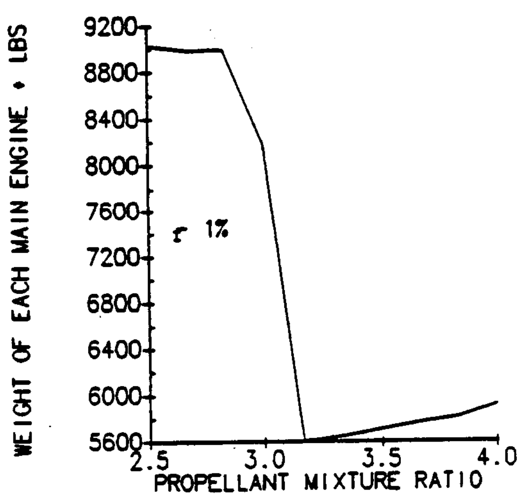
(e-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(e-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

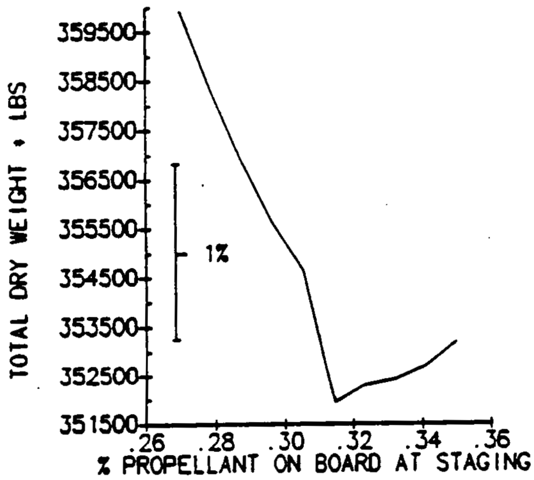


(e-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

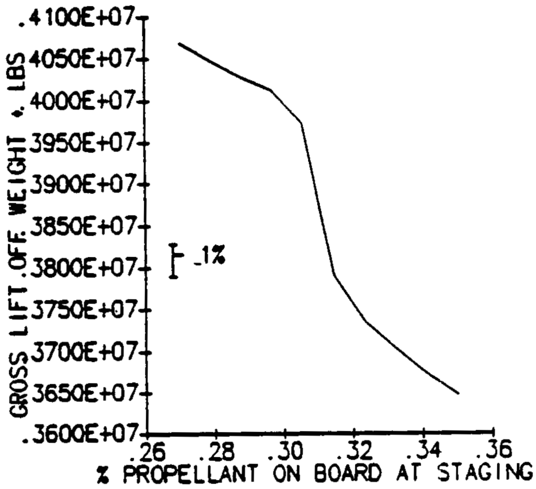


(e-48) Booster Engine Weight Versus Propellant Mixture Ratio

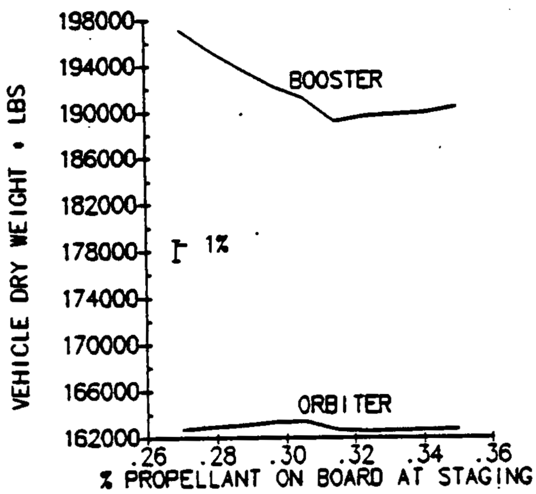
Configuration 2.E Sensitivity Studies (Continued)



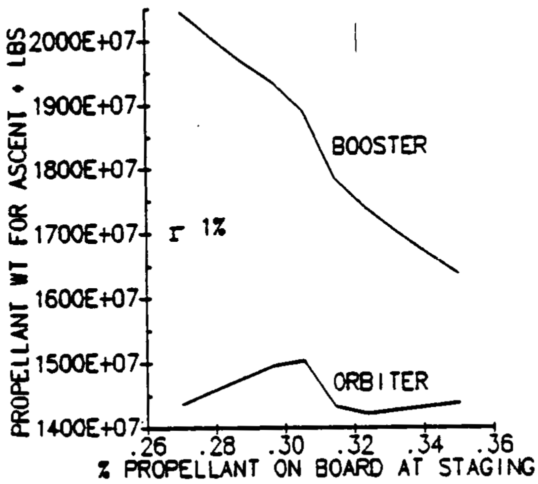
(e-49) Total Dry Weight Versus Orbiter Propellant at Staging



(e-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

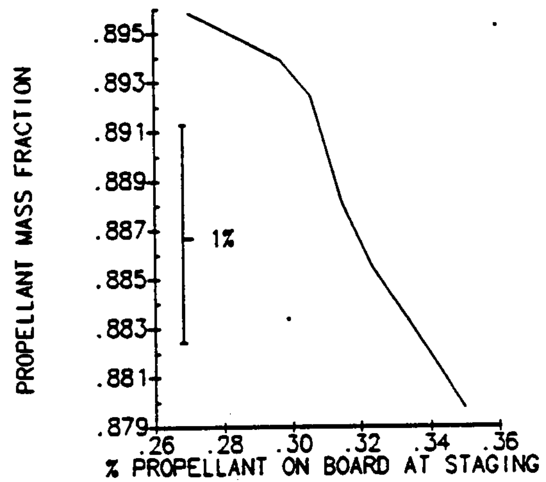


(e-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

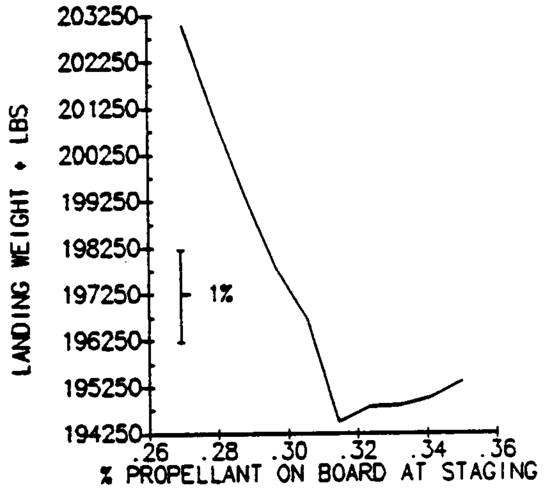


(e-52) Propellant Consumed Versus Orbiter Propellant at Staging

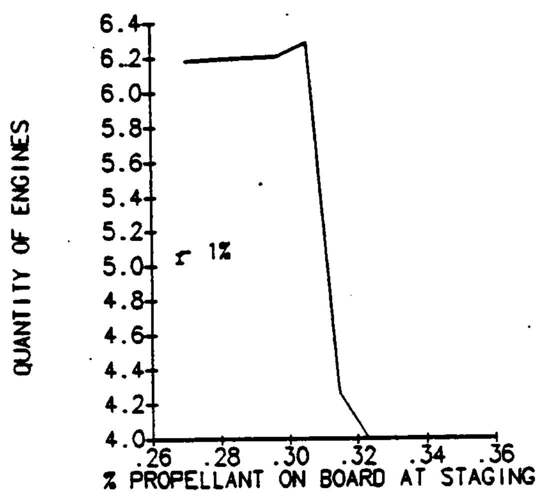
Configuration 2.E Sensitivity Studies (Continued)



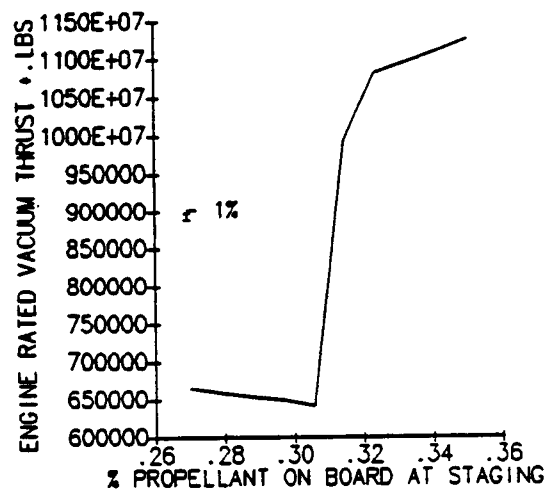
(e-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(e-54) Landing Weight Versus Orbiter Propellant at Staging

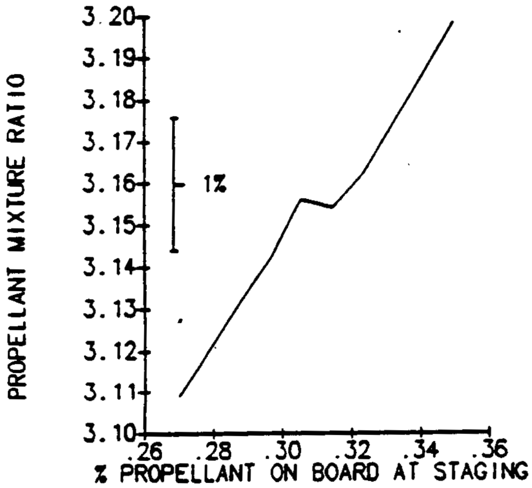


(e-55) Number of Booster Engines Versus Orbiter Propellant at Staging

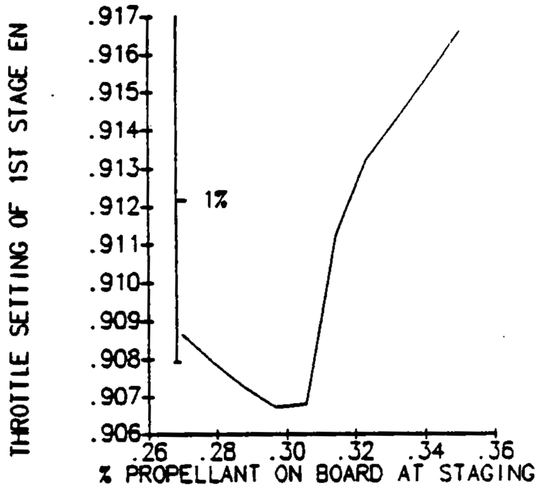


(e-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

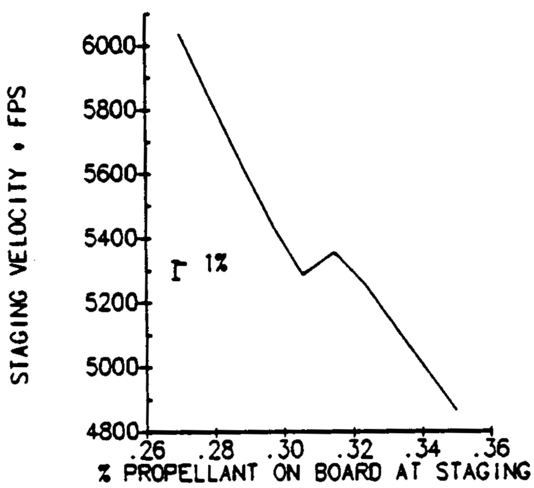
Configuration 2.E Sensitivity Studies (Continued)



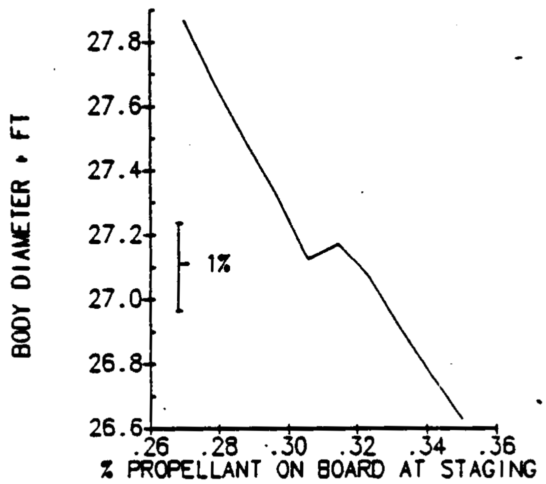
(e-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(e-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

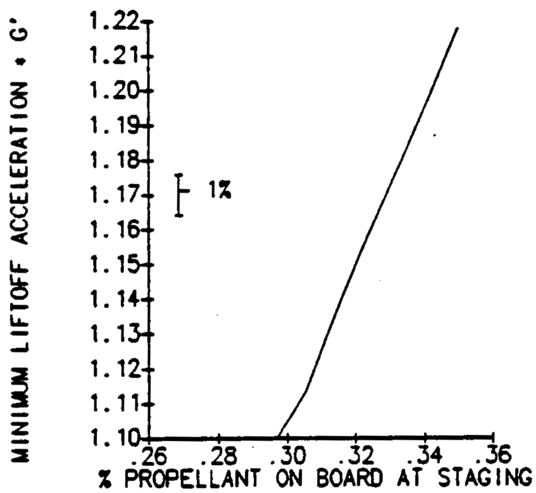


(e-59) Staging Velocity Versus Orbiter Propellant at Staging

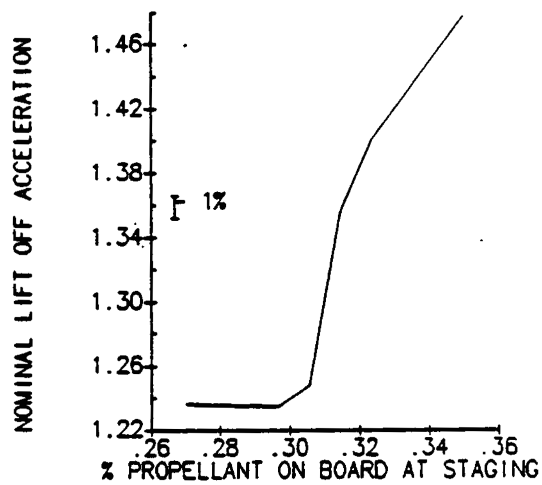


(e-60) Body Diameter Versus Orbiter Propellant at Staging

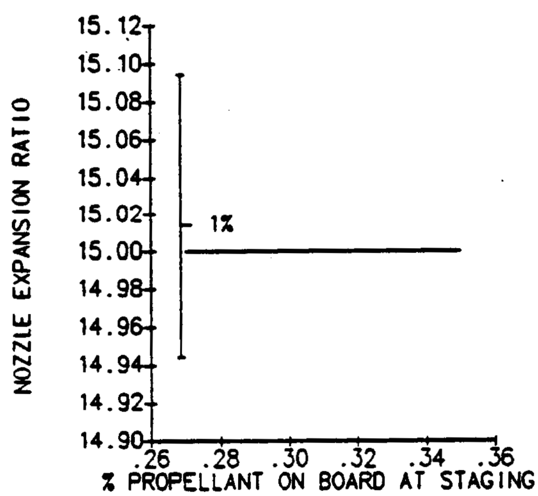
Configuration 2.E Sensitivity Studies (Continued)



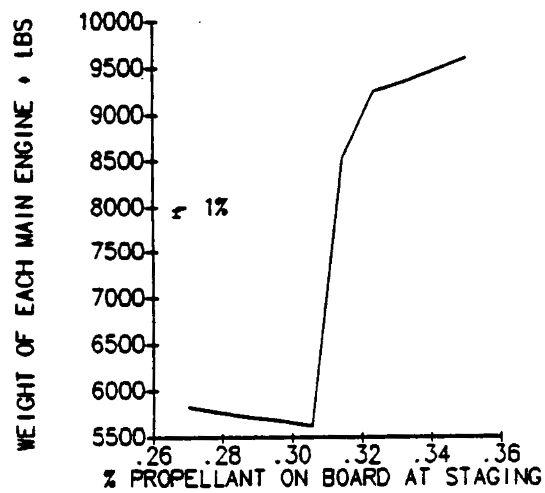
(e-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(e-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

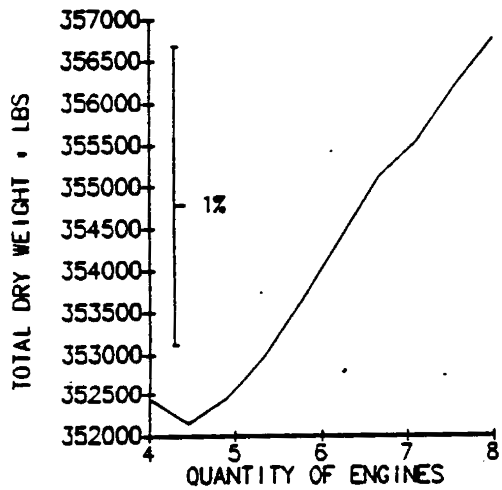


(e-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

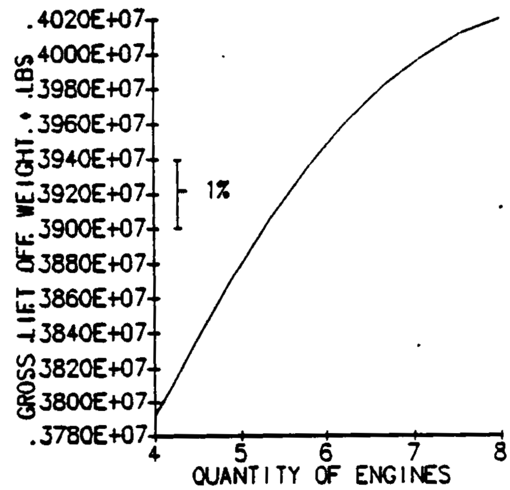


(e-64) Booster Engine Weight Versus Orbiter Propellant at Staging

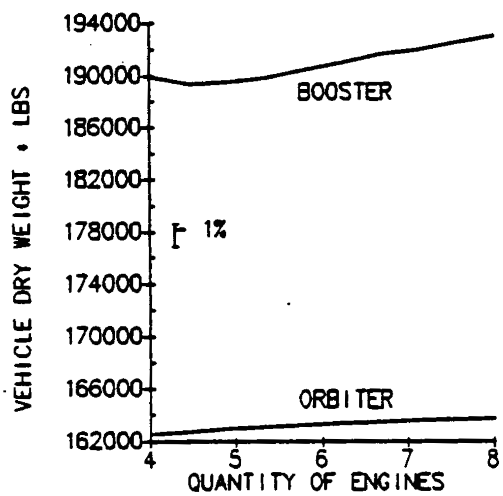
Configuration 2.E Sensitivity Studies (Continued)



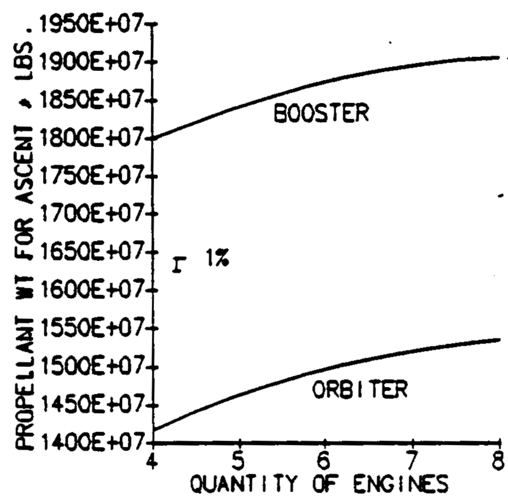
(e-65) Total Dry Weight Versus Number of Booster Engines



(e-66) Gross Lift Off Weight Versus Number of Booster Engines

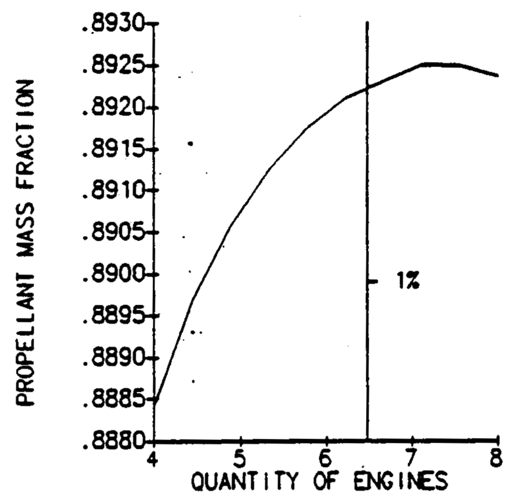


(e-67) Vehicle Dry Weight Versus Number of Booster Engines

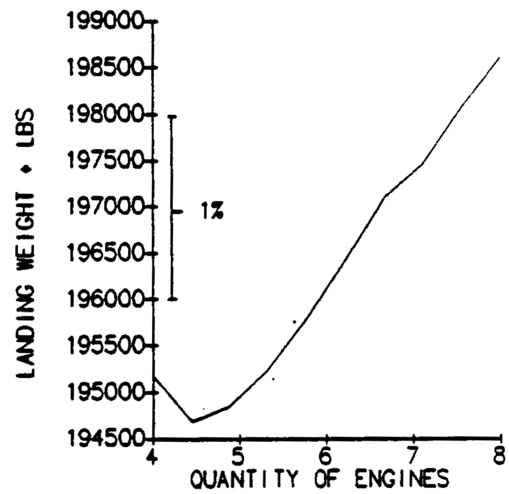


(e-68) Propellant Consumed Versus Number of Booster Engines

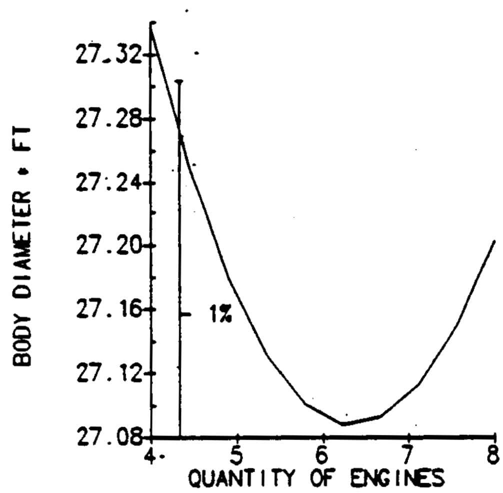
Configuration 2.E Sensitivity Studies (Continued)



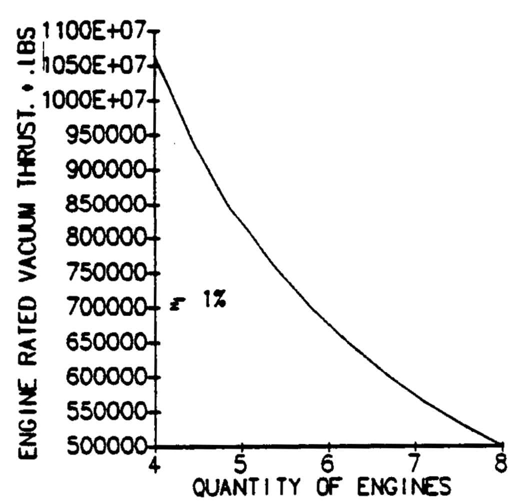
(e-69) Propellant Mass Fraction Versus Number of Booster Engines



(e-70) Landing Weight Versus Number of Booster Engines

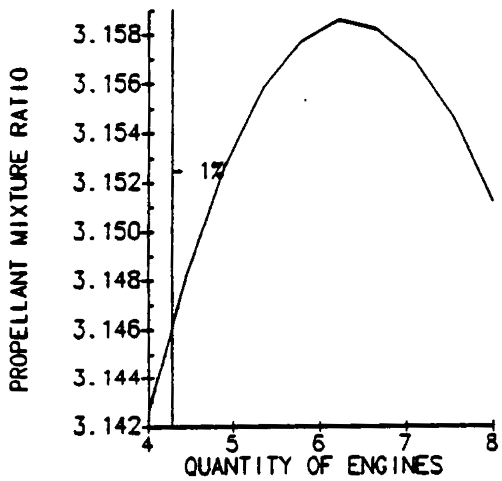


(e-71) Body Diameter Versus Number of Booster Engines

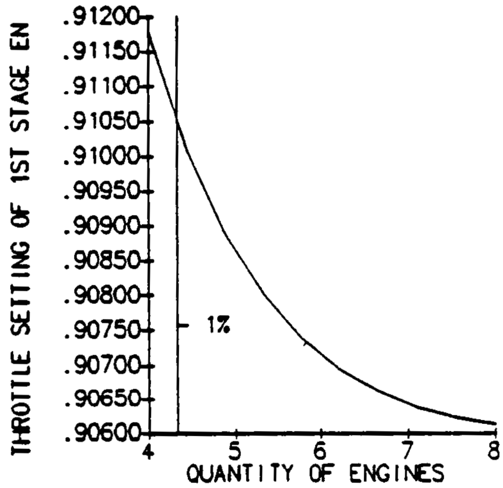


(e-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

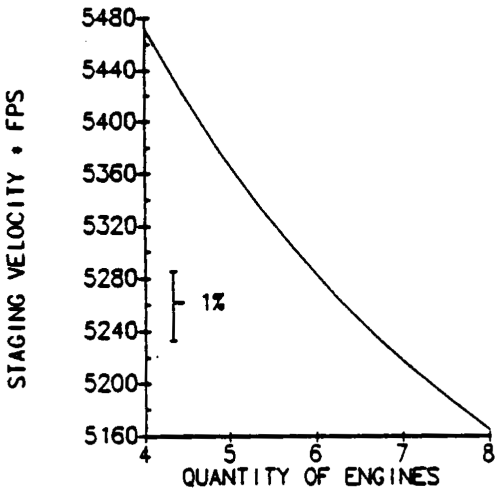
Configuration 2.E Sensitivity Studies (Continued)



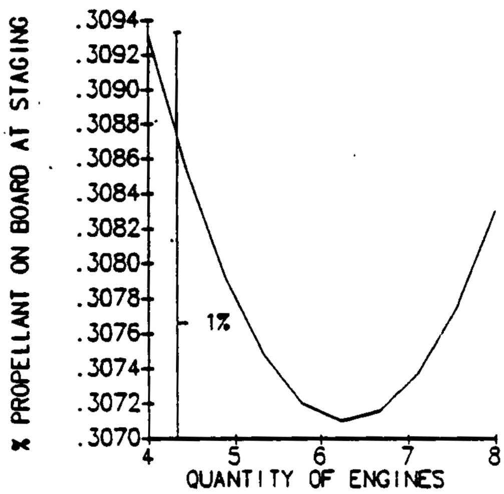
(e-73) Propellant Mixture Ratio Versus Number of Booster Engines



(e-74) Initial Booster Throttle Setting Versus Number of Booster Engines

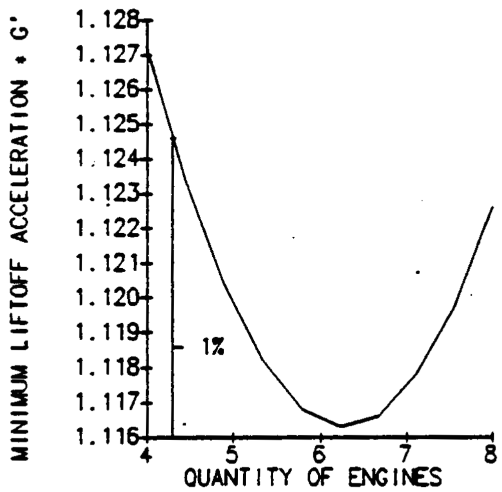


(e-75) Staging Velocity Versus Number of Booster Engines

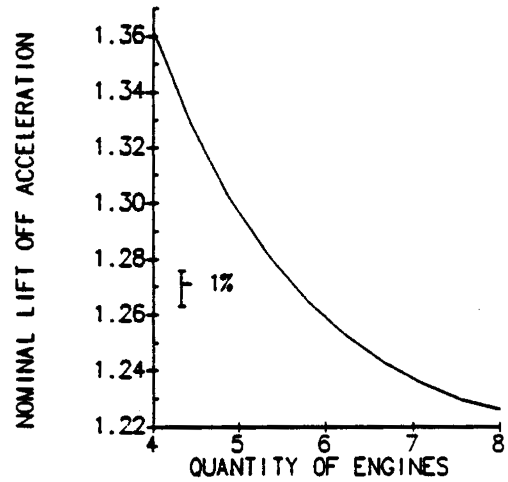


(e-76) Orbiter Propellant at Staging Versus Number of Booster Engines

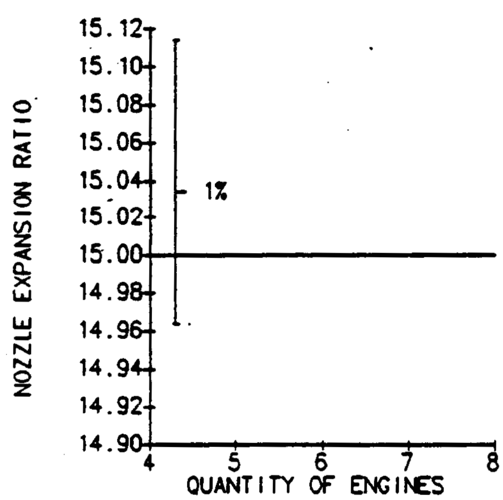
Configuration 2.E Sensitivity Studies (Continued)



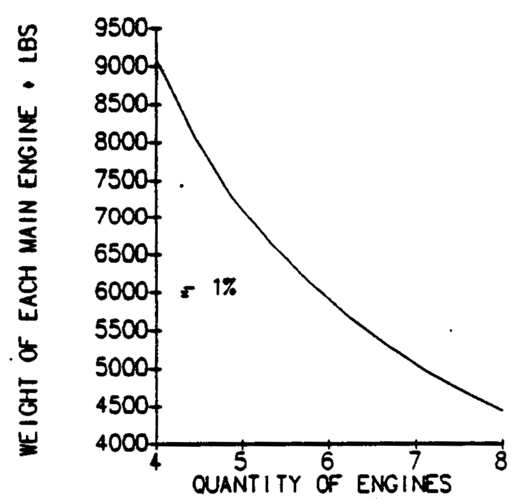
(e-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(e-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

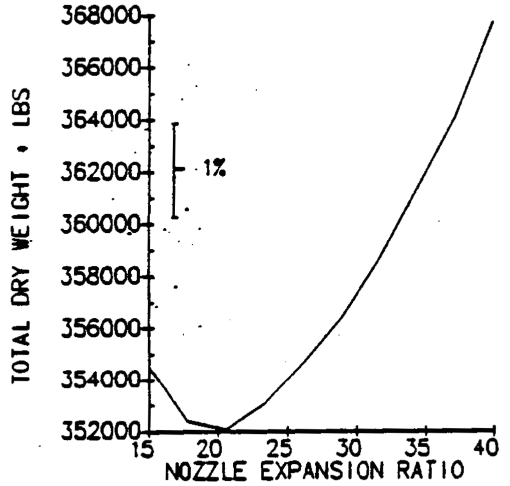


(e-79) Nozzle Expansion Ratio Versus Number of Booster Engines

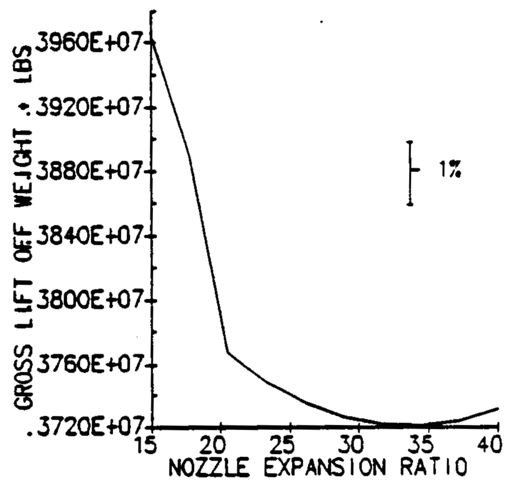


(e-80) Booster Engine Weight Versus Number of Booster Engines

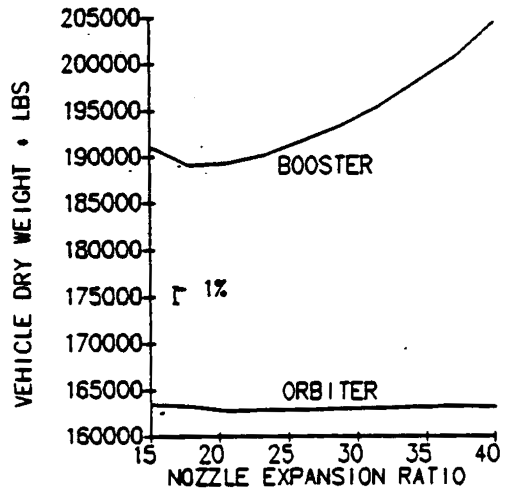
Configuration 2.E Sensitivity Studies (Continued)



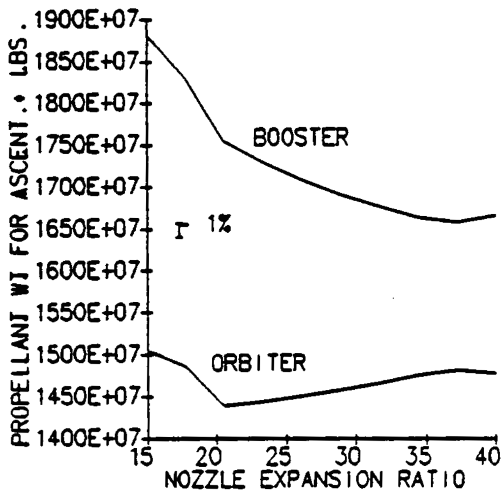
(e-81) Total Dry Weight Versus Nozzle Expansion Ratio



(e-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

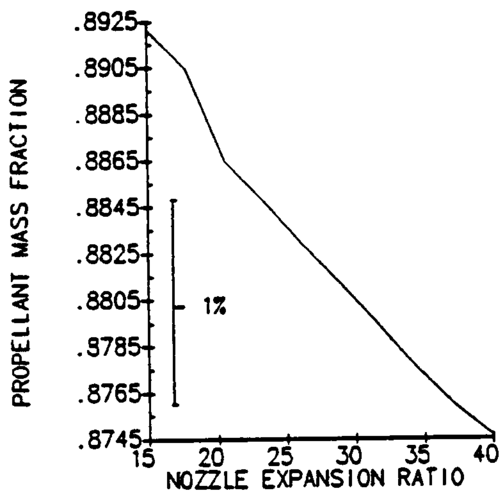


(e-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

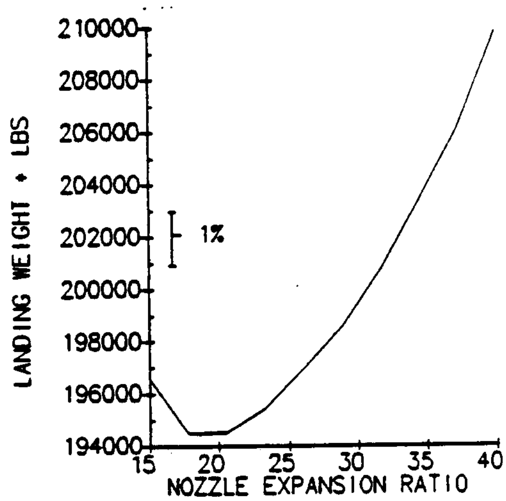


(e-84) Propellant Consumed Versus Nozzle Expansion Ratio

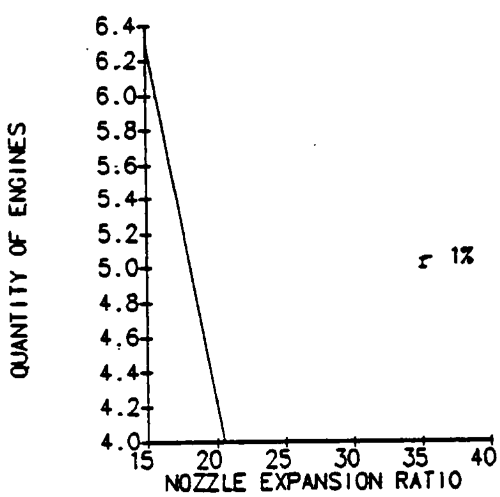
Configuration 2.E Sensitivity Studies (Continued)



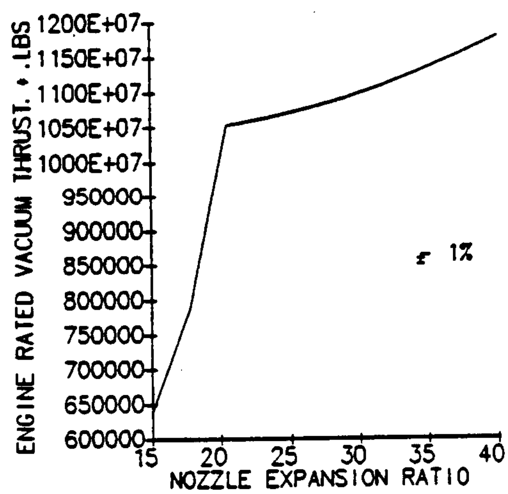
(e-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(e-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

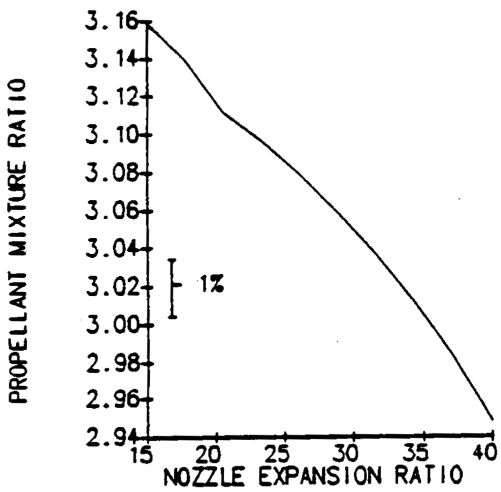


(e-87) Number of Booster Engines Versus Nozzle Expansion Ratio

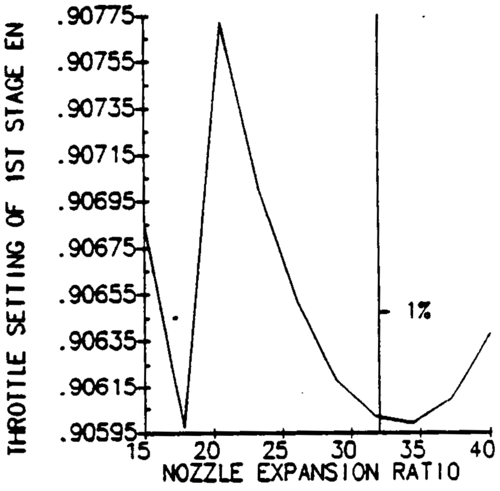


(e-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

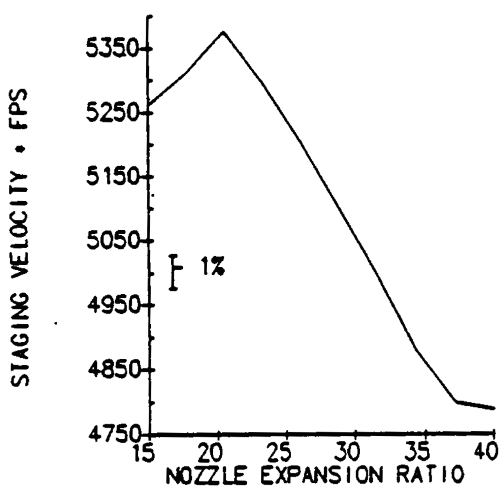
Configuration 2.E Sensitivity Studies (Continued)



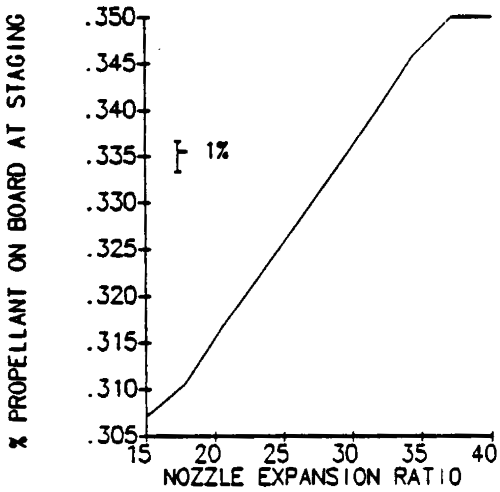
(e-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(e-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

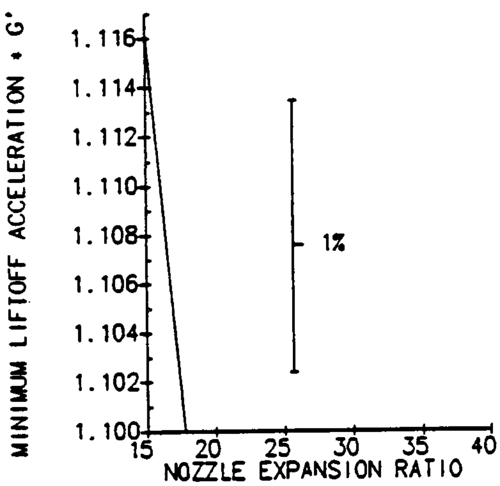


(e-91) Staging Velocity Versus Nozzle Expansion Ratio

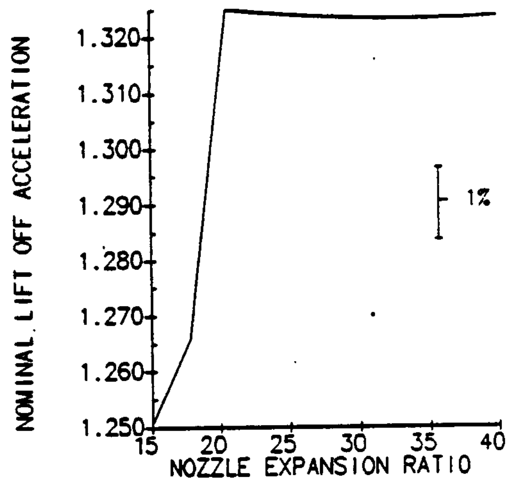


(e-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

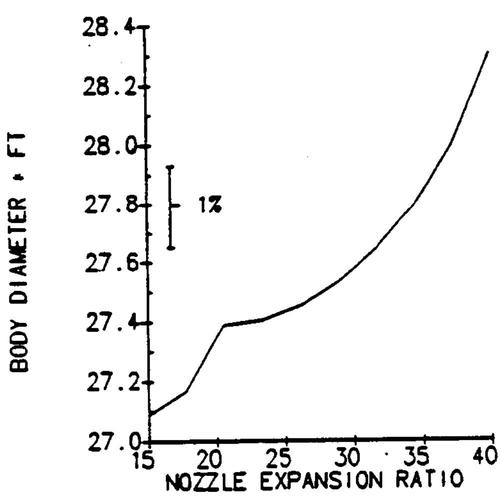
Configuration 2.E Sensitivity Studies (Continued)



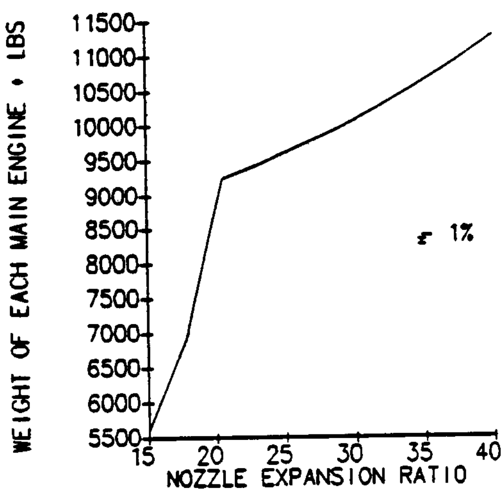
(e-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(e-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

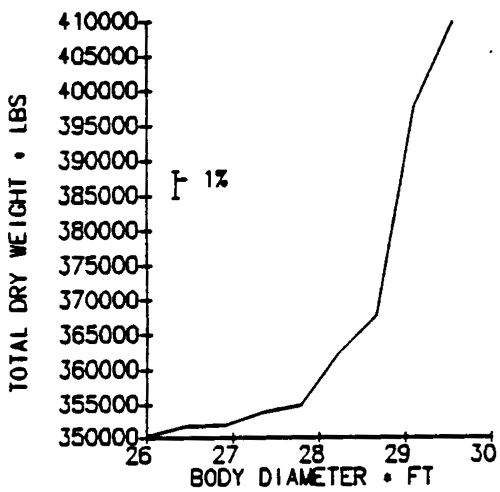


(e-95) Body Diameter Versus Nozzle Expansion Ratio

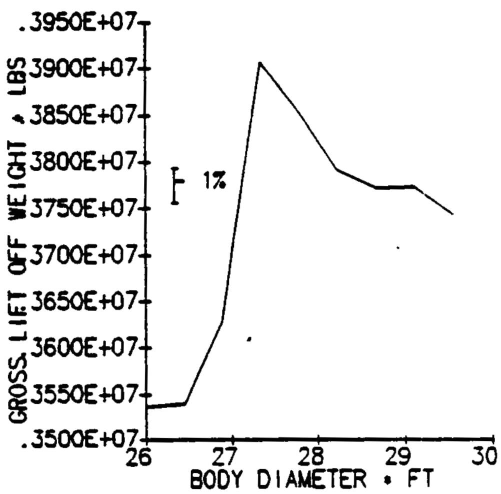


(e-96) Booster Engine Weight Versus Nozzle Expansion Ratio

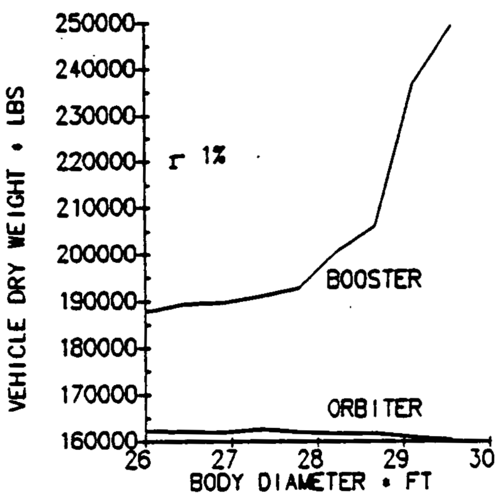
Configuration 2.E Sensitivity Studies (Continued)



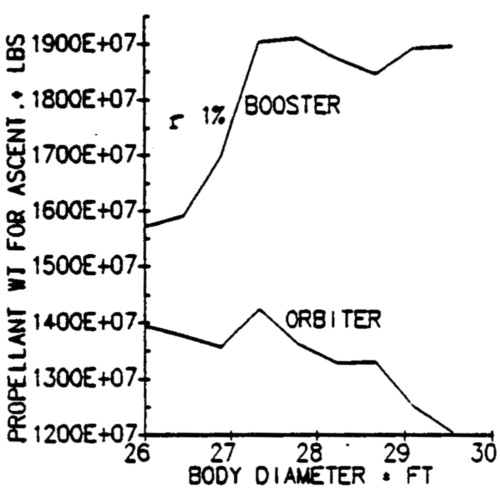
(f-1) Total Dry Weight Versus Body Diameter



(f-2) Gross Lift Off Weight Versus Body Diameter

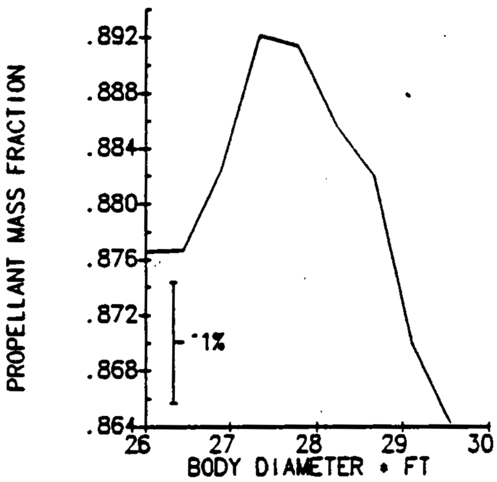


(f-3) Vehicle Dry Weight Versus Body Diameter

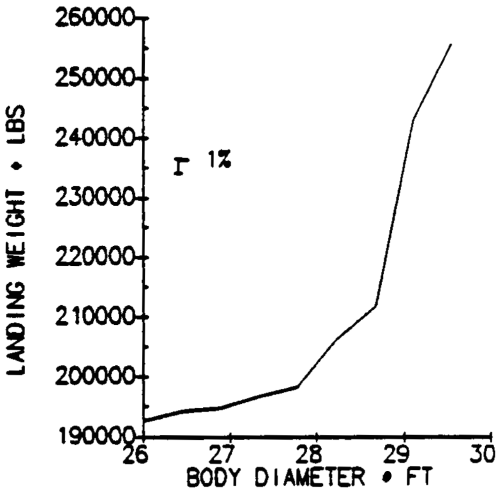


(f-4) Propellant Consumed Versus Body Diameter

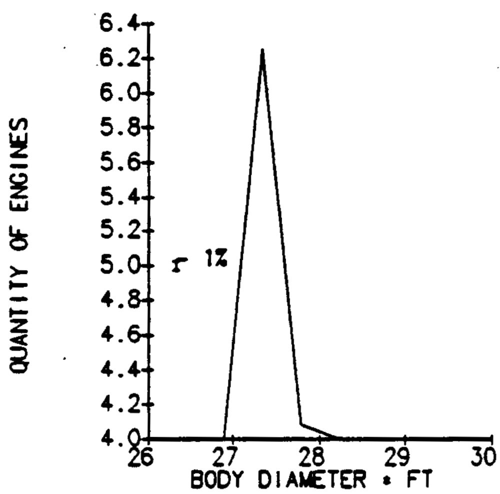
Configuration 2.F Sensitivity Studies



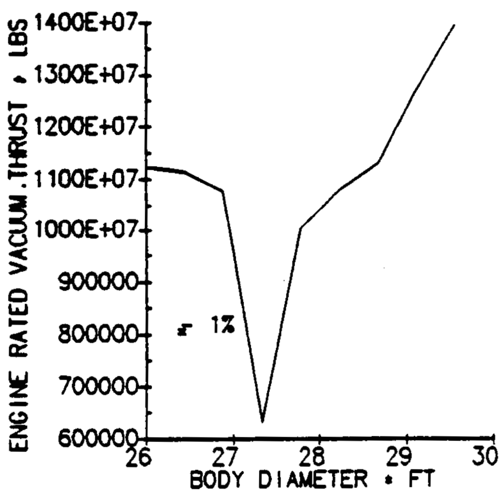
(f-5) Propellant Mass Fraction Versus Body Diameter



(f-6) Landing Weight Versus Body Diameter

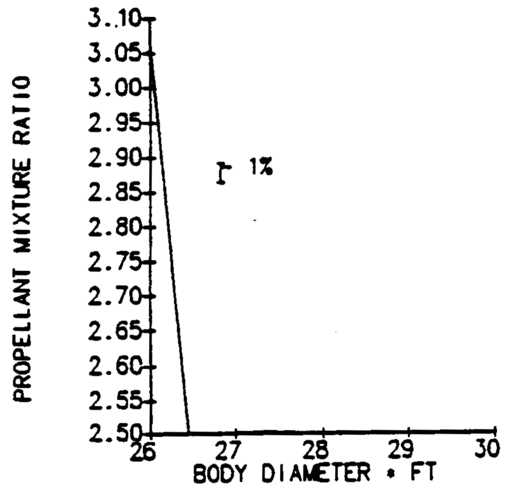


(f-7) Number of Booster Engines Versus Body Diameter

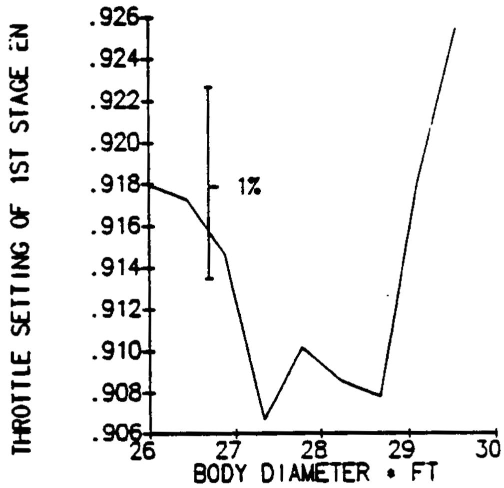


(f-8) Engine Rated Vacuum Thrust Versus Body Diameter

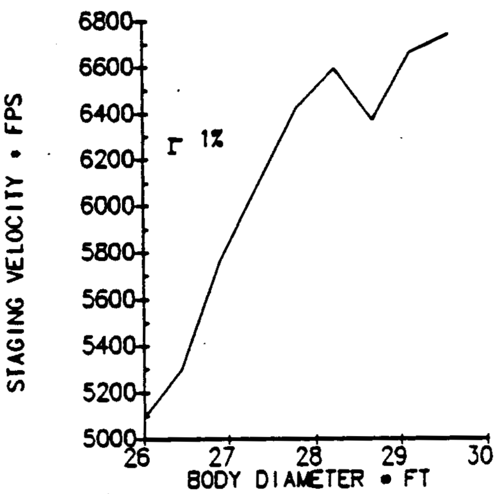
Configuration 2.F Sensitivity Studies (Continued)



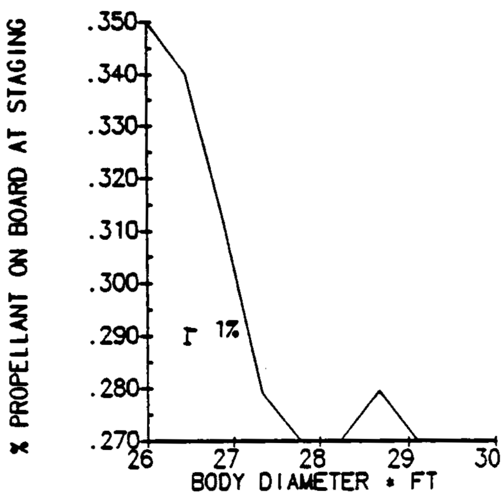
(f-9) Propellant Mixture Ratio Versus Body Diameter



(f-10) Initial Booster Throttle Setting Versus Body Diameter

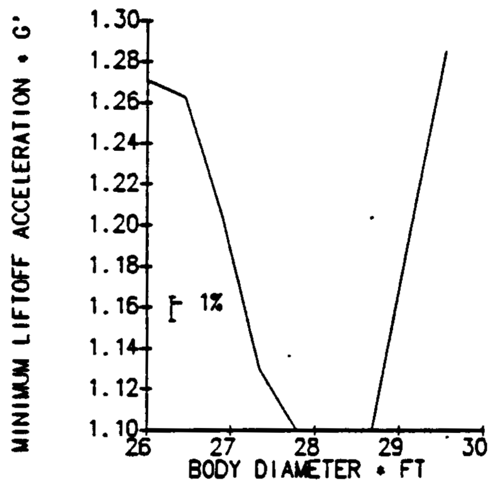


(f-11) Staging Velocity Versus Body Diameter

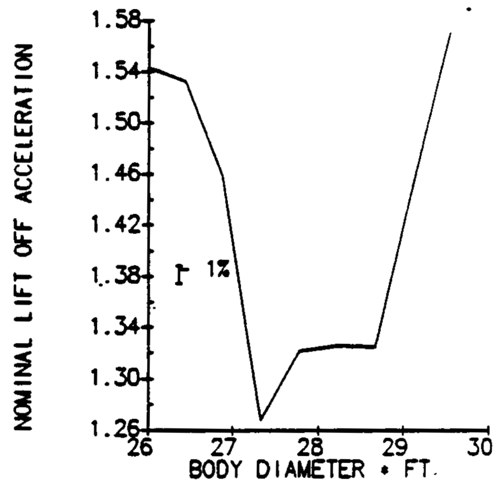


(f-12) Orbiter Propellant at Staging Versus Body Diameter

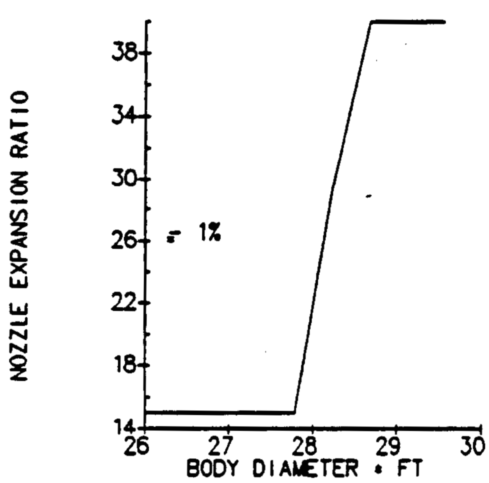
Configuration 2.F Sensitivity Studies (Continued)



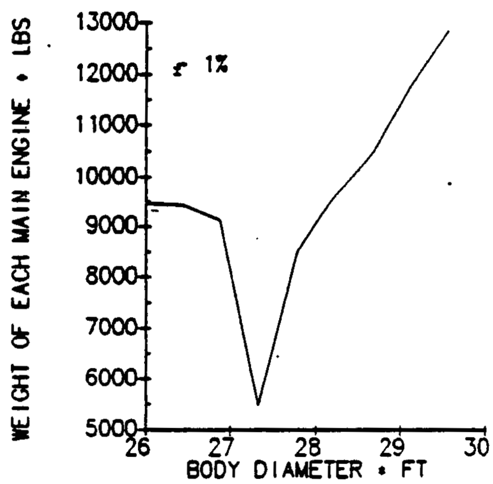
(f-13) Engine-out Lift Off Acceleration Versus Body Diameter



(f-14) Nominal Lift Off Acceleration Versus Body Diameter

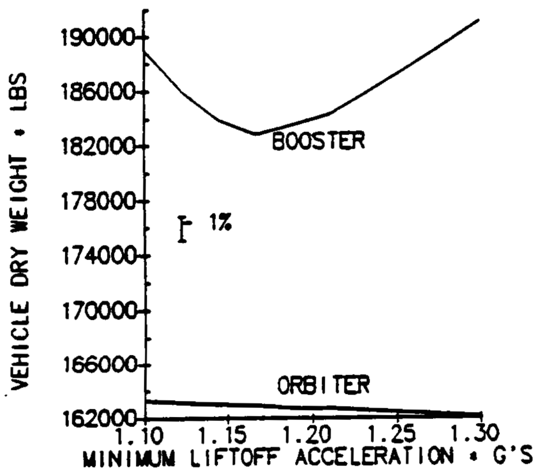


(f-15) Nozzle Expansion Ratio Versus Body Diameter

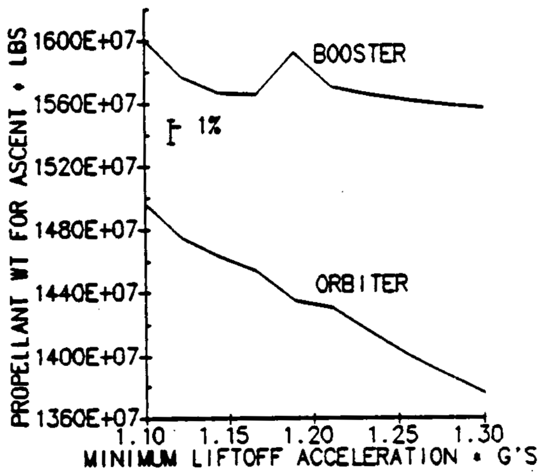


(f-16) Booster Engine Weight Versus Body Diameter

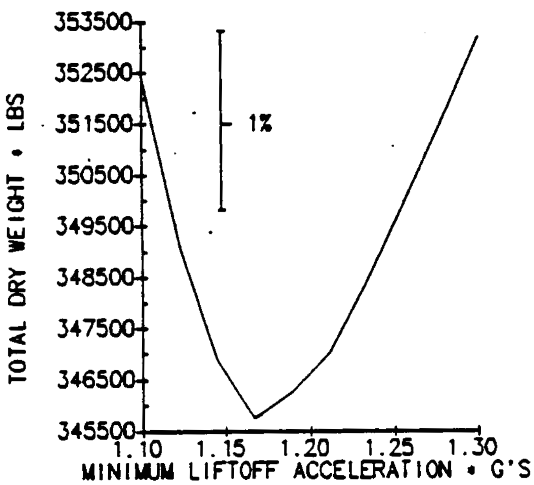
Configuration 2.F Sensitivity Studies (Continued)



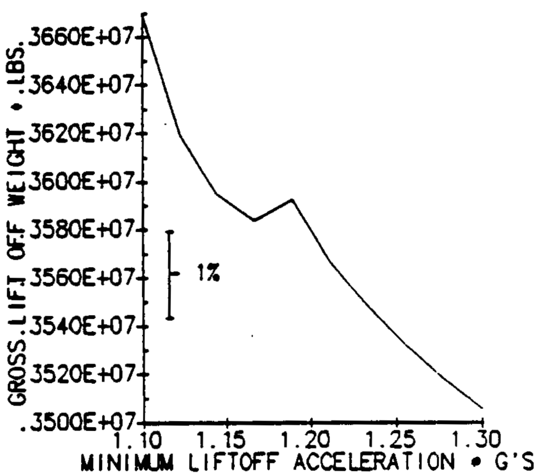
(f-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(f-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

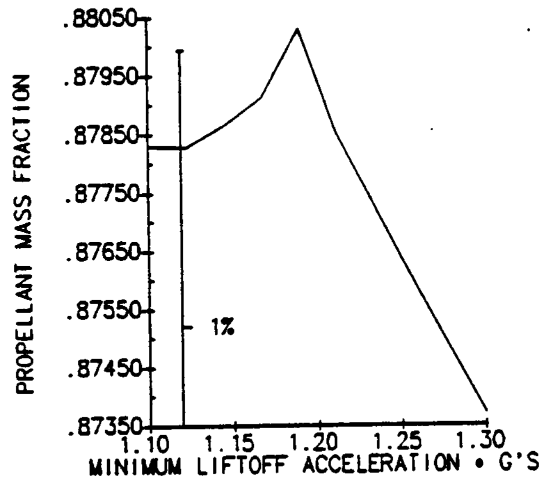


(f-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

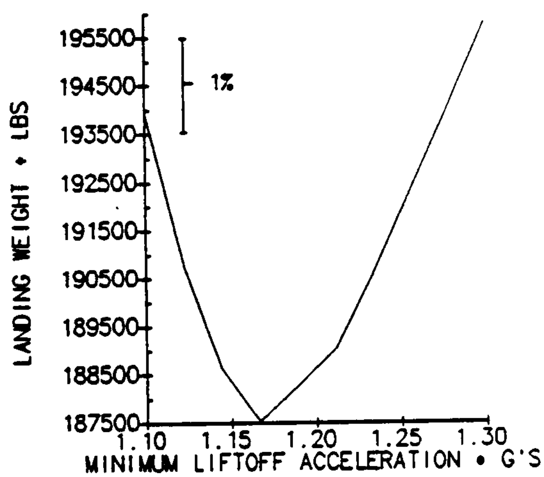


(f-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

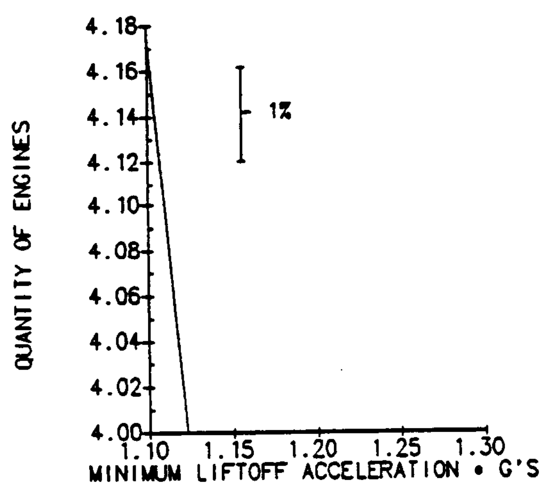
Configuration 2.F Sensitivity Studies (Continued)



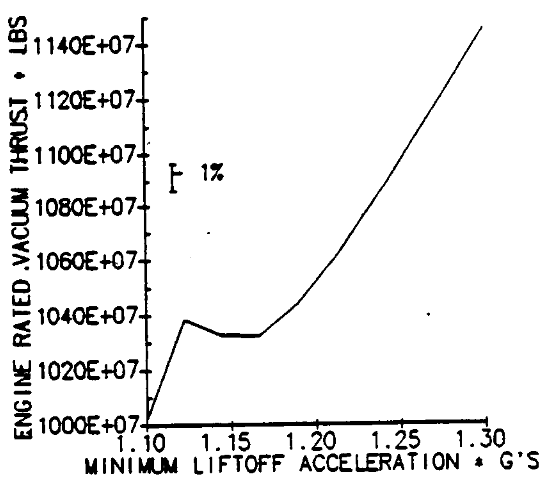
(f-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(f-22) Landing Weight Versus Engine-out Lift Off Acceleration

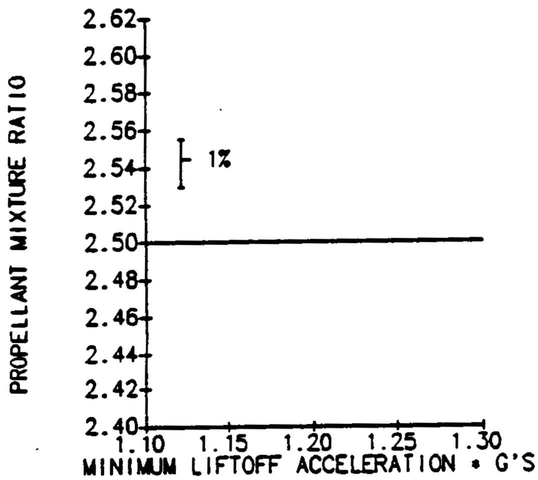


(f-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

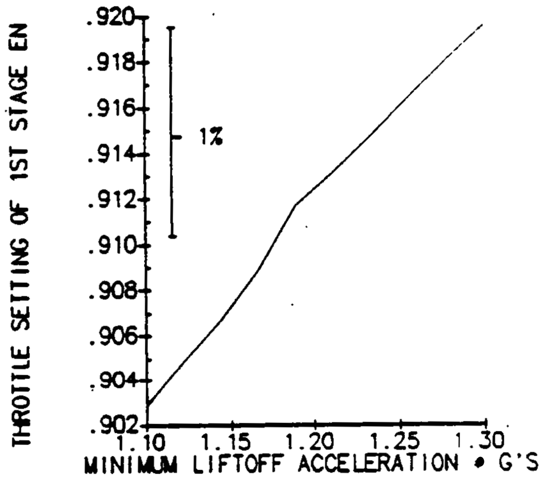


(f-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

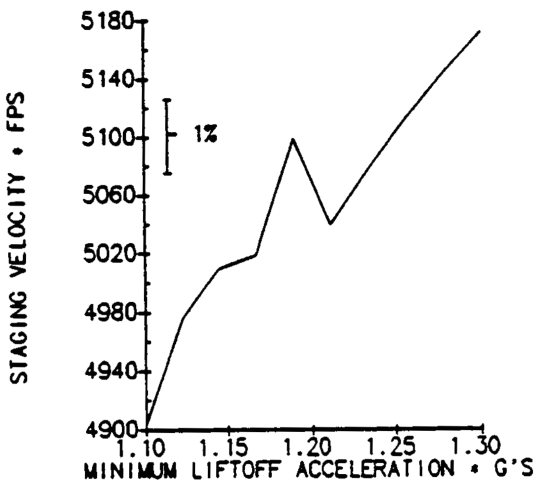
Configuration 2.F Sensitivity Studies (Continued)



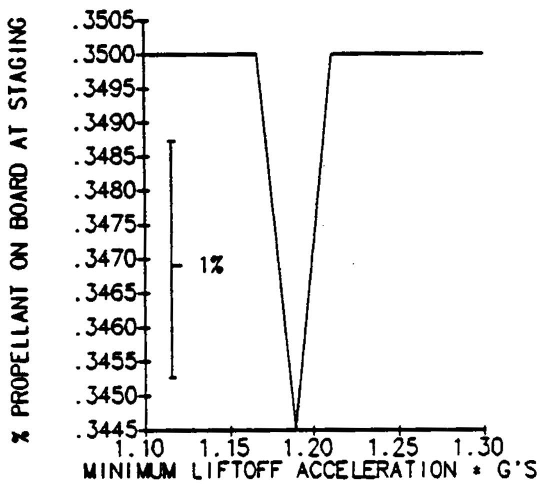
(f-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(f-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

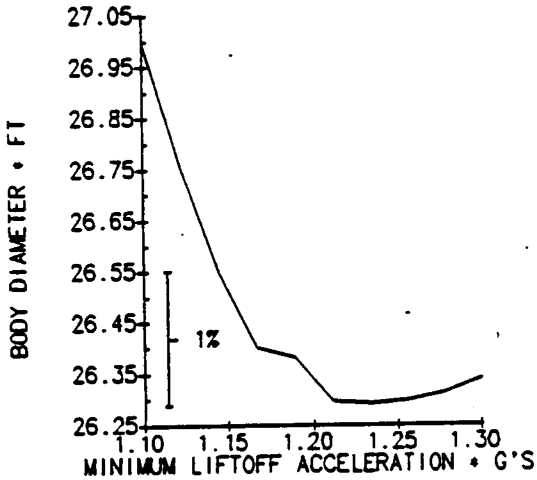


(f-27) Staging Velocity Versus Engine-out Lift Off Acceleration

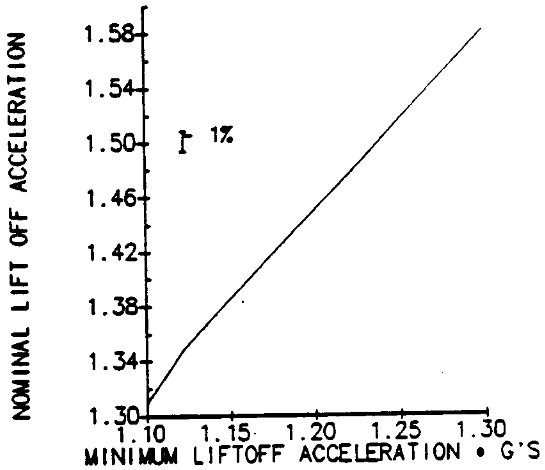


(f-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

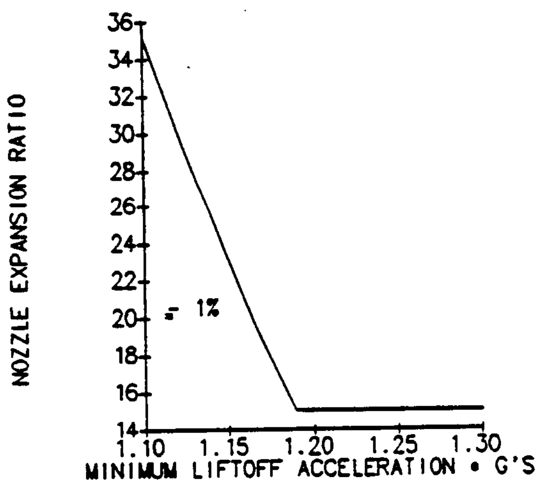
Configuration 2.F Sensitivity Studies (Continued)



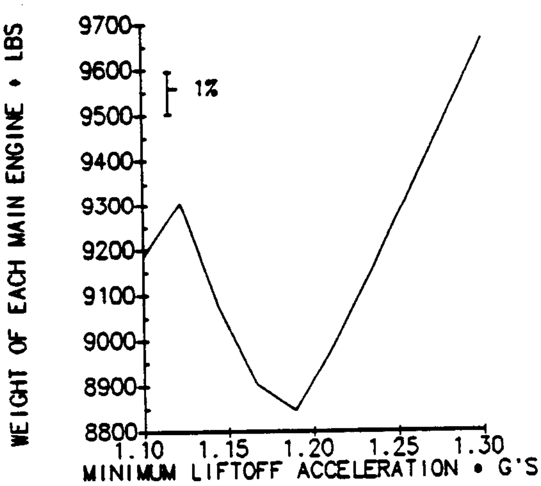
(f-29) Body Diameter Versus Engine-out Lift Off Acceleration



(f-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

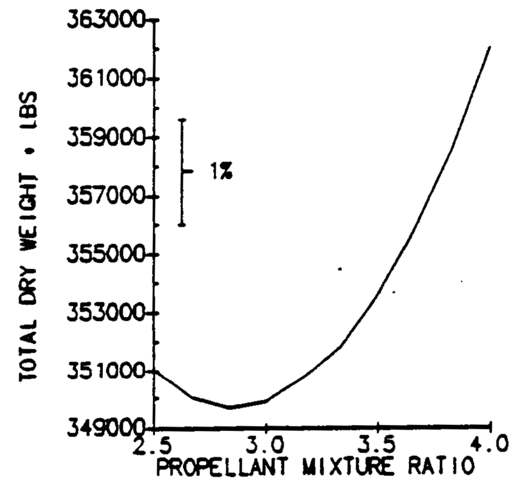


(f-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

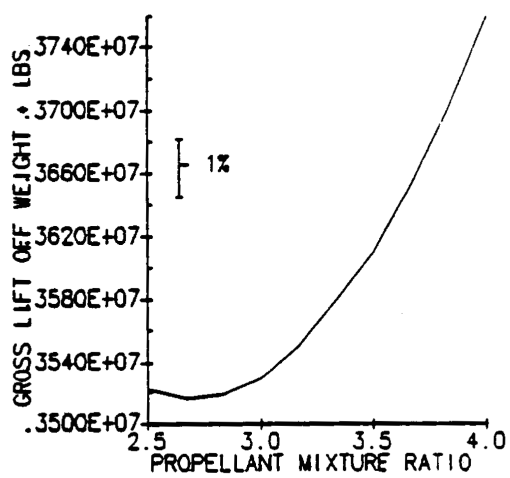


(f-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

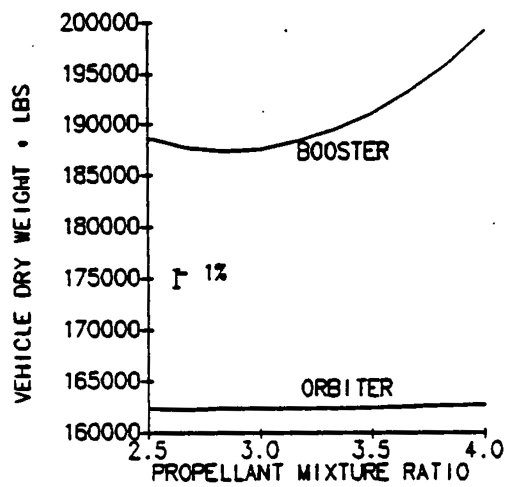
Configuration 2.F Sensitivity Studies (Continued)



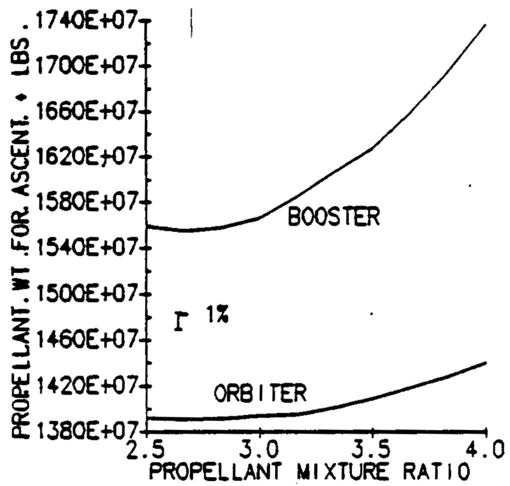
(f-33) Total Dry Weight Versus Propellant Mixture Ratio



(f-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

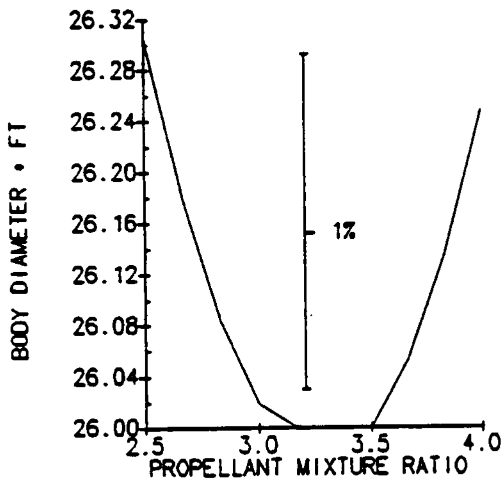


(f-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

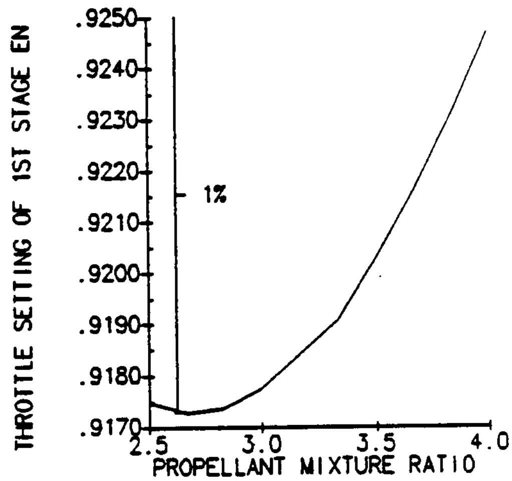


(f-36) Propellant Consumed Versus Propellant Mixture Ratio

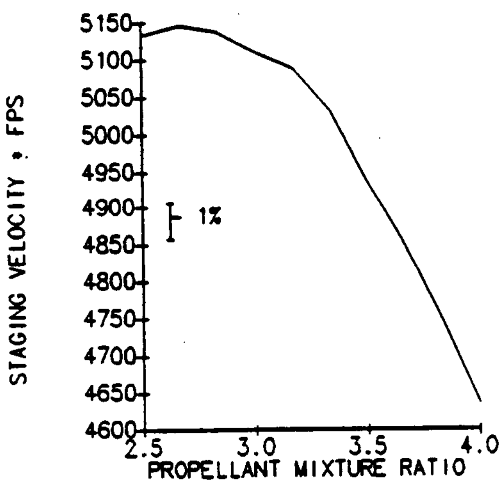
Configuration 2.F Sensitivity Studies (Continued)



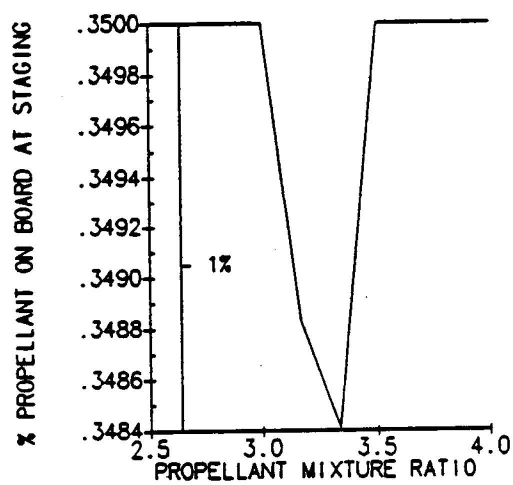
(f-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(f-38) Landing Weight Versus Propellant Mixture Ratio

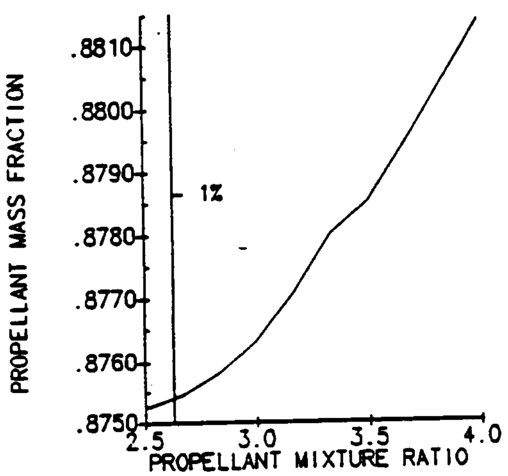


(f-39) Number of Booster Engines Versus Propellant Mixture Ratio

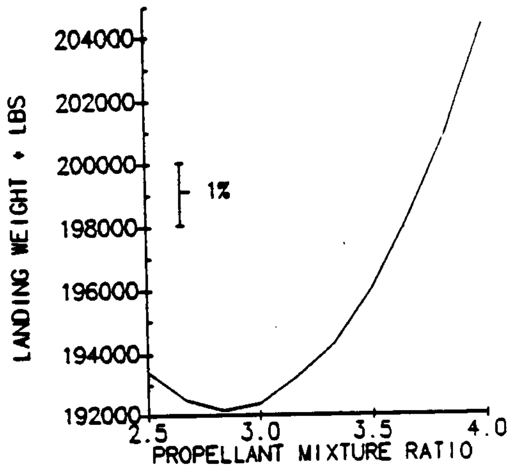


(f-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

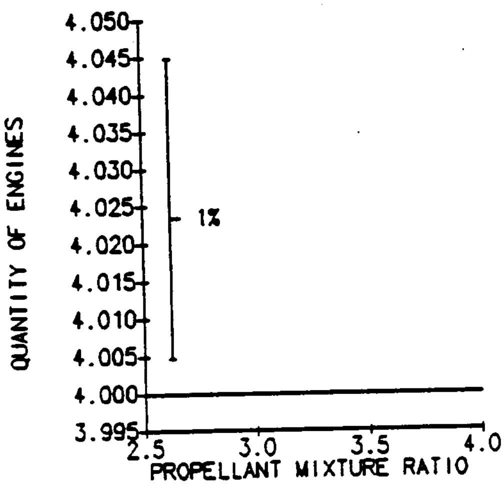
Configuration 2.F Sensitivity Studies (Continued)



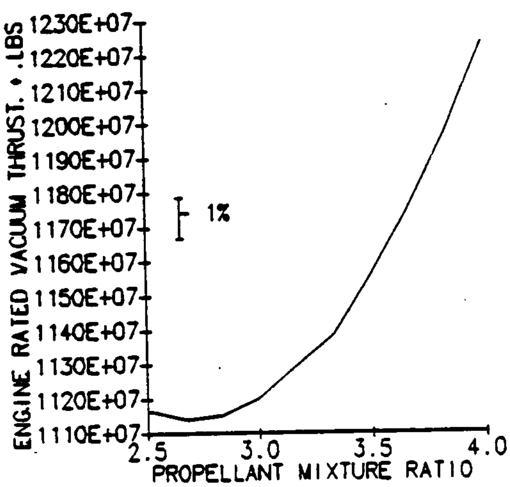
(f-41) Body Diameter Versus Propellant Mixture Ratio



(f-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

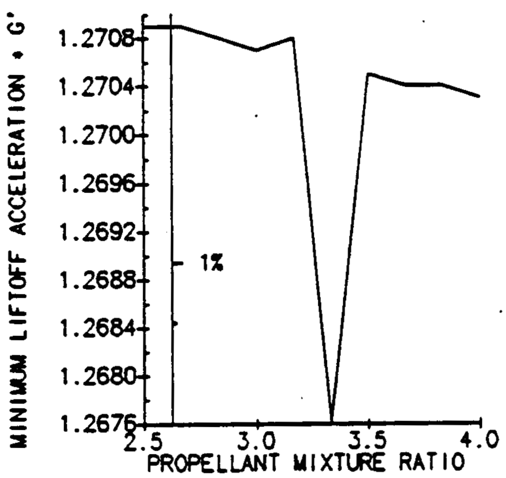


(f-43) Staging Velocity Versus Propellant Mixture Ratio

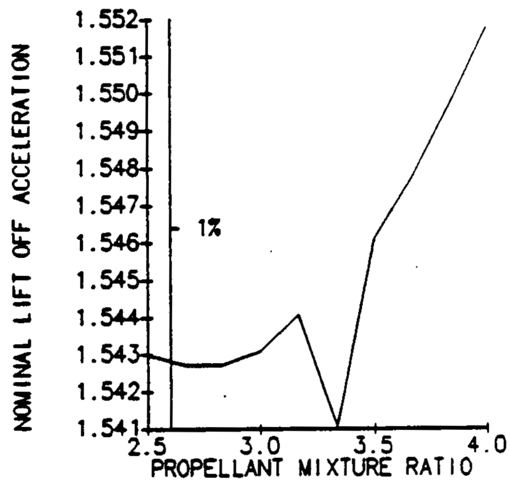


(f-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

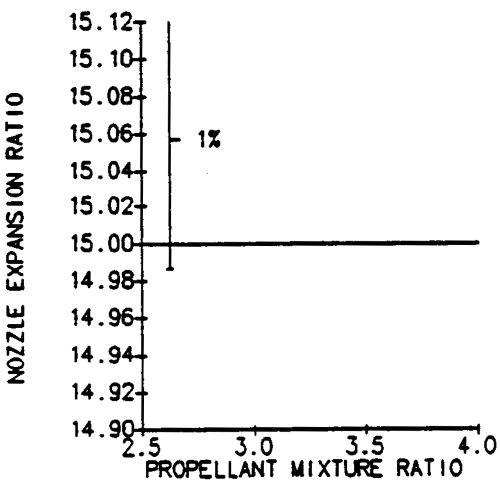
Configuration 2.F Sensitivity Studies (Continued)



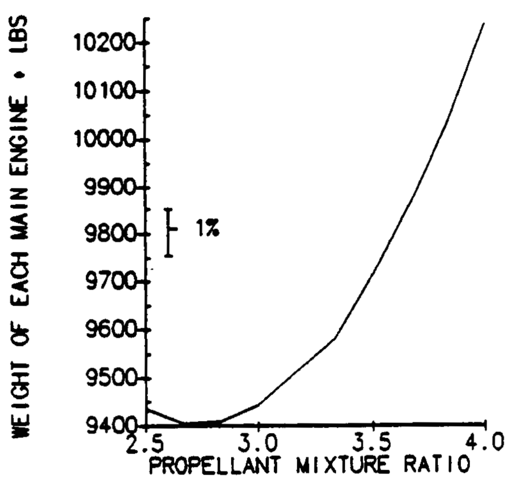
(f-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(f-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

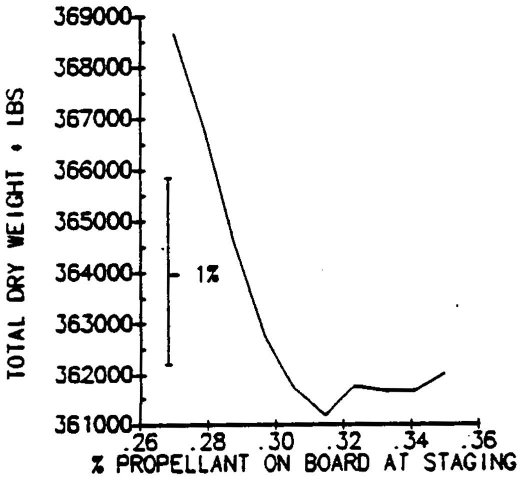


(f-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

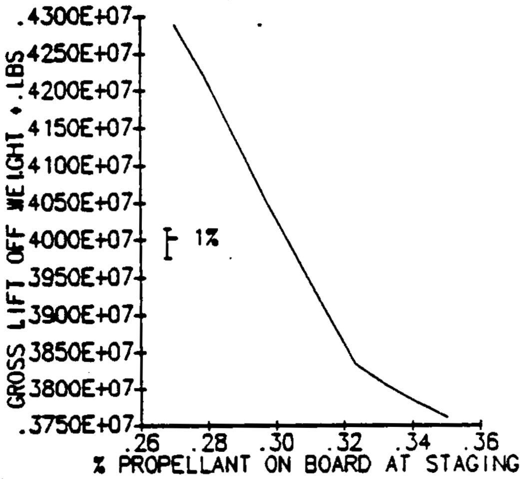


(f-48) Booster Engine Weight Versus Propellant Mixture Ratio

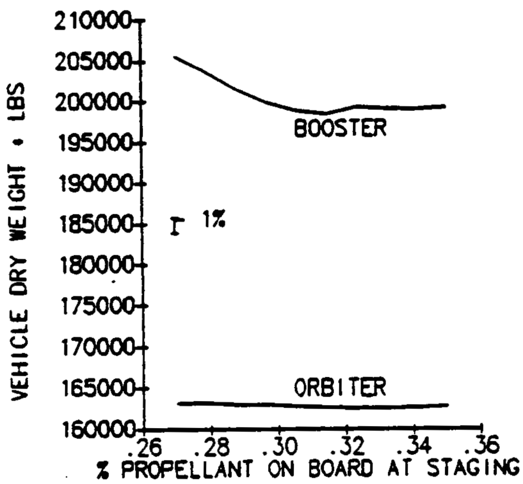
Configuration 2.F Sensitivity Studies (Continued)



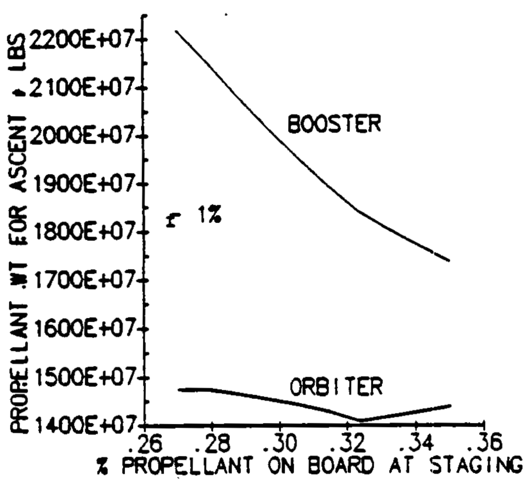
(f-49) Total Dry Weight Versus Orbiter Propellant at Staging



(f-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

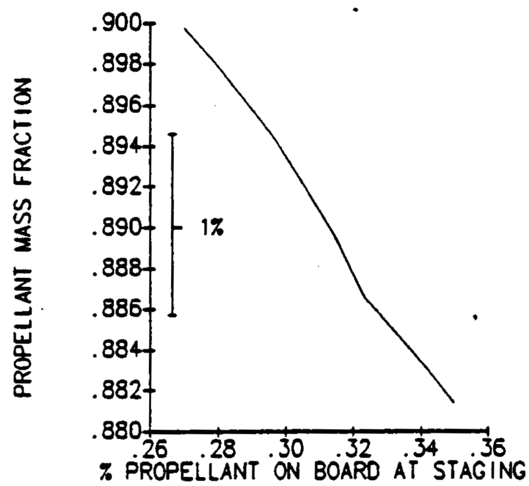


(f-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

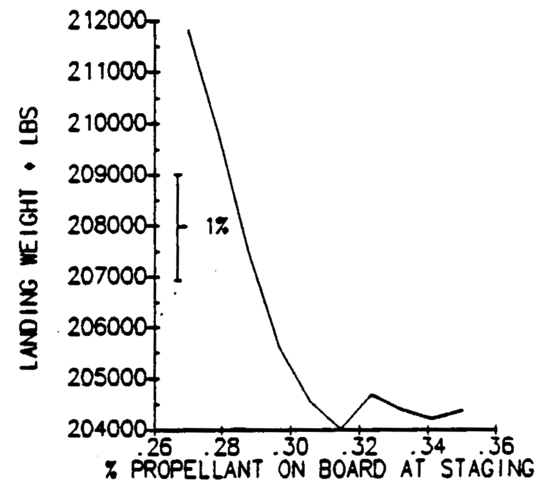


(f-52) Propellant Consumed Versus Orbiter Propellant at Staging

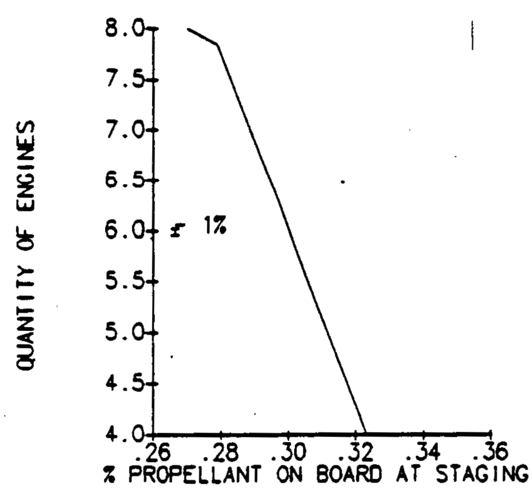
Configuration 2.F Sensitivity Studies (Continued)



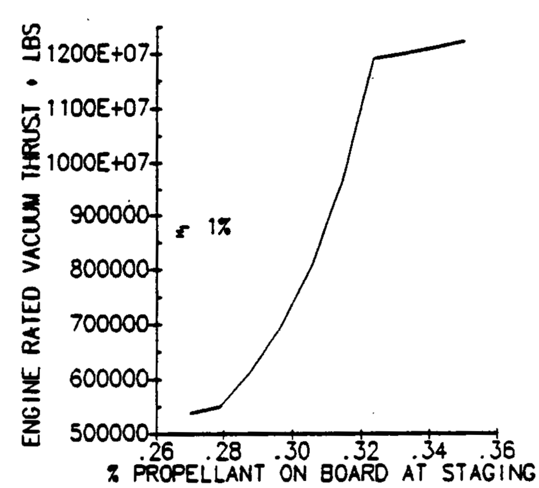
(f-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(f-54) Landing Weight Versus Orbiter Propellant at Staging

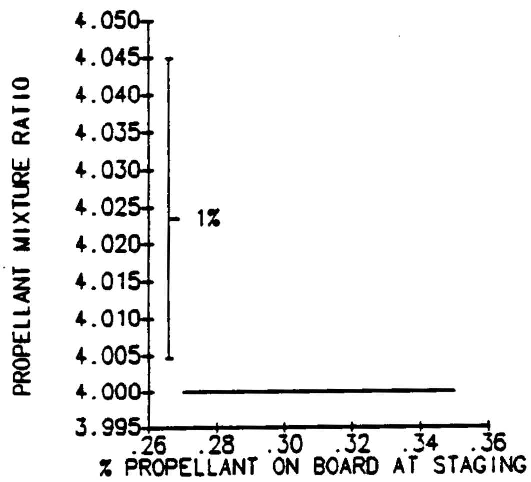


(f-55) Number of Booster Engines Versus Orbiter Propellant at Staging

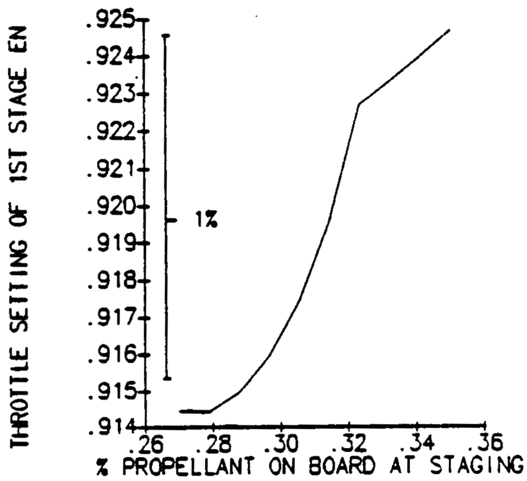


(f-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

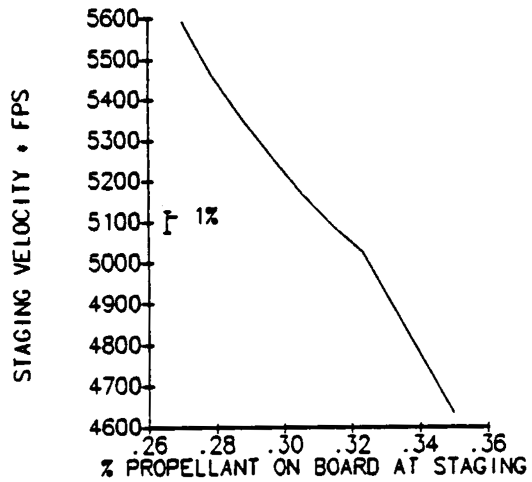
Configuration 2.F Sensitivity Studies (Continued)



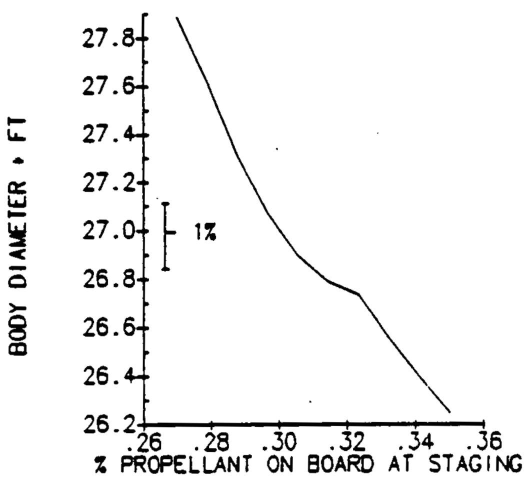
(f-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(f-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

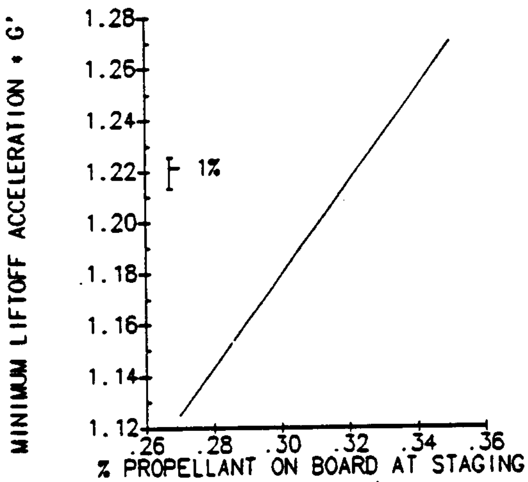


(f-59) Staging Velocity Versus Orbiter Propellant at Staging

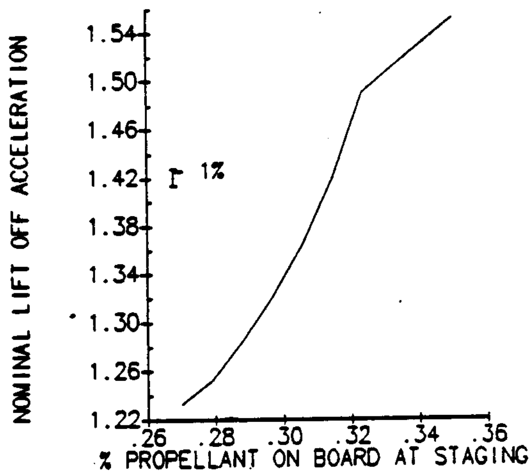


(f-60) Body Diameter Versus Orbiter Propellant at Staging

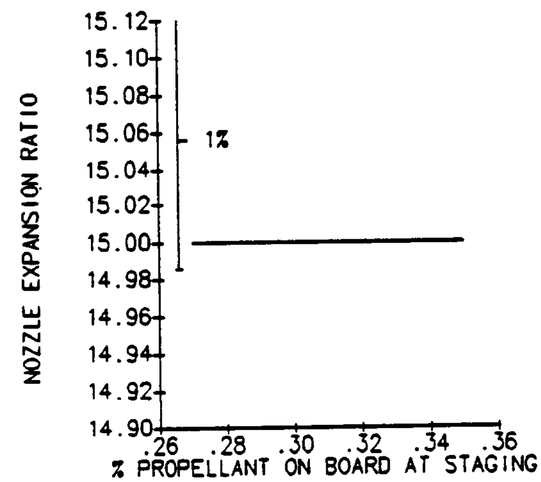
Configuration 2.F Sensitivity Studies (Continued)



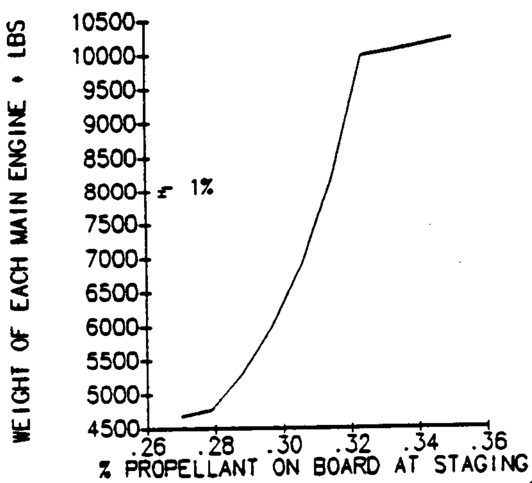
(f-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(f-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

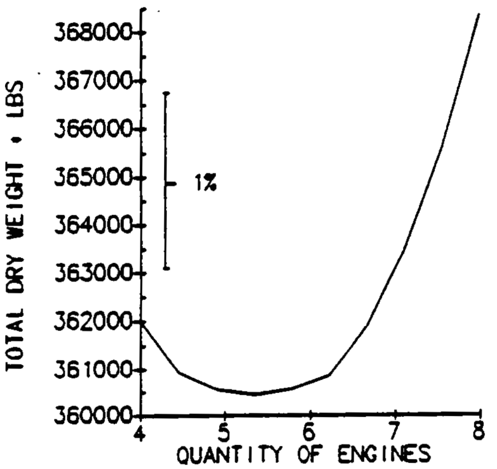


(f-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

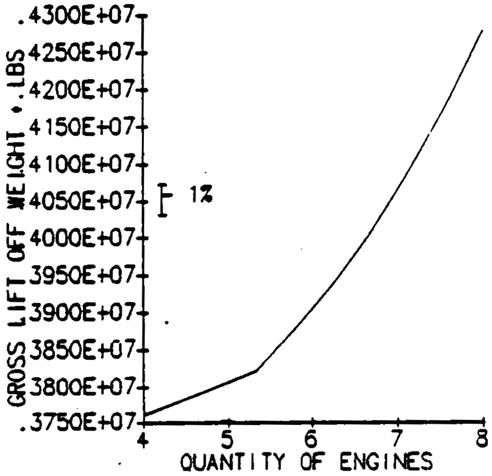


(f-64) Booster Engine Weight Versus Orbiter Propellant at Staging

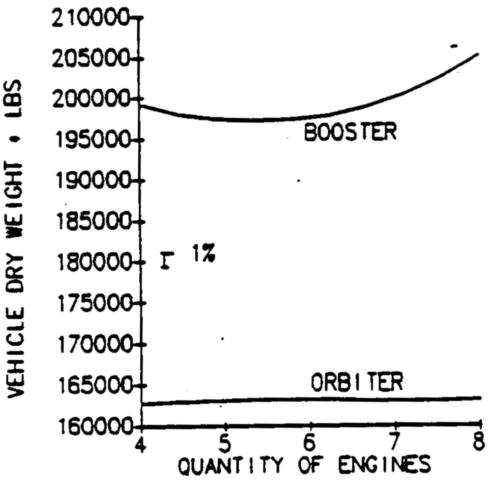
Configuration 2.F Sensitivity Studies (Continued)



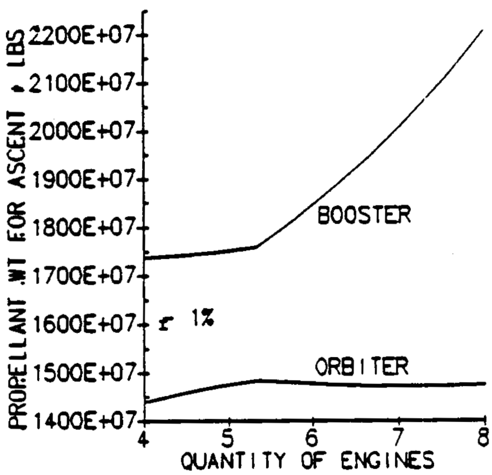
(f-65) Total Dry Weight Versus Number of Booster Engines



(f-66) Gross Lift Off Weight Versus Number of Booster Engines

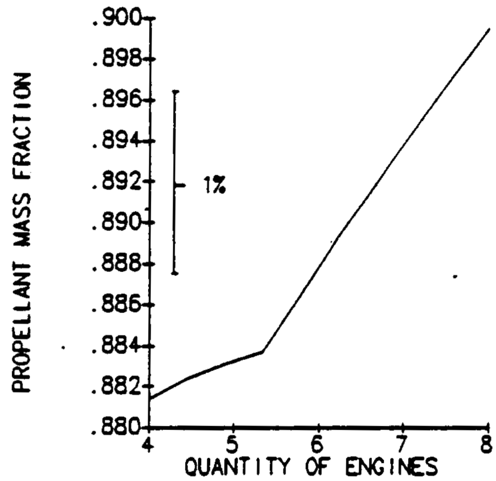


(f-67) Vehicle Dry Weight Versus Number of Booster Engines

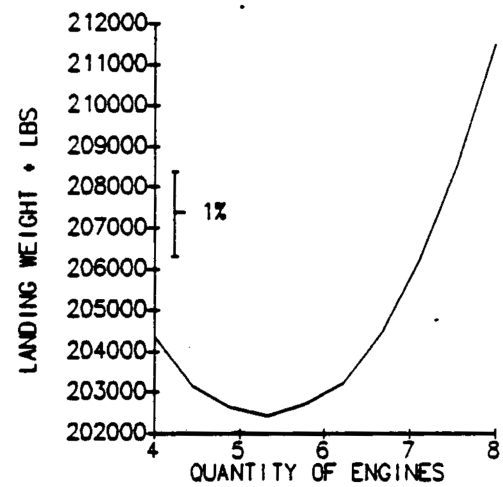


(f-68) Propellant Consumed Versus Number of Booster Engines

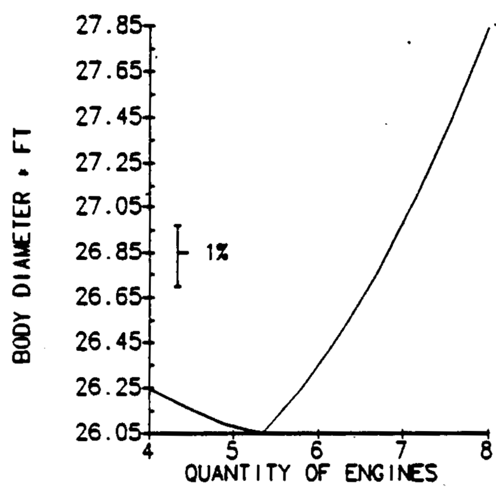
Configuration 2.F Sensitivity Studies (Continued)



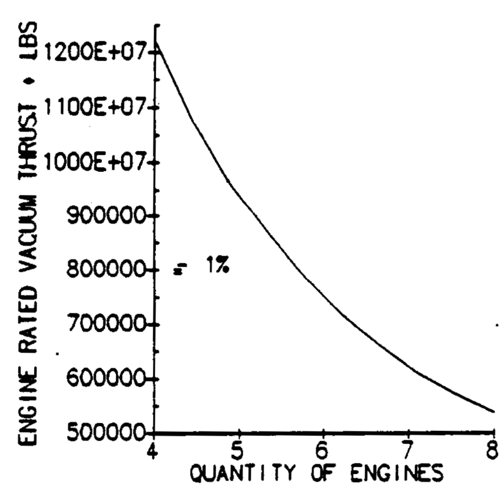
(f-69) Propellant Mass Fraction Versus Number of Booster Engines



(f-70) Landing Weight Versus Number of Booster Engines

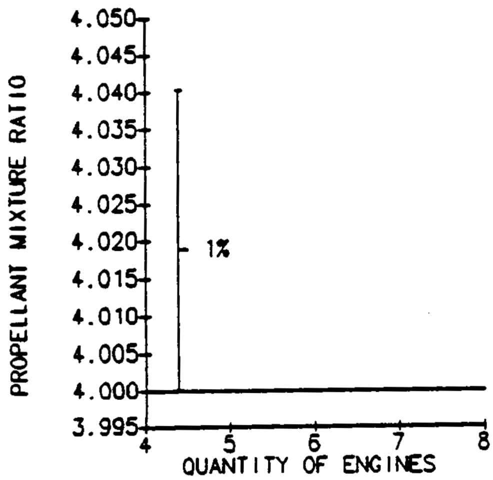


(f-71) Body Diameter Versus Number of Booster Engines

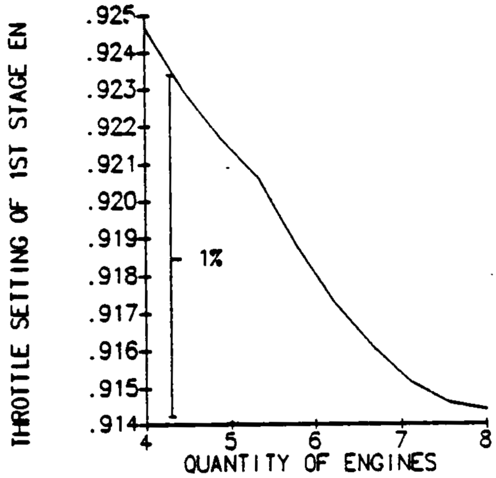


(f-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

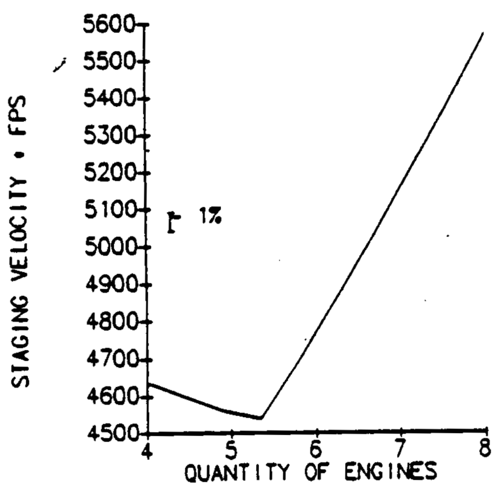
Configuration 2.F Sensitivity Studies (Continued)



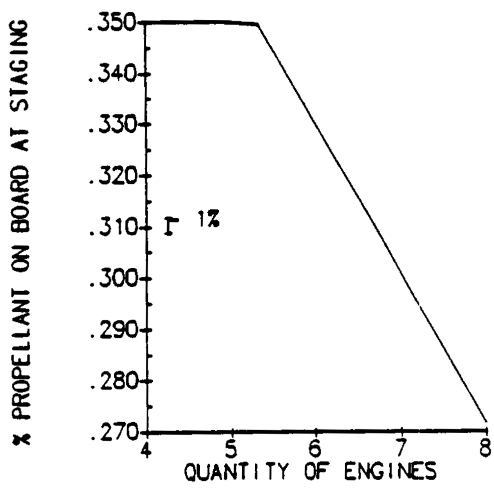
(f-73) Propellant Mixture Ratio Versus Number of Booster Engines



(f-74) Initial Booster Throttle Setting Versus Number of Booster Engines

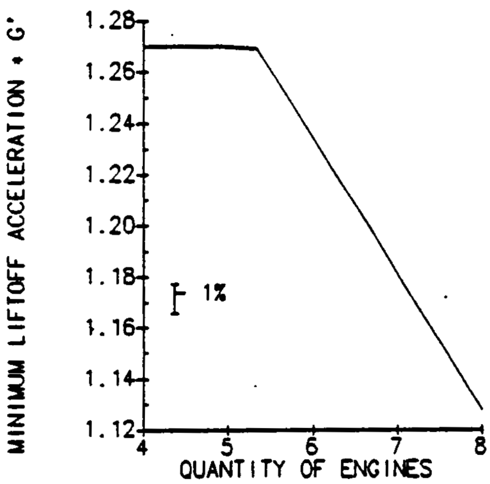


(f-75) Staging Velocity Versus Number of Booster Engines

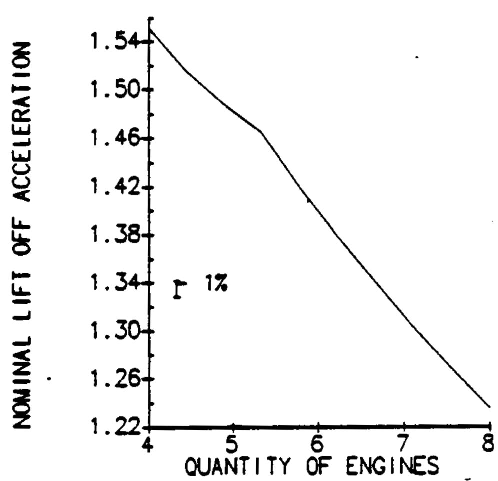


(f-76) Orbiter Propellant at Staging Versus Number of Booster Engines

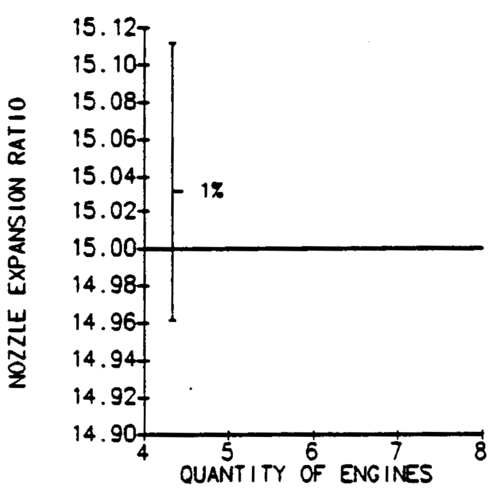
Configuration 2.F Sensitivity Studies (Continued)



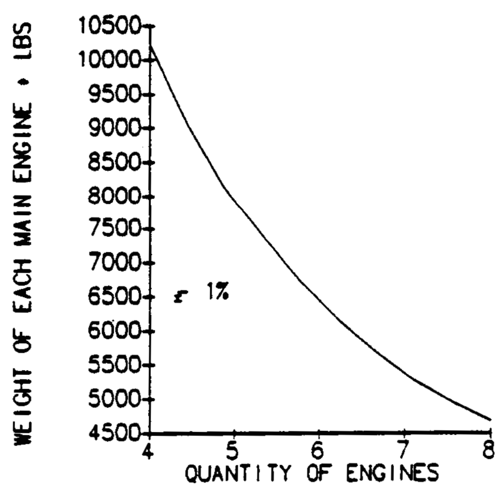
(f-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(f-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

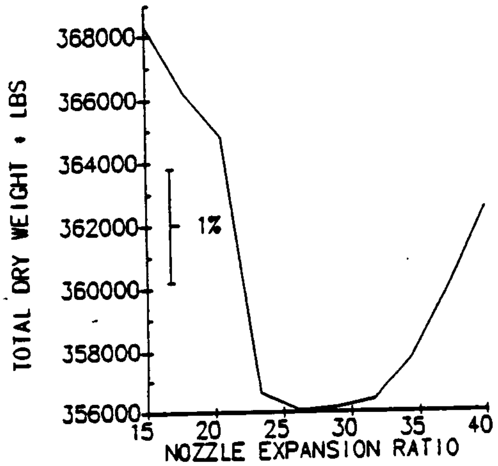


(f-79) Nozzle Expansion Ratio Versus Number of Booster Engines

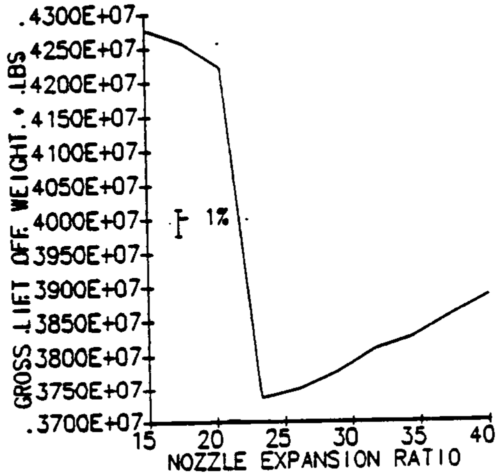


(f-80) Booster Engine Weight Versus Number of Booster Engines

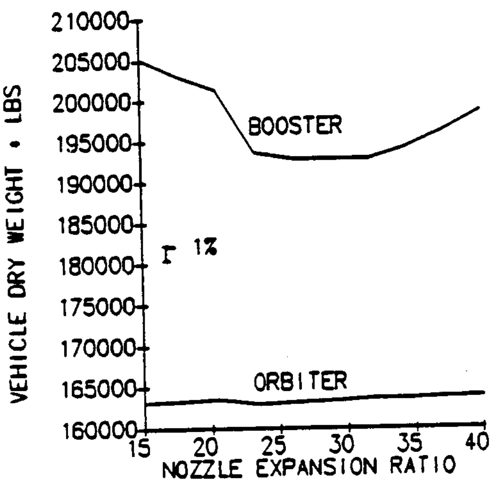
Configuration 2.F Sensitivity Studies (Continued)



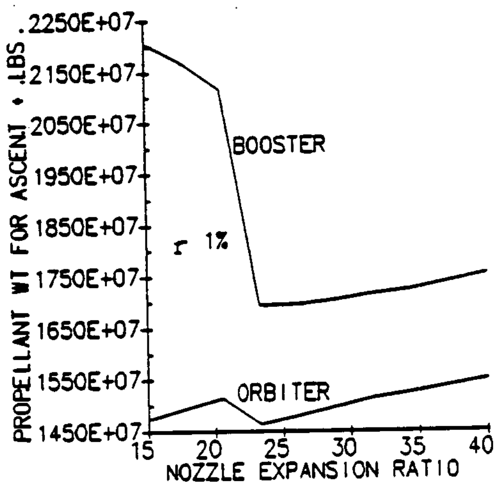
(f-81) Total Dry Weight Versus Nozzle Expansion Ratio



(f-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

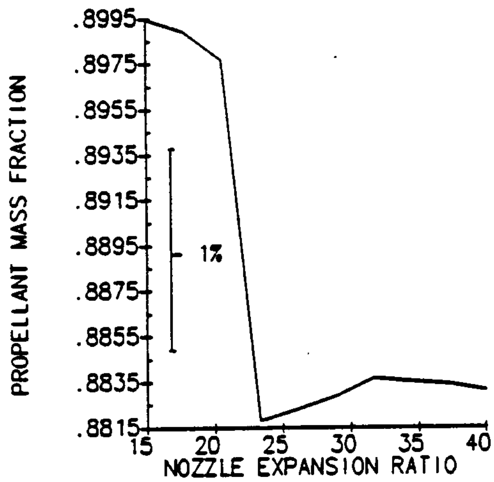


(f-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

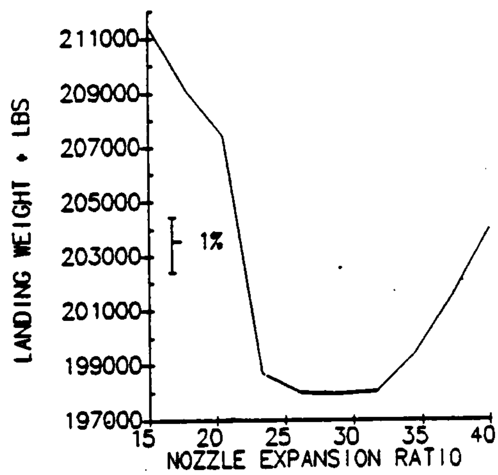


(f-84) Propellant Consumed Versus Nozzle Expansion Ratio

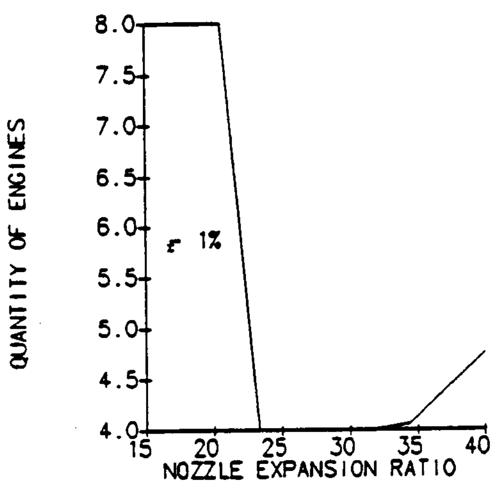
Configuration 2.F Sensitivity Studies (Continued)



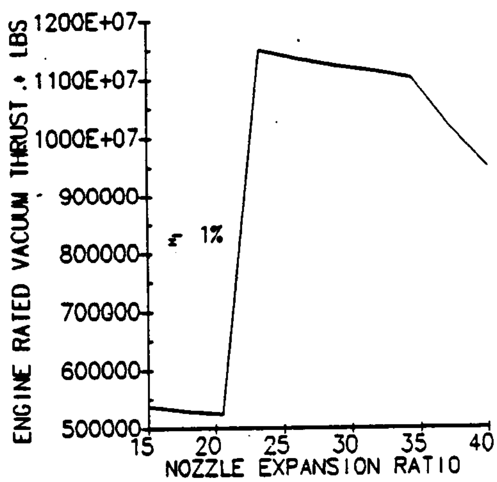
(f-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(f-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

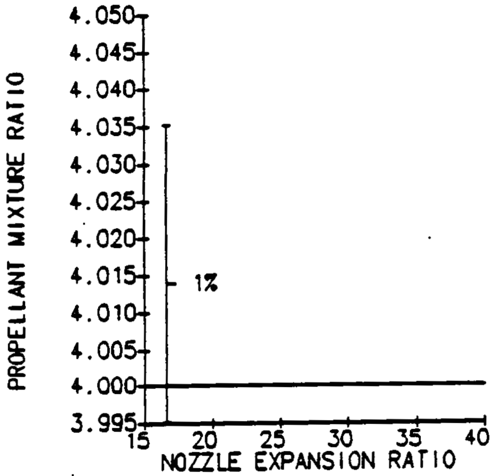


(f-87) Number of Booster Engines Versus Nozzle Expansion Ratio

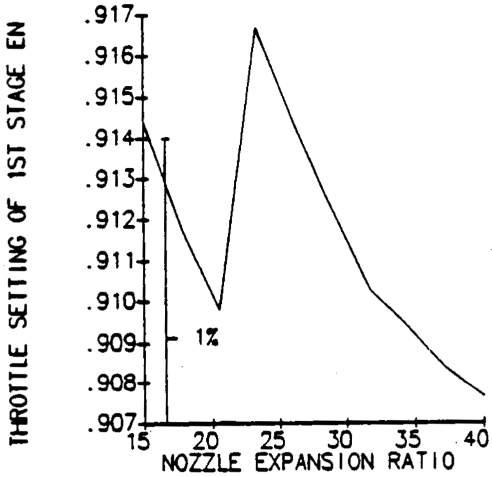


(f-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

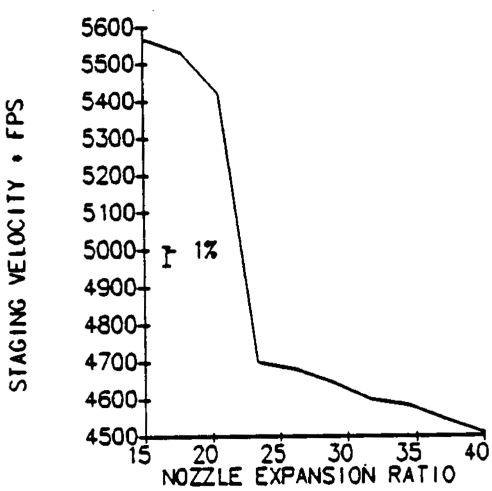
Configuration 2.F Sensitivity Studies (Continued)



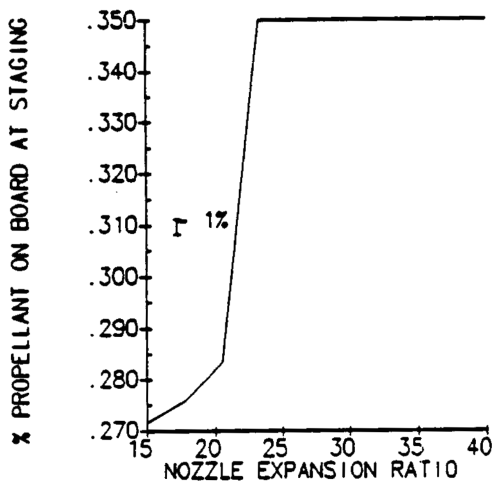
(f-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(f-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

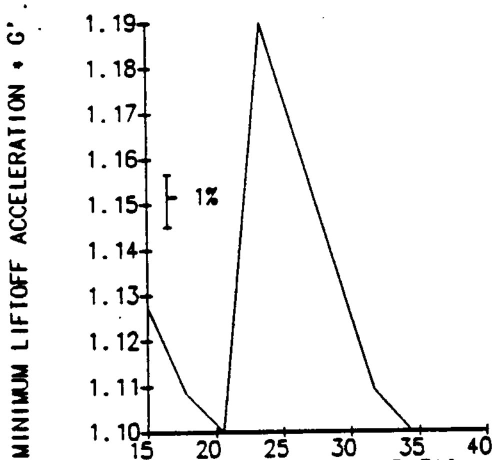


(f-91) Staging Velocity Versus Nozzle Expansion Ratio

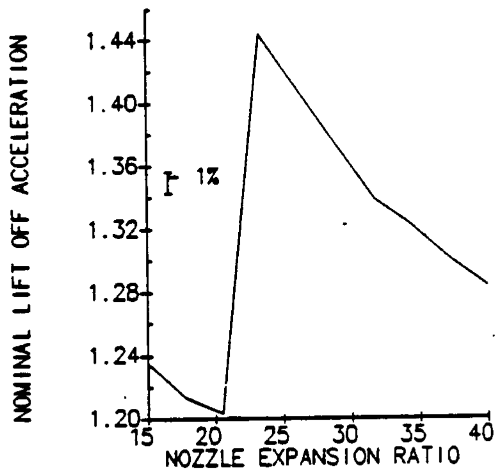


(f-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

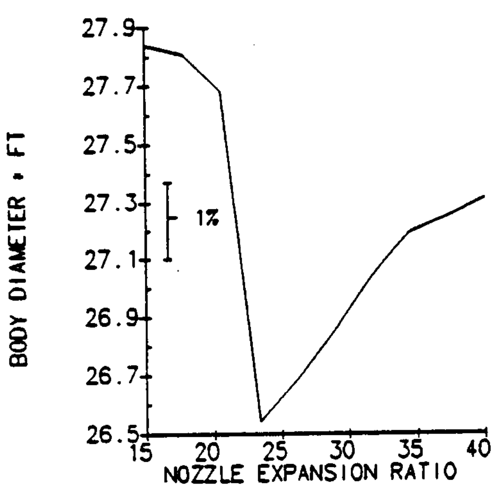
Configuration 2.F Sensitivity Studies (Continued)



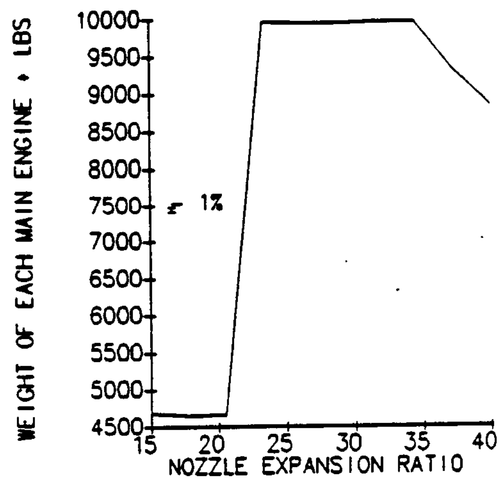
(f-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(f-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

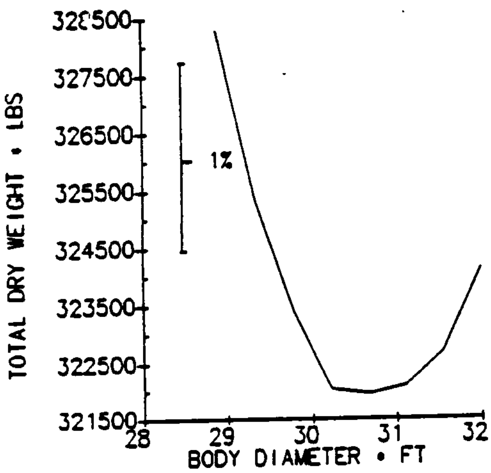


(f-95) Body Diameter Versus Nozzle Expansion Ratio

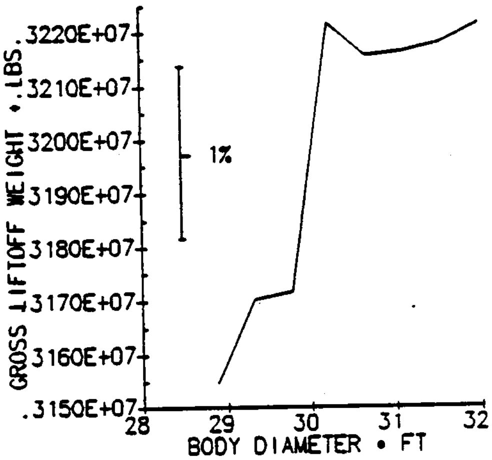


(f-96) Booster Engine Weight Versus Nozzle Expansion Ratio

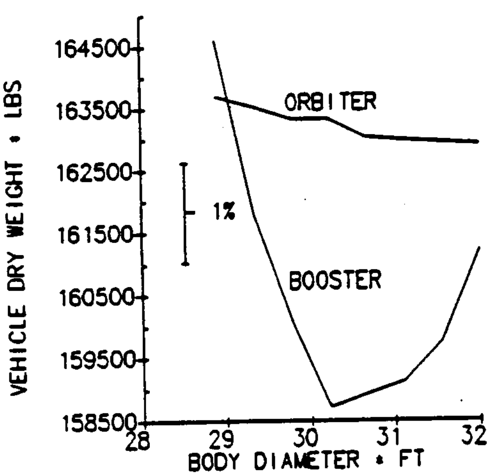
Configuration 2.F Sensitivity Studies (Continued)



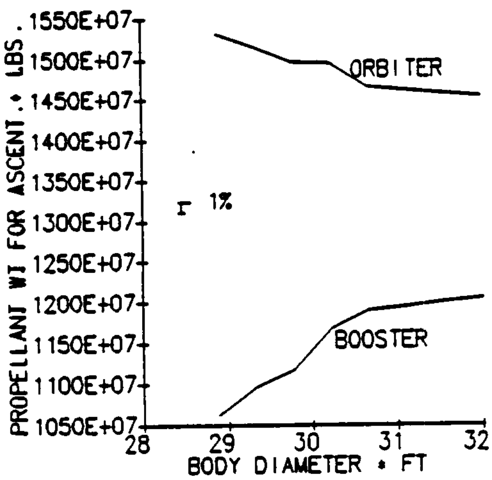
(g-1) Total Dry Weight Versus Body Diameter



(g-2) Gross Lift Off Weight Versus Body Diameter

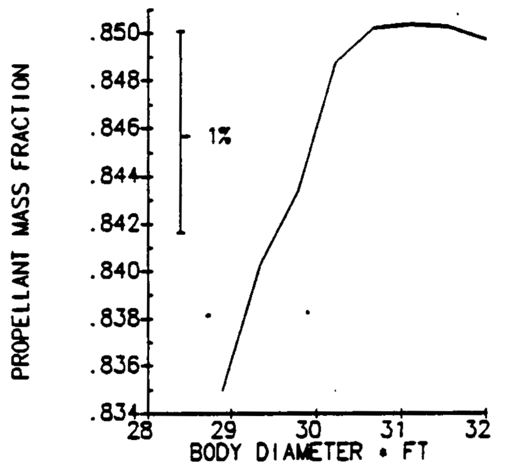


(g-3) Vehicle Dry Weight Versus Body Diameter

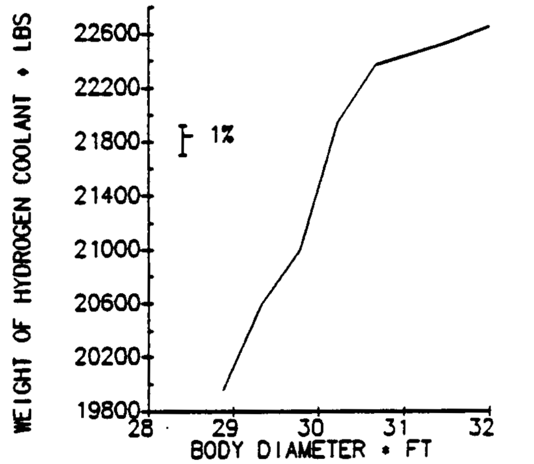


(g-4) Propellant Consumed Versus Body Diameter

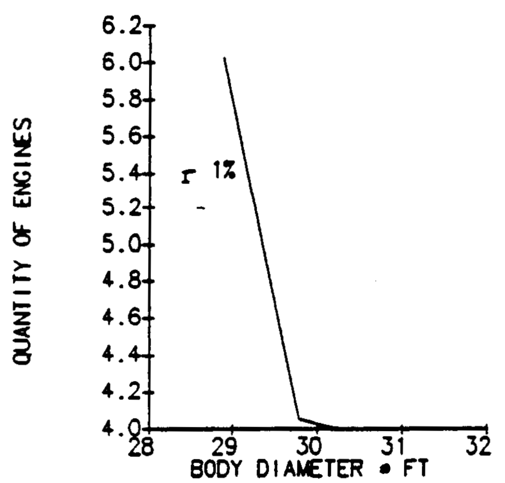
Configuration 2.G Sensitivity Studies



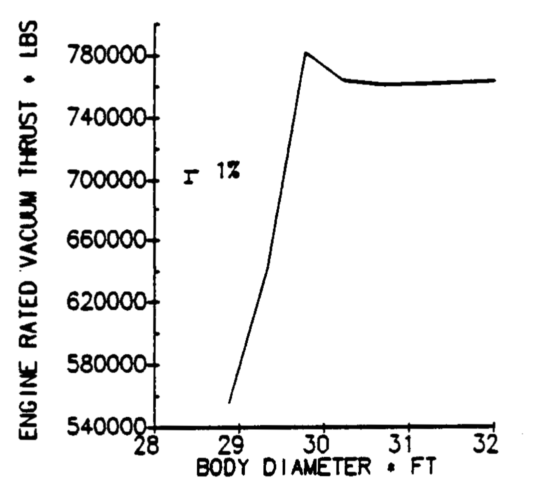
(g-5) Propellant Mass Fraction Versus Body Diameter



(g-6) Weight of Hydrogen Coolant Versus Body Diameter

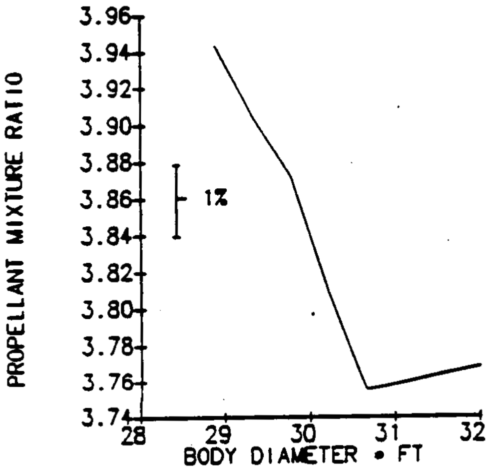


(g-7) Number of Booster Engines Versus Body Diameter

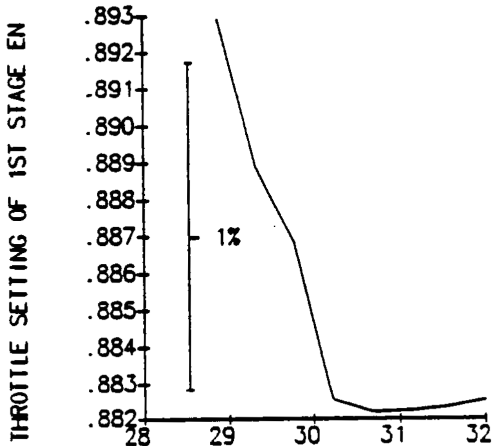


(g-8) Engine Rated Vacuum Thrust Versus Body Diameter

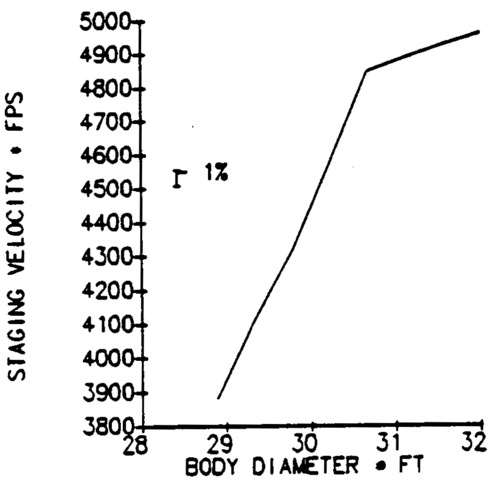
Configuration 2.G Sensitivity Studies (Continued)



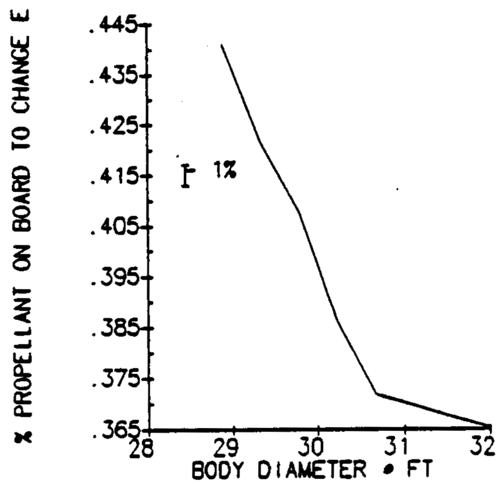
(g-9) Propellant Mixture Ratio Versus Body Diameter



(g-10)Initial Booster Throttle Setting Versus Body Diameter

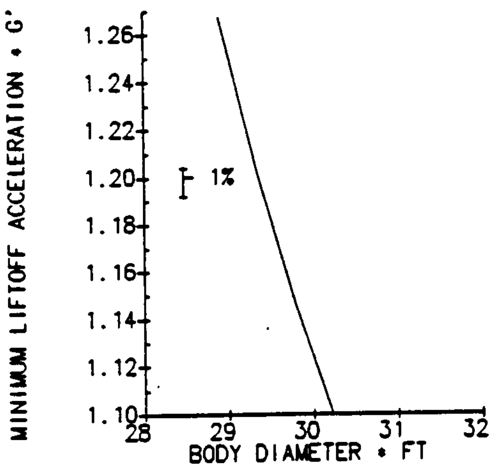


(g-11) Staging Velocity Versus Body Diameter

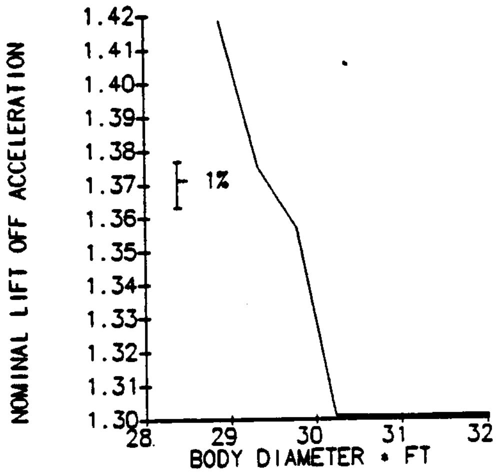


(g-12) Orbiter Propellant at Staging Versus Body Diameter

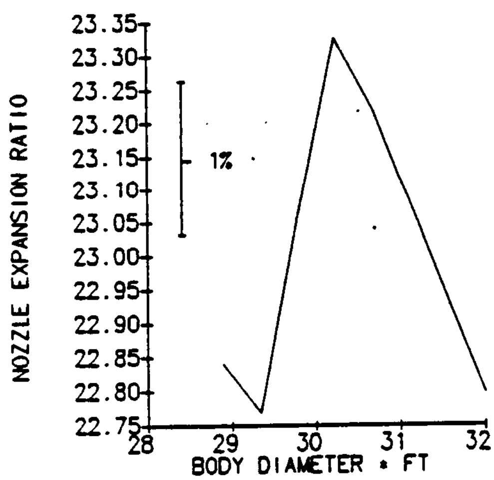
Configuration 2.G Sensitivity Studies (Continued)



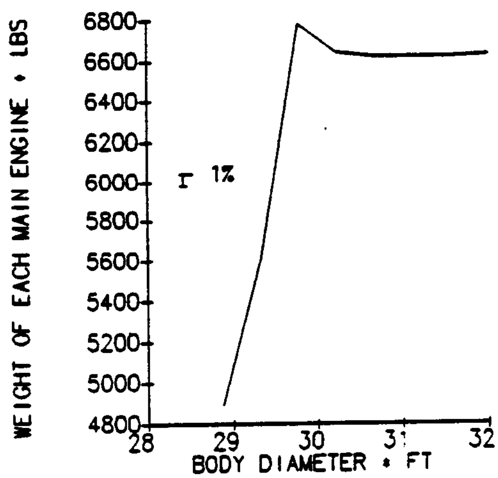
(g-13) Engine-out Lift Off Acceleration Versus Body Diameter



(g-14) Nominal Lift Off Acceleration Versus Body Diameter

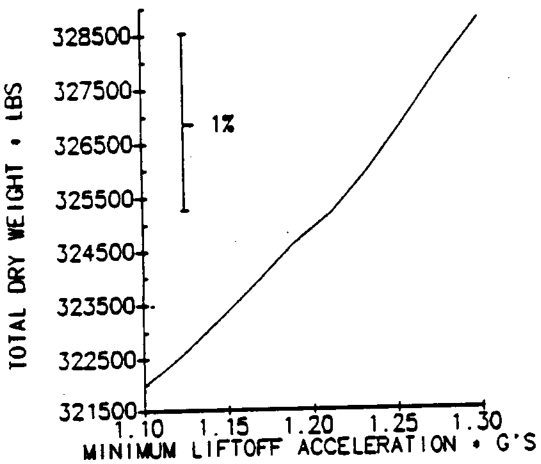


(g-15) Nozzle Expansion Ratio Versus Body Diameter

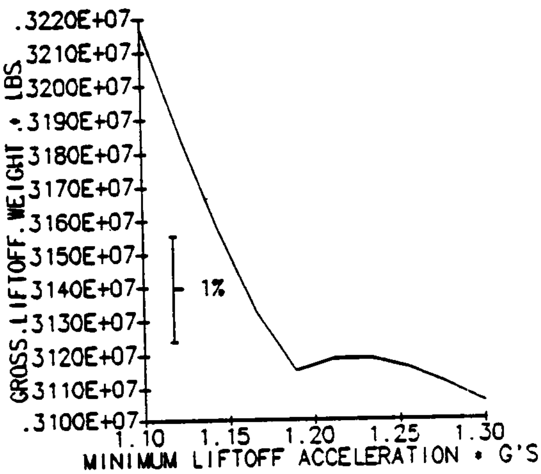


(g-16) Booster Engine Weight Versus Body Diameter

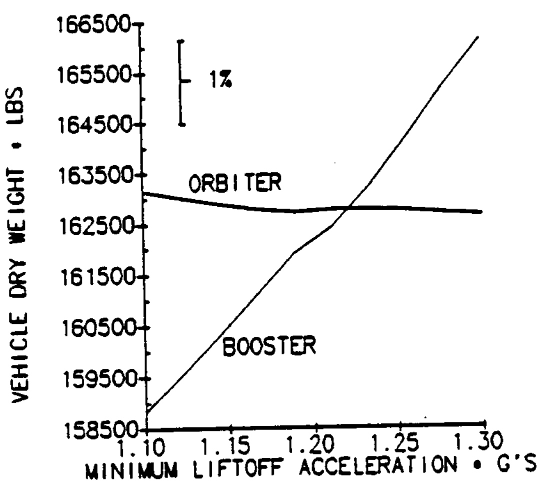
Configuration 2.G Sensitivity Studies (Continued)



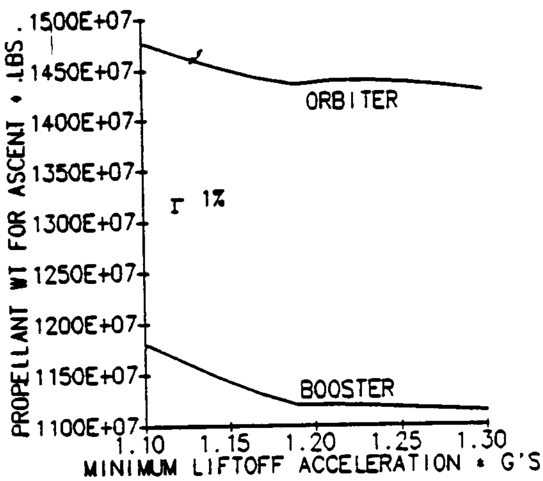
(g-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(g-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

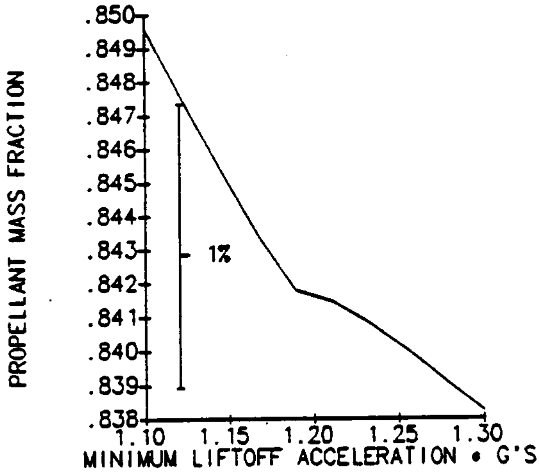


(g-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

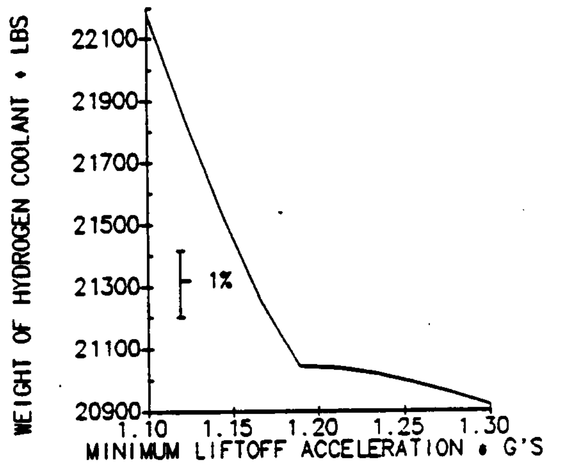


(g-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

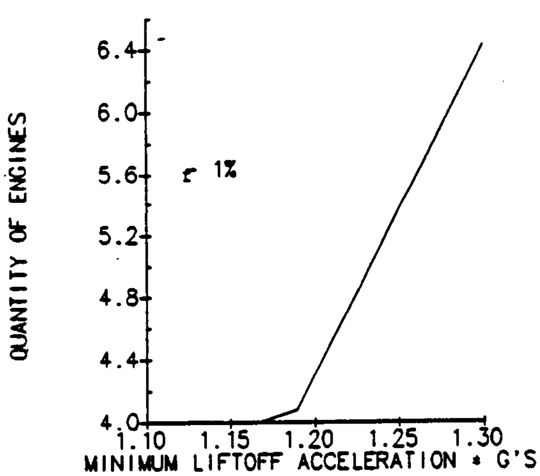
Configuration 2.G Sensitivity Studies (Continued)



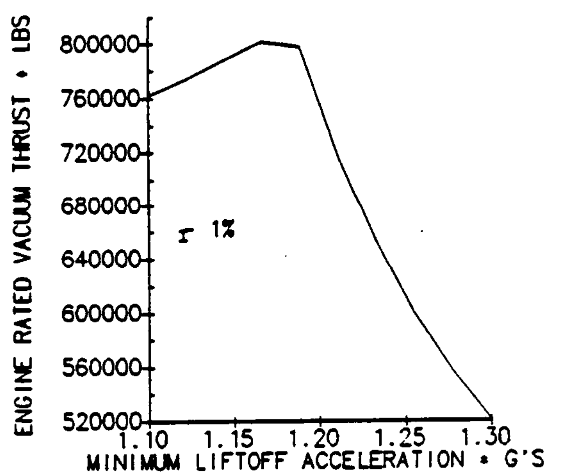
(g-21) **Propellant Mass Fraction Versus Engine-out Lift Off Acceleration**



(g-22) **Weight of Hydrogen Coolant Versus Engine-out Lift Off Acceleration**

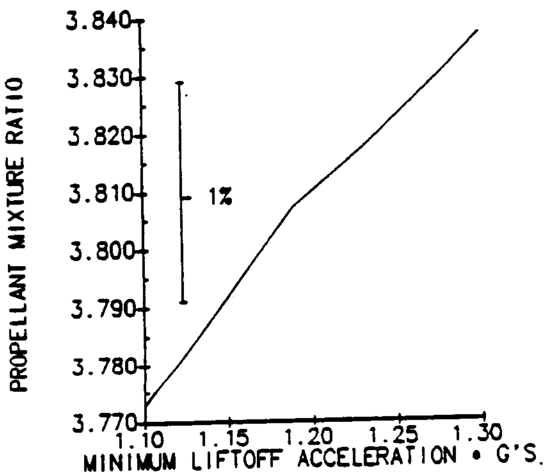


(g-23) **Number of Booster Engines Versus Engine-out Lift Off Acceleration**

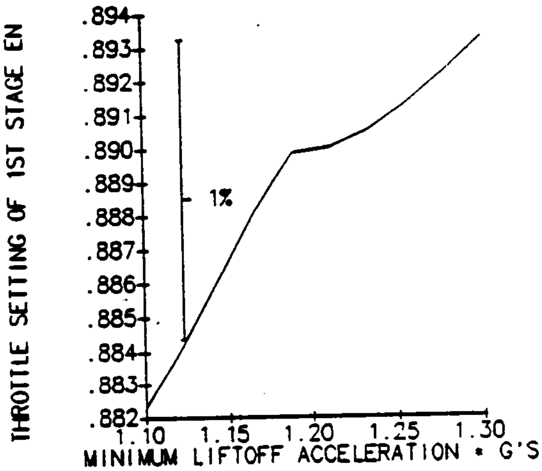


(g-24) **Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration**

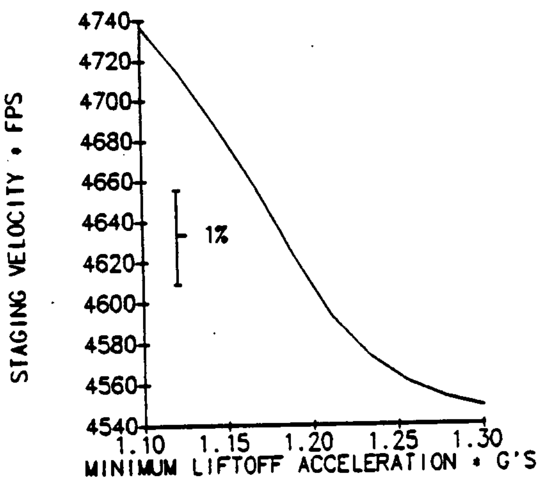
Configuration 2.G Sensitivity Studies (Continued)



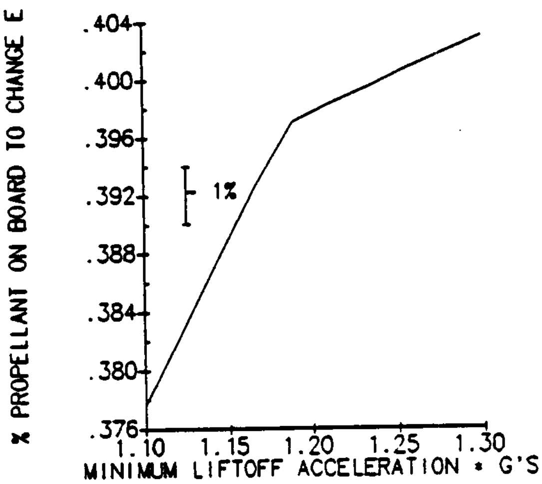
(g-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(g-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

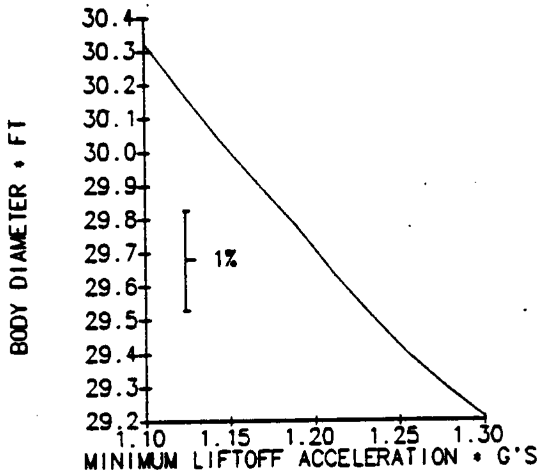


(g-27) Staging Velocity Versus Engine-out Lift Off Acceleration

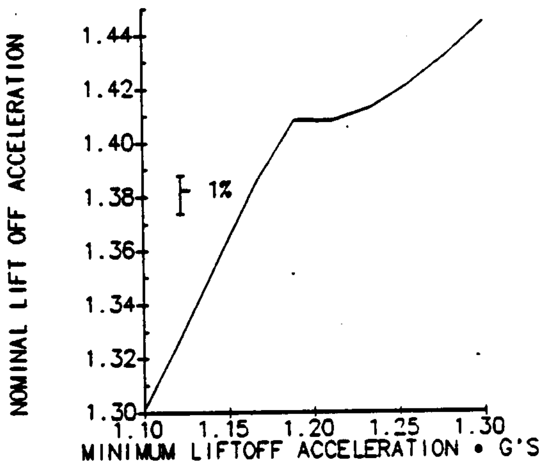


(g-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

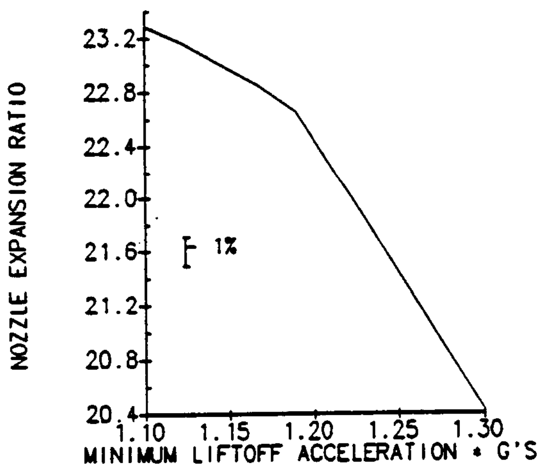
Configuration 2.G Sensitivity Studies (Continued)



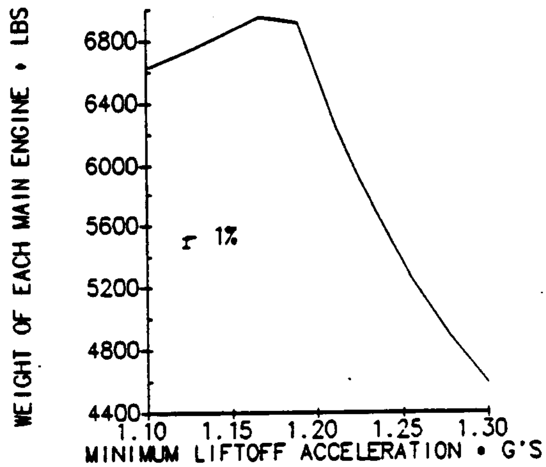
(g-29) Body Diameter Versus Engine-out Lift Off Acceleration



(g-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

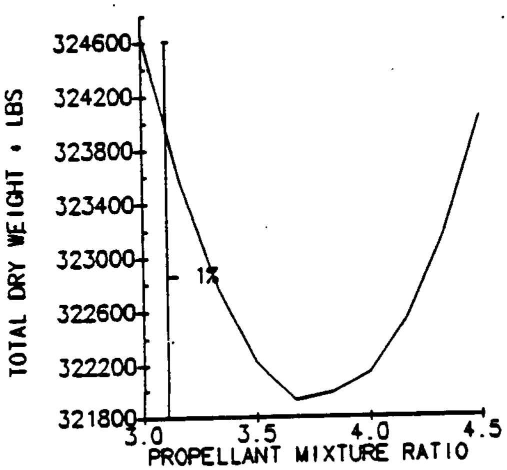


(g-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

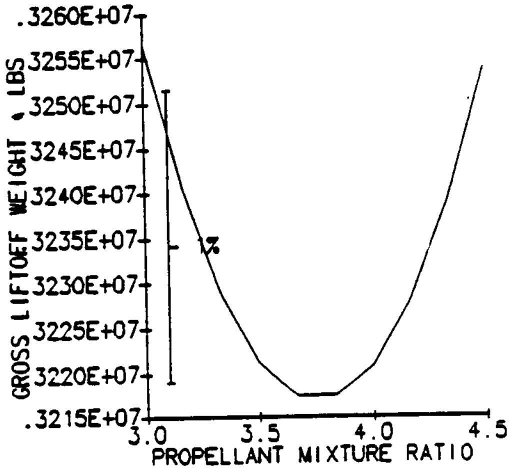


(g-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

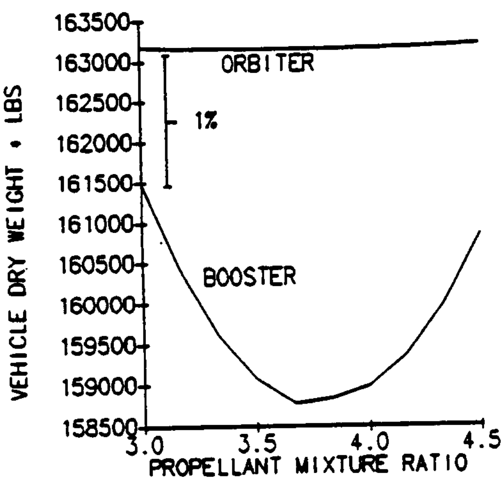
Configuration 2.G Sensitivity Studies (Continued)



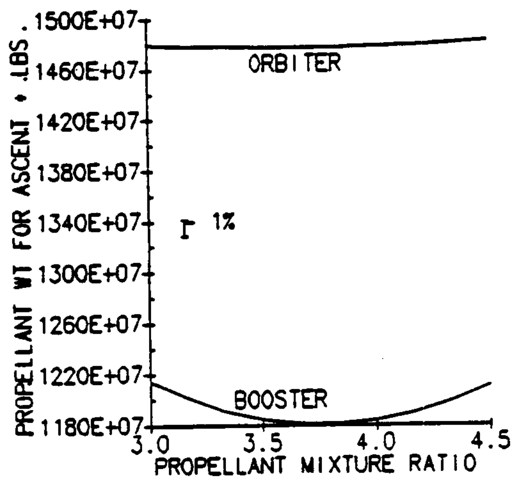
(g-33) Total Dry Weight Versus Propellant Mixture Ratio



(g-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

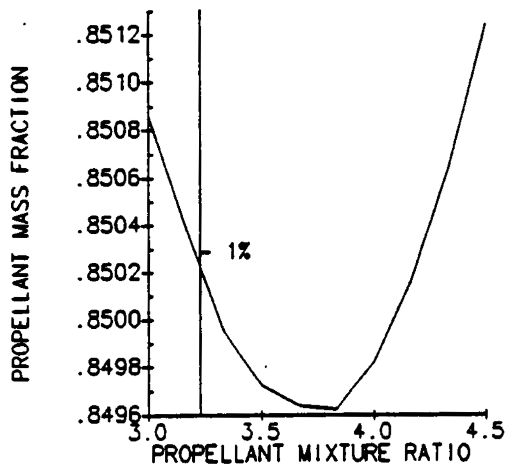


(g-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

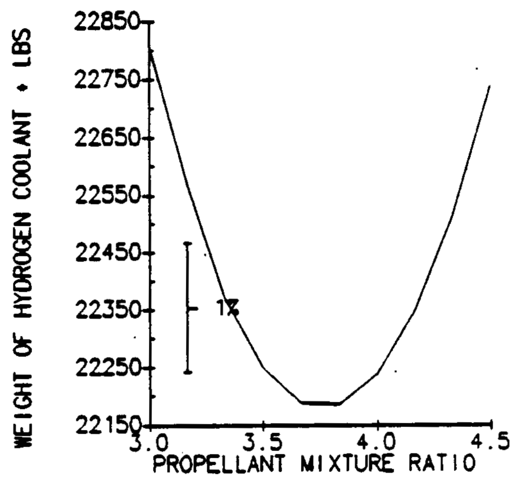


(g-36) Propellant Consumed Versus Propellant Mixture Ratio

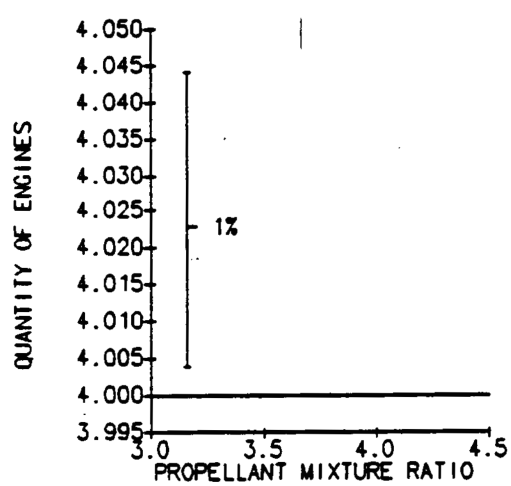
Configuration 2.G Sensitivity Studies (Continued)



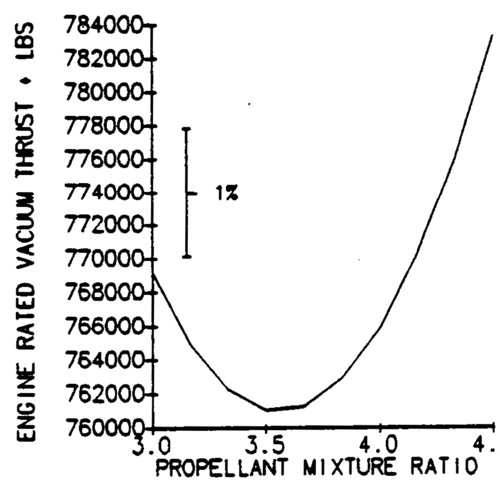
(g-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(g-38) Weight of Hydrogen Coolant Versus Propellant Mixture Ratio

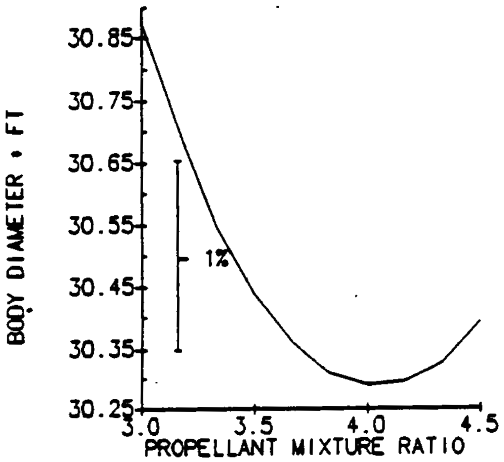


(g-39) Number of Booster Engines Versus Propellant Mixture Ratio

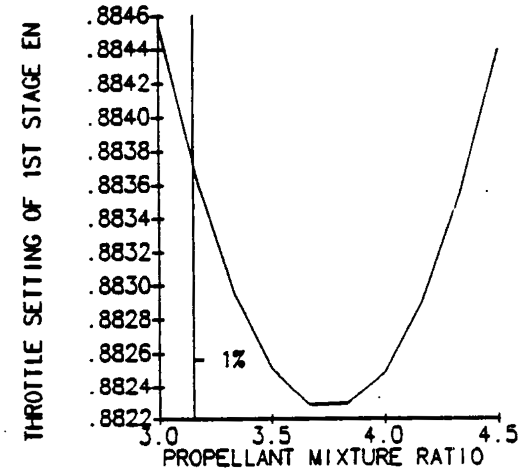


(g-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

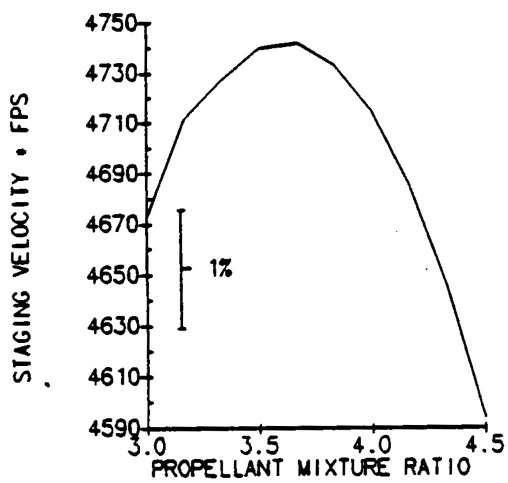
Configuration 2.G Sensitivity Studies (Continued)



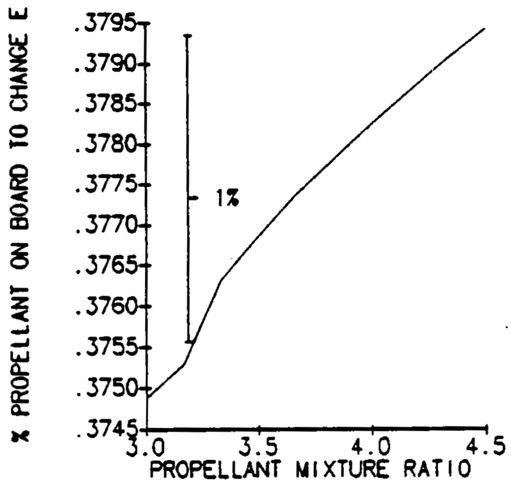
(g-41) Body Diameter Versus Propellant Mixture Ratio



(g-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

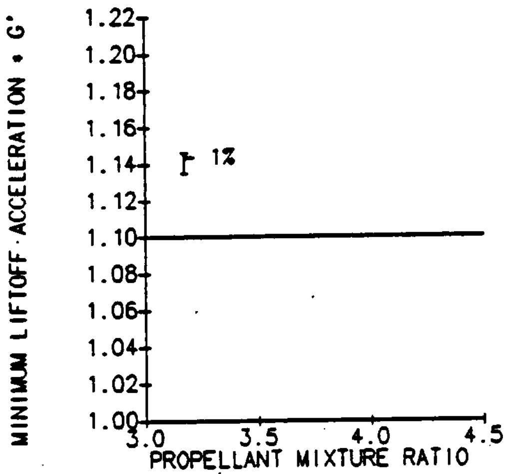


(g-43) Staging Velocity Versus Propellant Mixture Ratio

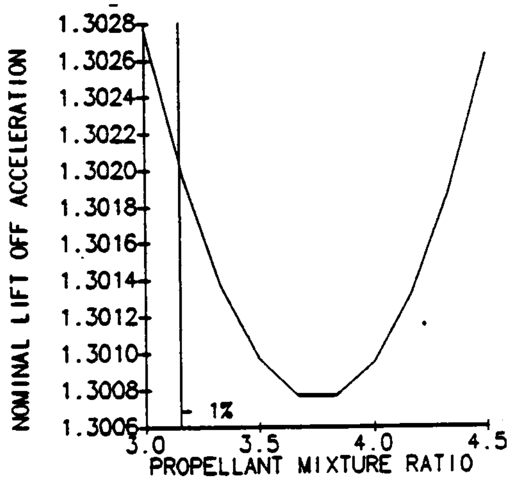


(g-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

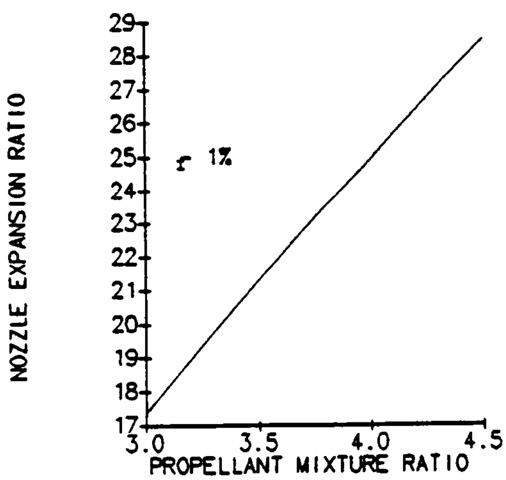
Configuration 2.G Sensitivity Studies (Continued)



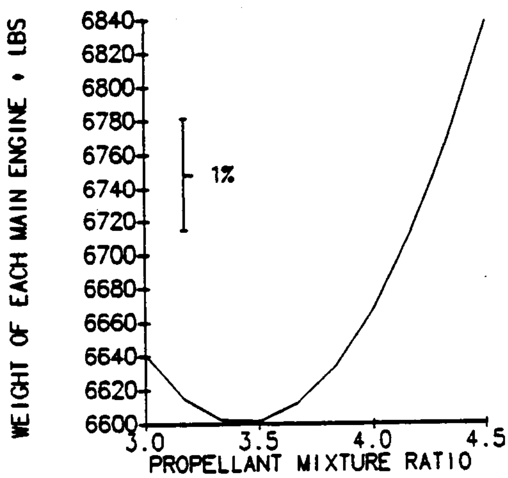
(g-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(g-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

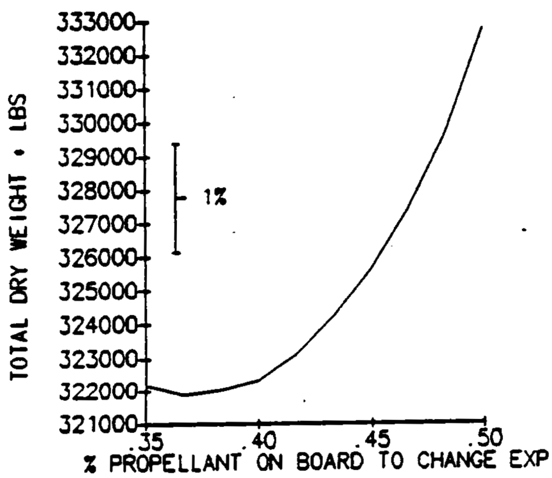


(g-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

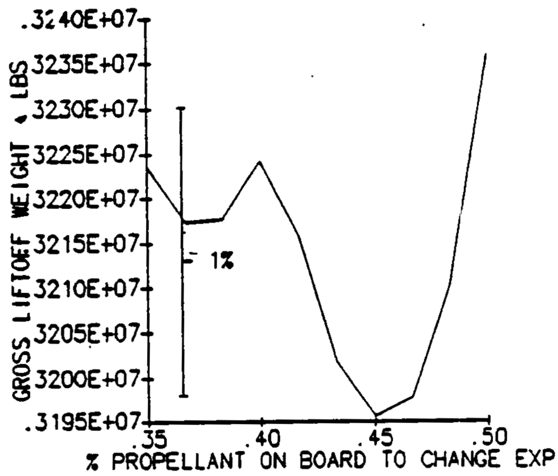


(g-48) Booster Engine Weight Versus Propellant Mixture Ratio

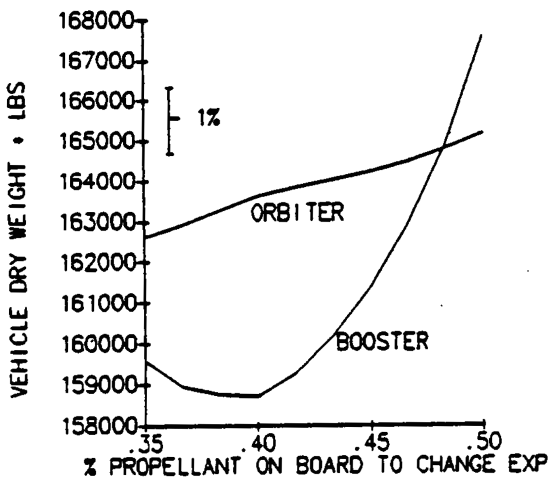
Configuration 2.G Sensitivity Studies (Continued)



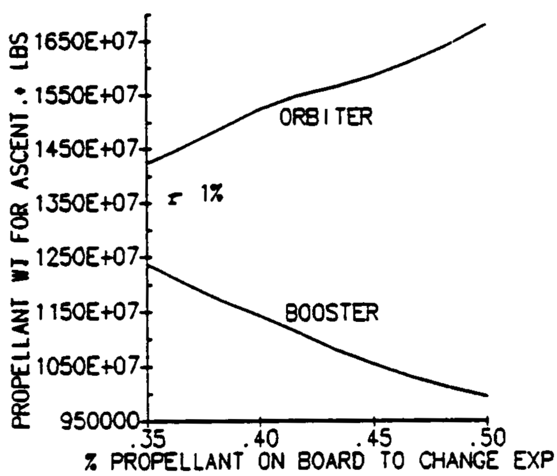
(g-49) Total Dry Weight Versus Orbiter Propellant at Staging



(g-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

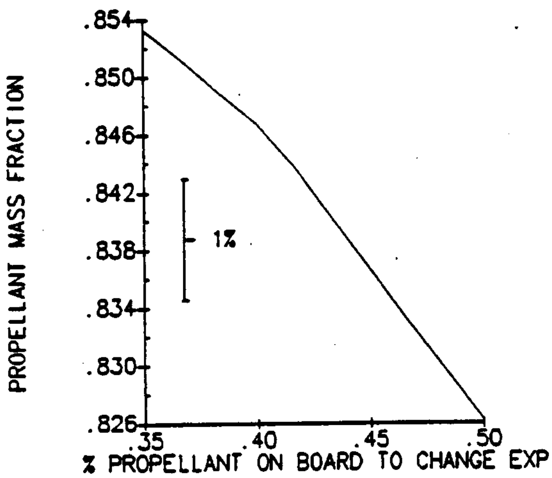


(g-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

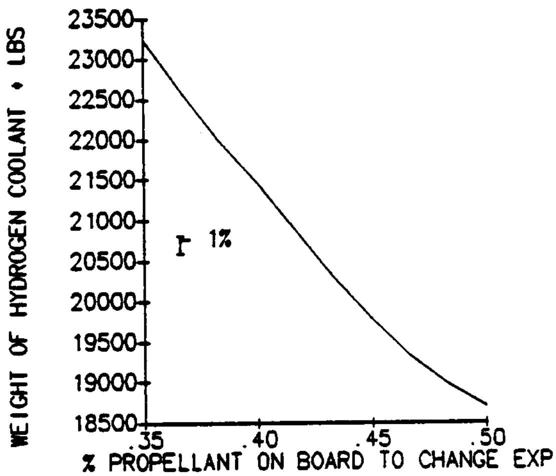


(g-52) Propellant Consumed Versus Orbiter Propellant at Staging

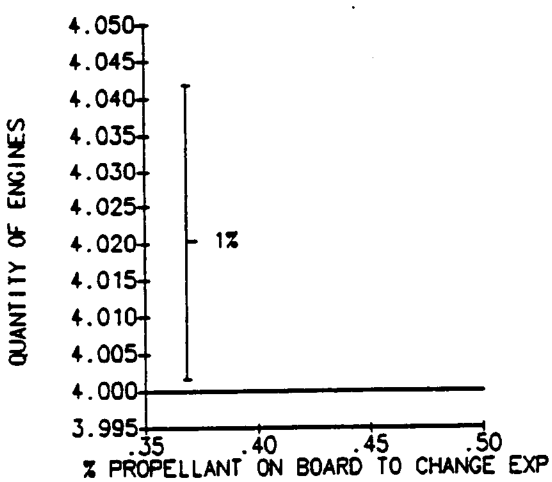
Configuration 2.G Sensitivity Studies (Continued)



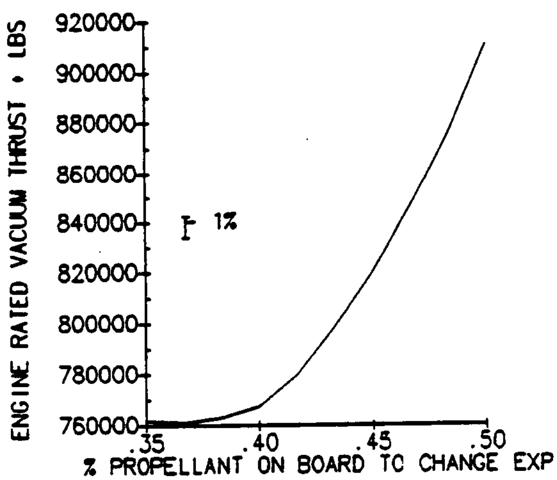
(g-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(g-54) Weight of Hydrogen Coolant Versus Orbiter Propellant at Staging

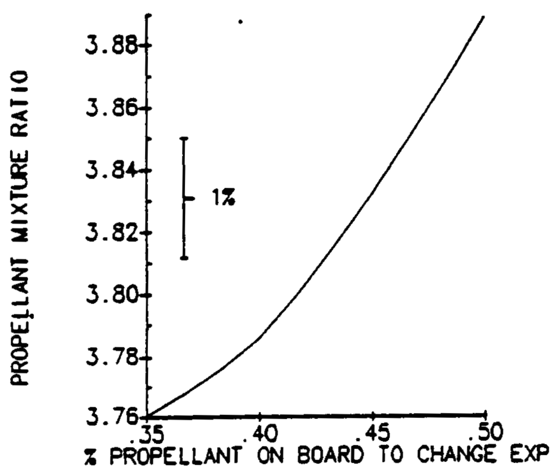


(g-55) Number of Booster Engines Versus Orbiter Propellant at Staging

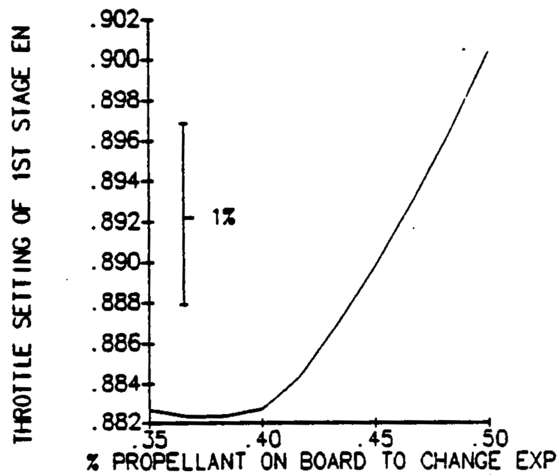


(g-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

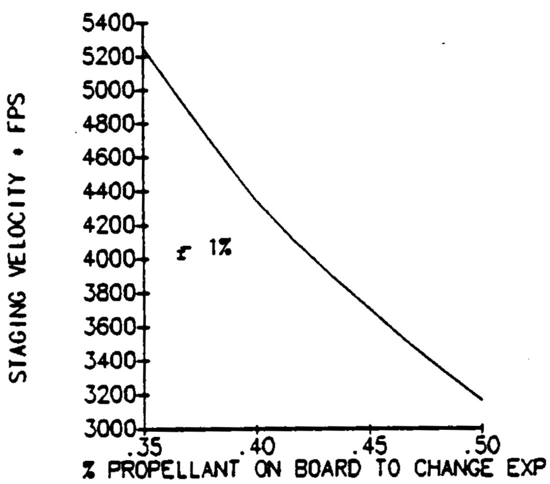
Configuration 2.G Sensitivity Studies (Continued)



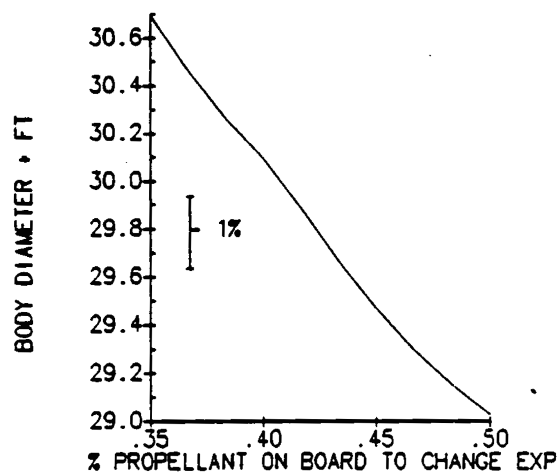
(g-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(g-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

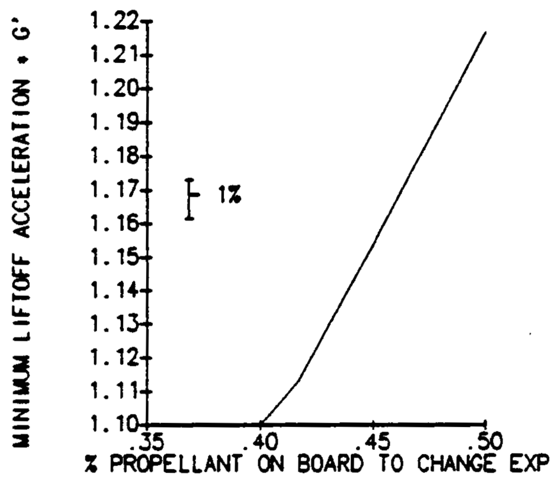


(g-59) Staging Velocity Versus Orbiter Propellant at Staging

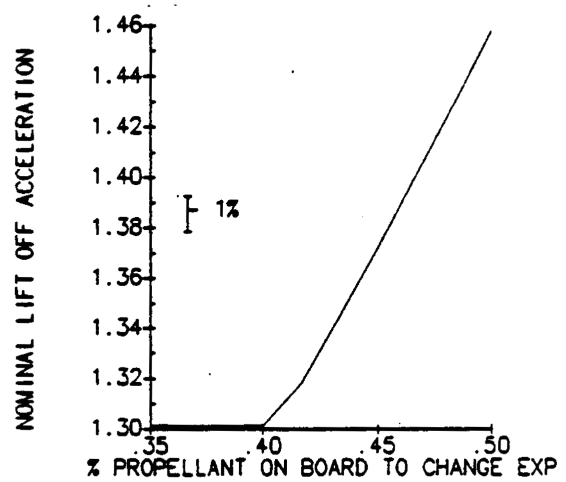


(g-60) Body Diameter Versus Orbiter Propellant at Staging

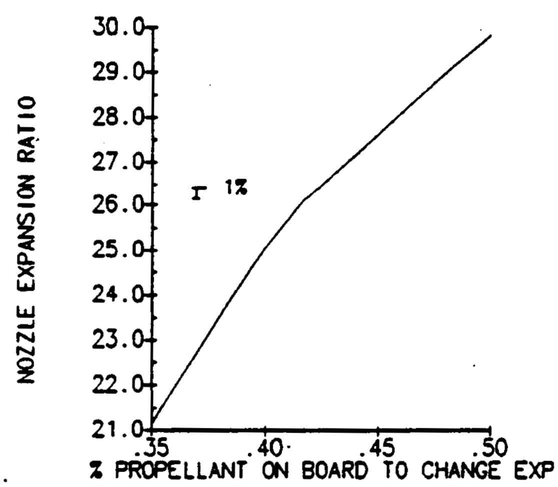
Configuration 2.G Sensitivity Studies (Continued)



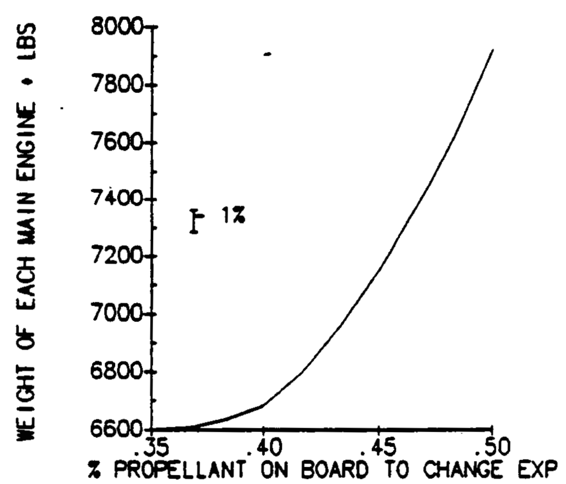
(g-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(g-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

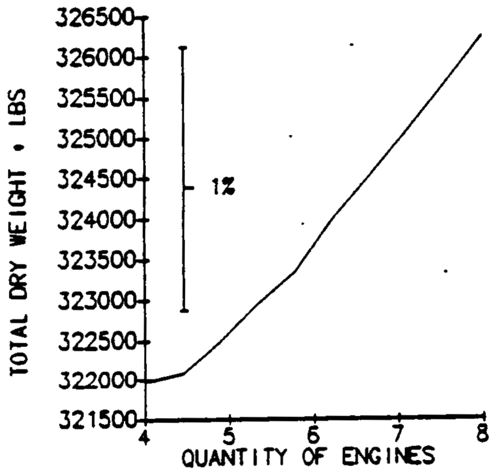


(g-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

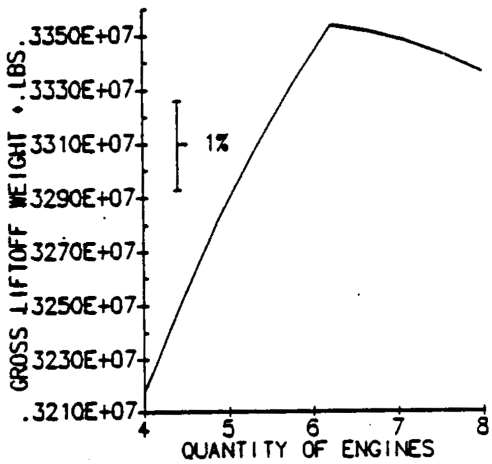


(g-64) Booster Engine Weight Versus Orbiter Propellant at Staging

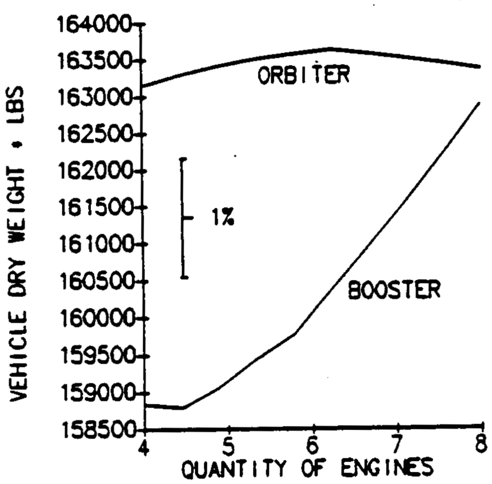
Configuration 2.G Sensitivity Studies (Continued)



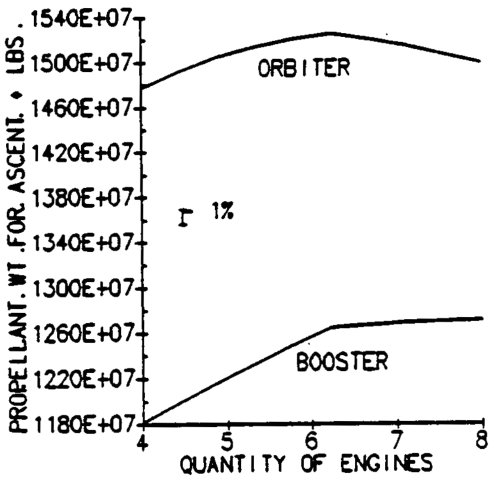
(g-65) Total Dry Weight Versus Number of Booster Engines



(g-66) Gross Lift Off Weight Versus Number of Booster Engines

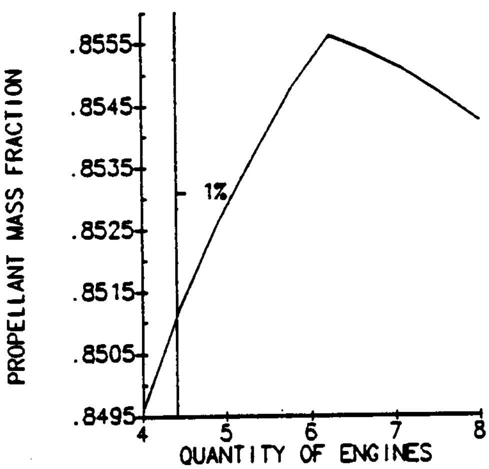


(g-67) Vehicle Dry Weight Versus Number of Booster Engines

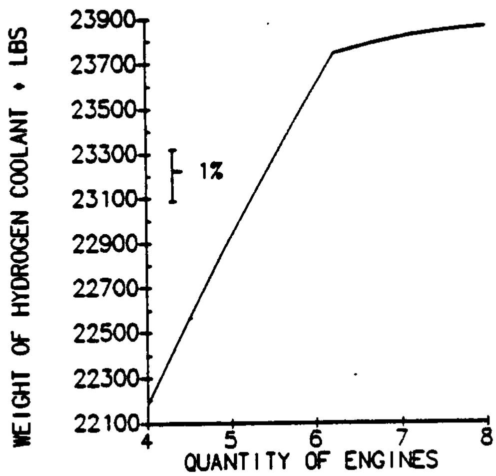


(g-68) Propellant Consumed Versus Number of Booster Engines

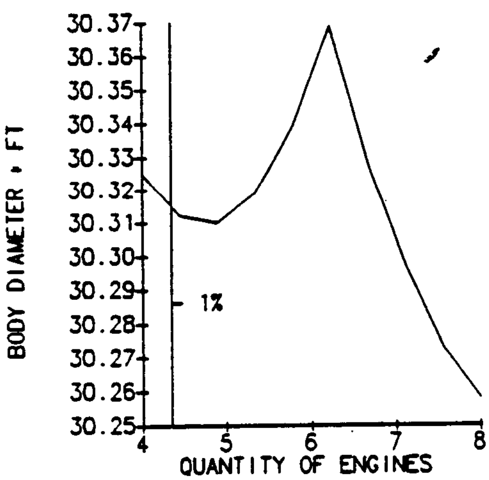
Configuration 2.G Sensitivity Studies (Continued)



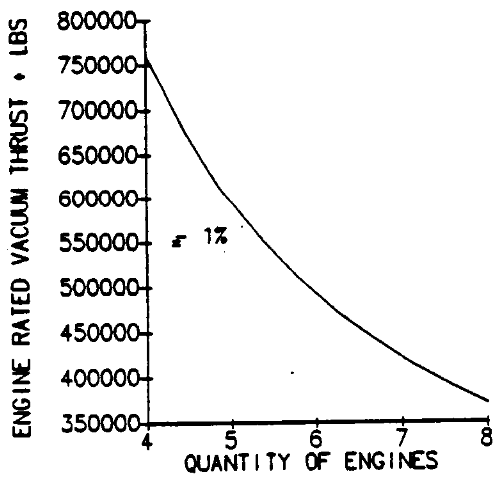
(g-69) Propellant Mass Fraction Versus Number of Booster Engines



(g-70) Weight of Hydrogen Coolant Versus Number of Booster Engines

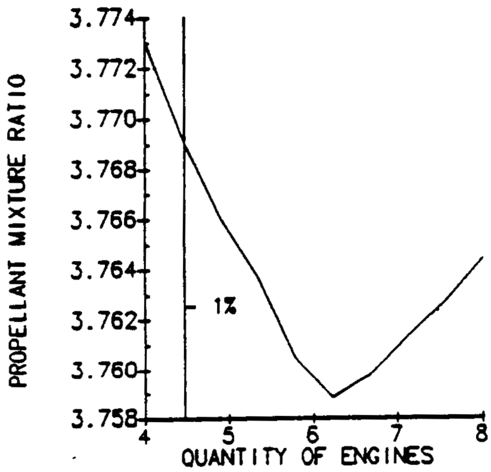


(g-71) Body Diameter Versus Number of Booster Engines

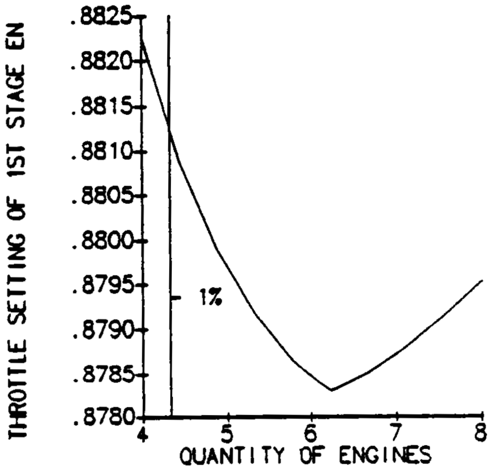


(g-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

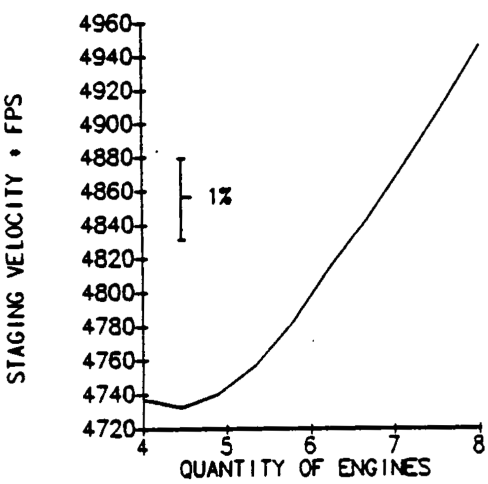
Configuration 2.G Sensitivity Studies (Continued)



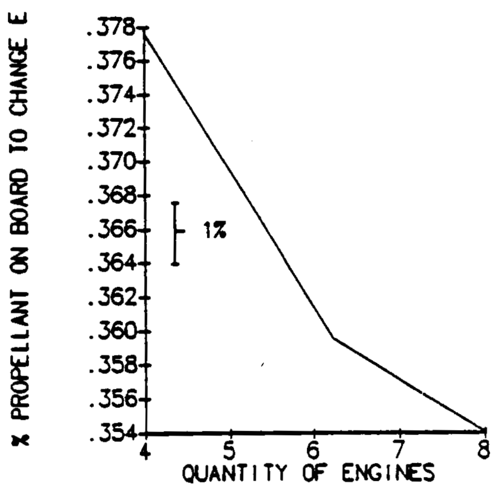
(g-73) Propellant Mixture Ratio Versus Number of Booster Engines



(g-74) Initial Booster Throttle Setting Versus Number of Booster Engines

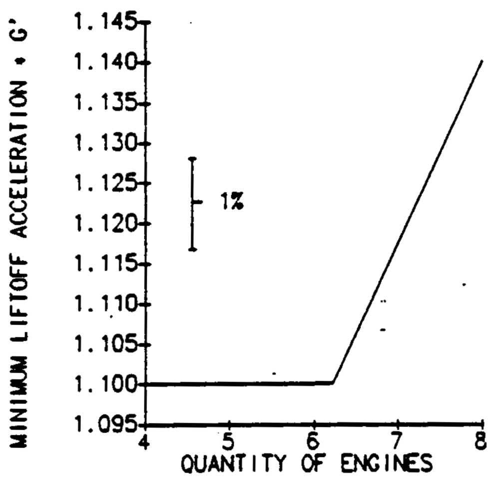


(g-75) Staging Velocity Versus Number of Booster Engines

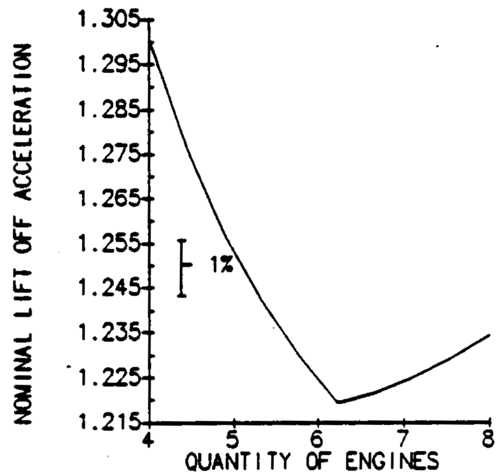


(g-76) Orbiter Propellant at Staging Versus Number of Booster Engines

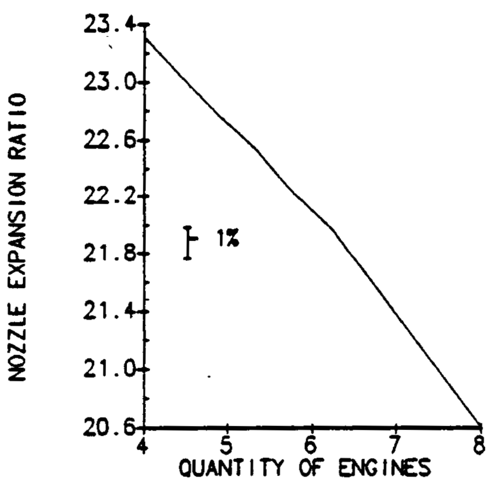
Configuration 2.G Sensitivity Studies (Continued)



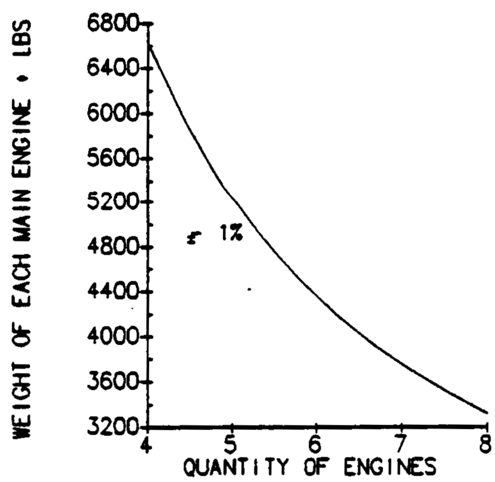
(g-77) **Engine-out Lift Off Acceleration Versus Number of Booster Engines**



(g-78) **Nominal Lift Off Acceleration Versus Number of Booster Engines**



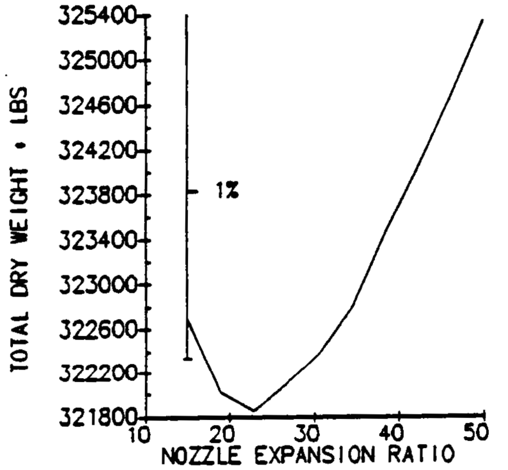
(g-79) **Nozzle Expansion Ratio Versus Number of Booster Engines**



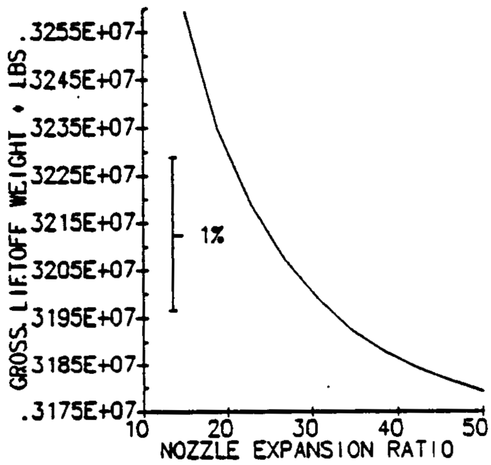
(g-80) **Booster Engine Weight Versus Number of Booster Engines**

Configuration 2.G Sensitivity Studies (Continued)

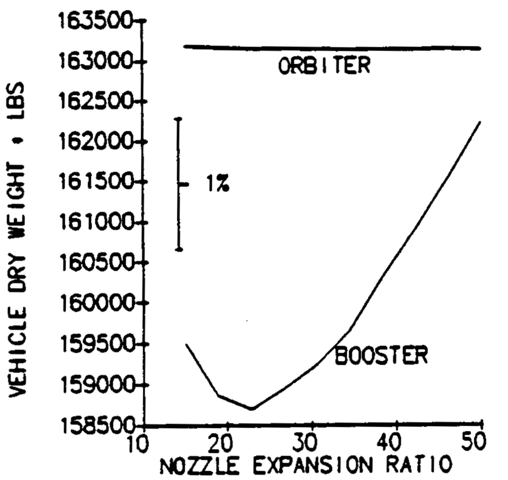
C-5



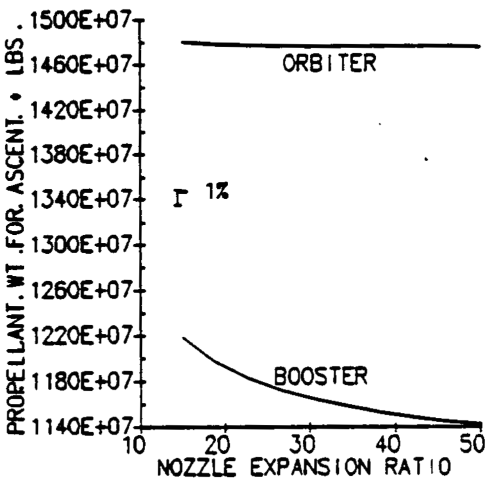
(g-81) Total Dry Weight Versus Nozzle Expansion Ratio



(g-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

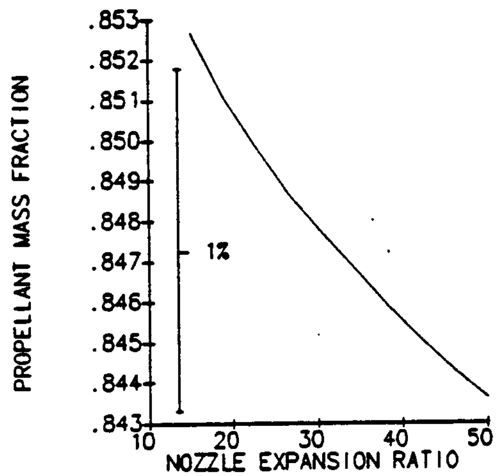


(g-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

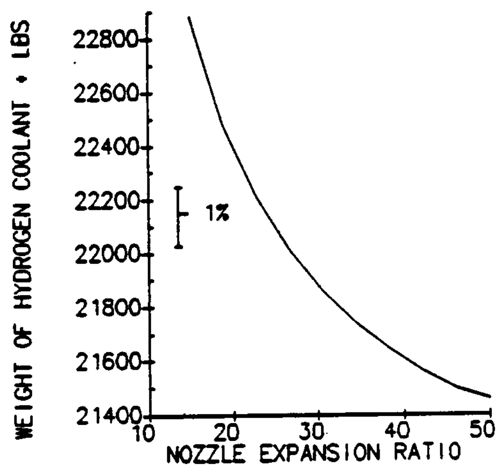


(g-84) Propellant Consumed Versus Nozzle Expansion Ratio

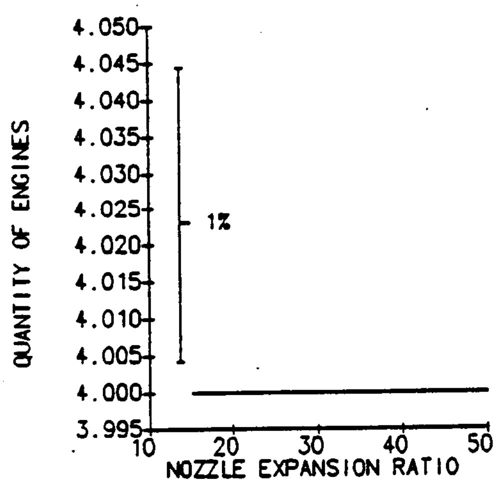
Configuration 2.G Sensitivity Studies (Continued)



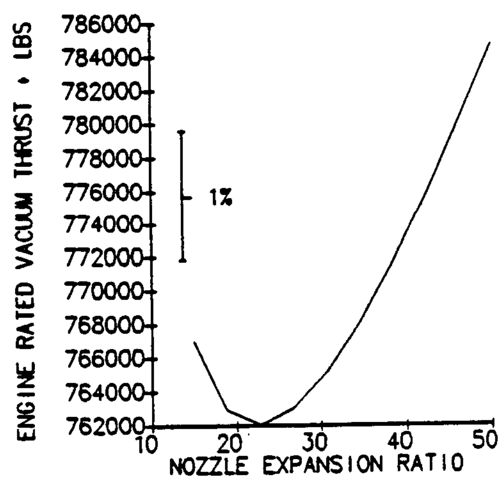
(g-85) **Propellant Mass Fraction Versus Nozzle Expansion Ratio**



(g-86) **Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio**

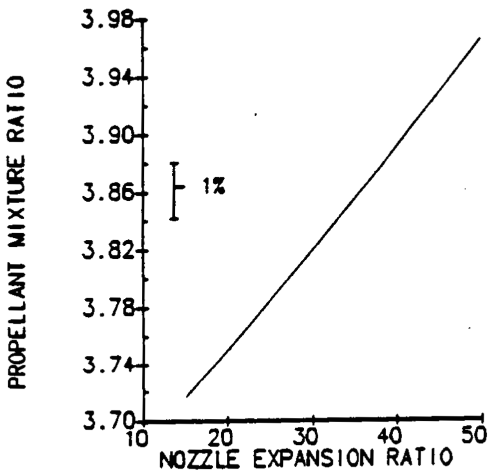


(g-87) **Number of Booster Engines Versus Nozzle Expansion Ratio**

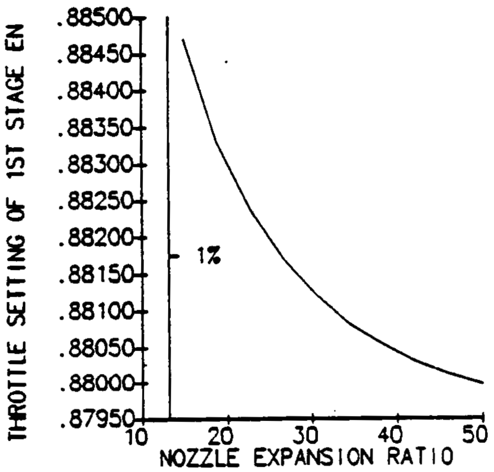


(g-88) **Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio**

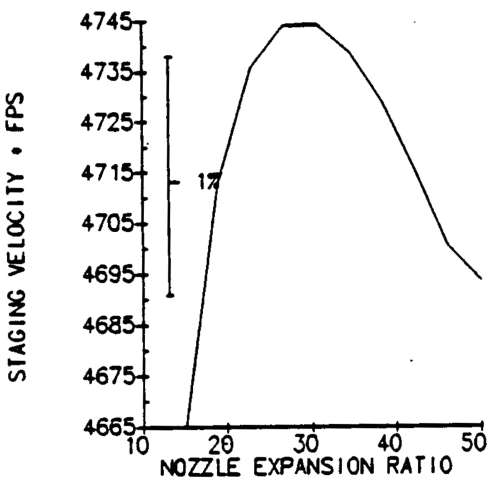
Configuration 2.G Sensitivity Studies (Continued)



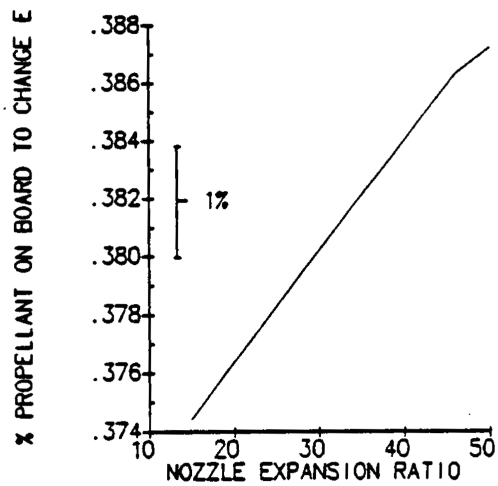
(g-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(g-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

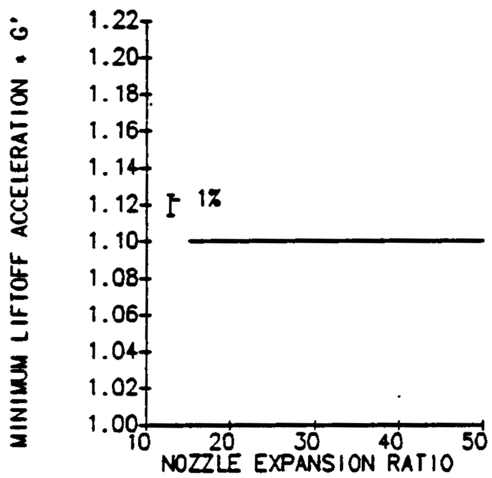


(g-91) Staging Velocity Versus Nozzle Expansion Ratio

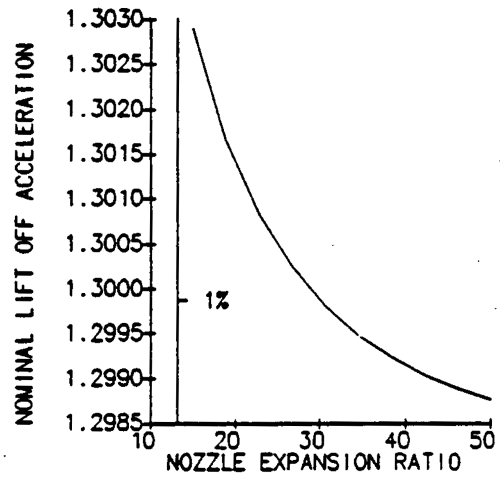


(g-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

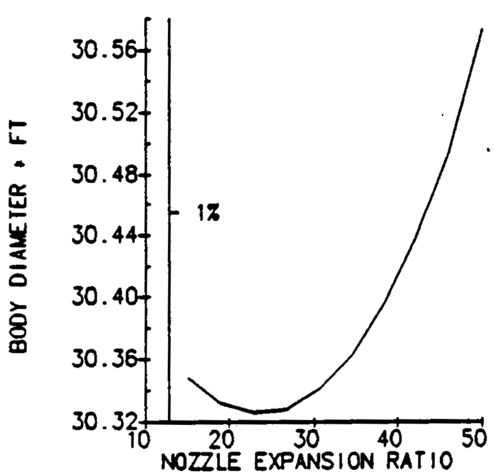
Configuration 2.G Sensitivity Studies (Continued)



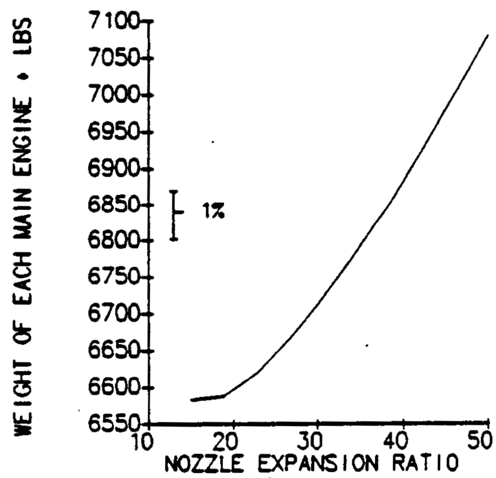
(g-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(g-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

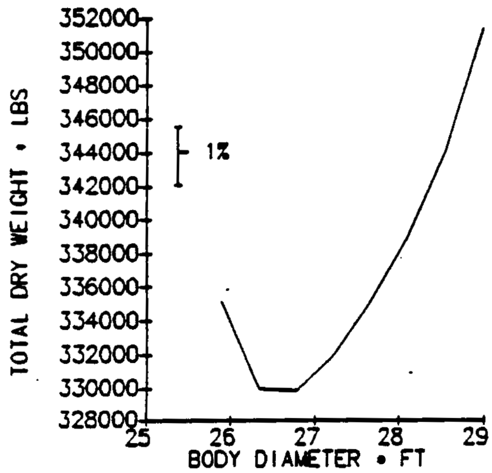


(g-95) Body Diameter Versus Nozzle Expansion Ratio

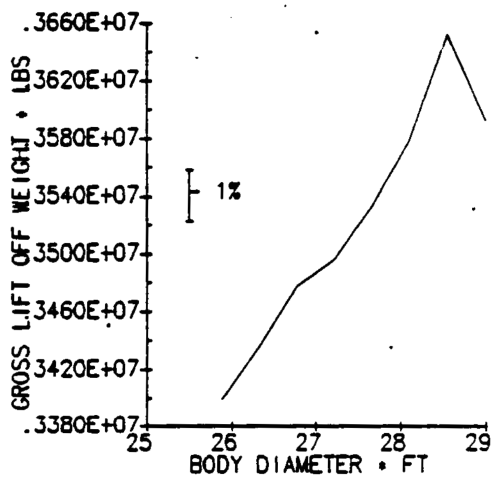


(g-96) Booster Engine Weight Versus Nozzle Expansion Ratio

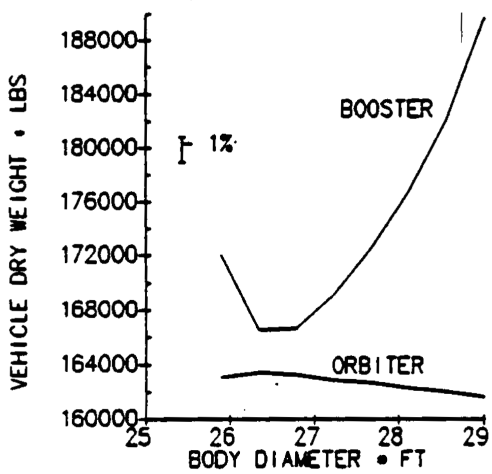
Configuration 2.G Sensitivity Studies (Continued)



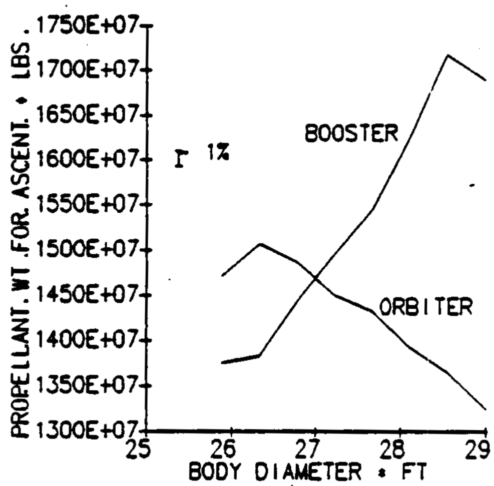
(h-1) Total Dry Weight Versus Body Diameter



(h-2) Gross Lift Off Weight Versus Body Diameter

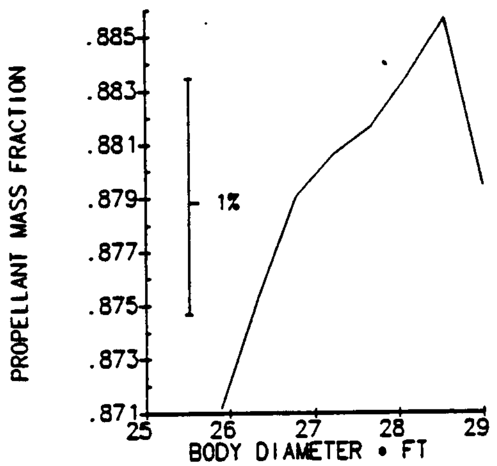


(h-3) Vehicle Dry Weight Versus Body Diameter

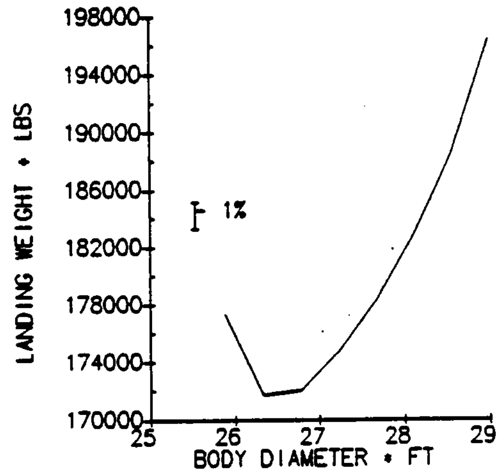


(h-4) Propellant Consumed Versus Body Diameter

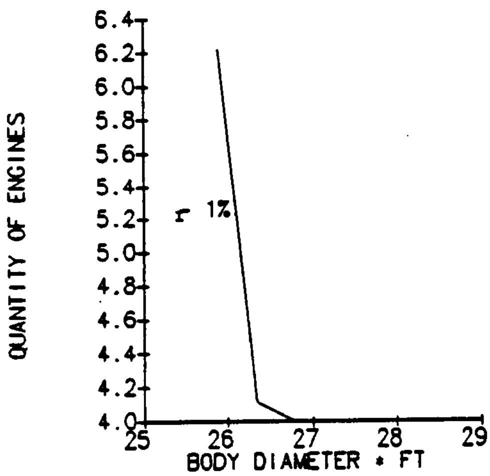
Configuration 2.H Sensitivity Studies



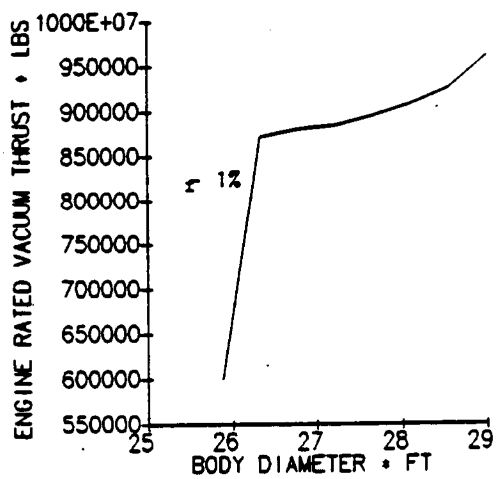
(h-5) Propellant Mass Fraction Versus Body Diameter



(h-6) Landing Weight Versus Body Diameter

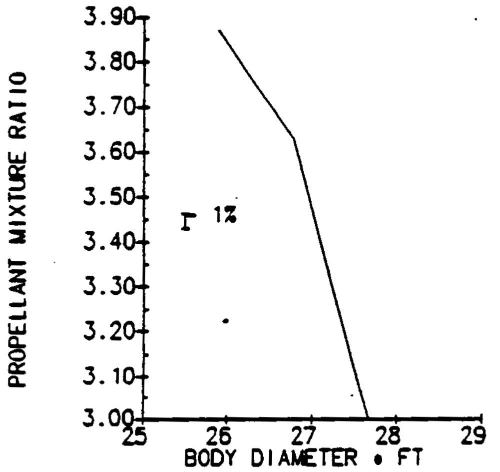


(h-7) Number of Booster Engines Versus Body Diameter

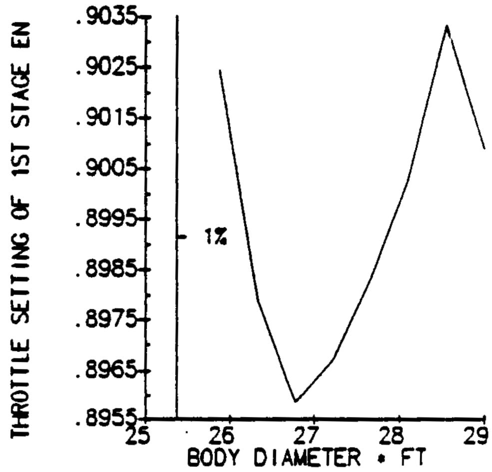


(h-8) Engine Rated Vacuum Thrust Versus Body Diameter

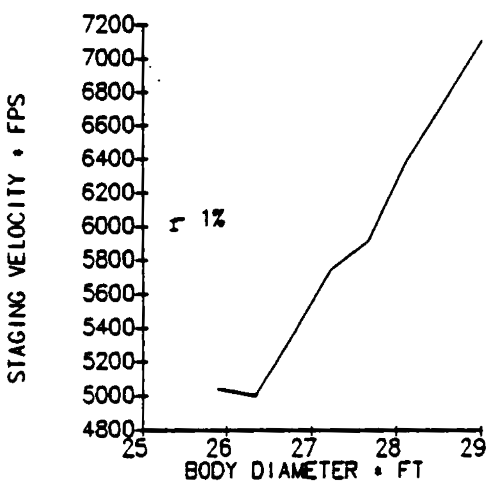
Configuration 2.H Sensitivity Studies (Continued)



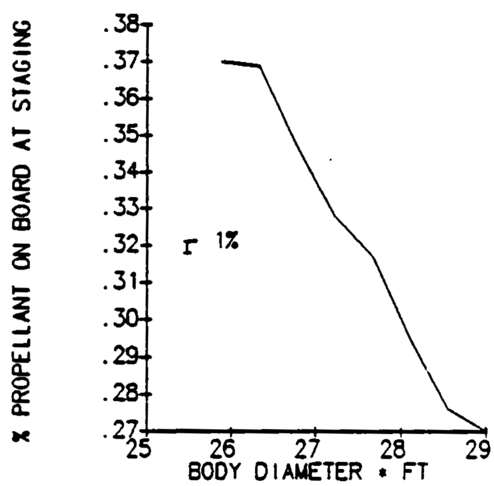
(h-9) Propellant Mixture Ratio Versus Body Diameter



(h-10) Initial Booster Throttle Setting Versus Body Diameter

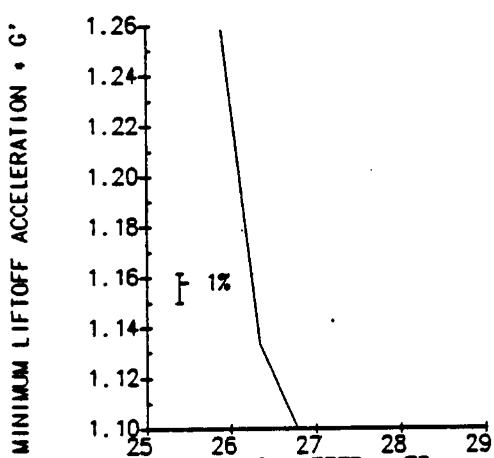


(h-11) Staging Velocity Versus Body Diameter

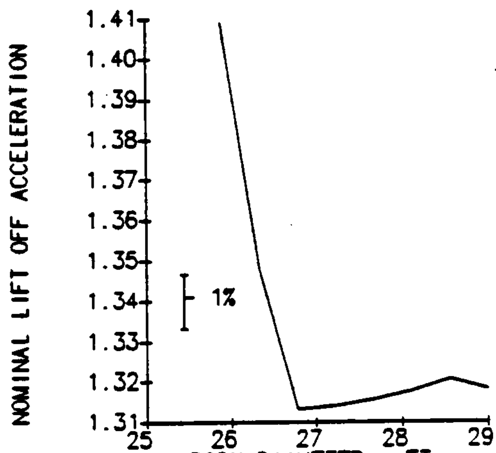


(h-12) Orbiter Propellant at Staging Versus Body Diameter

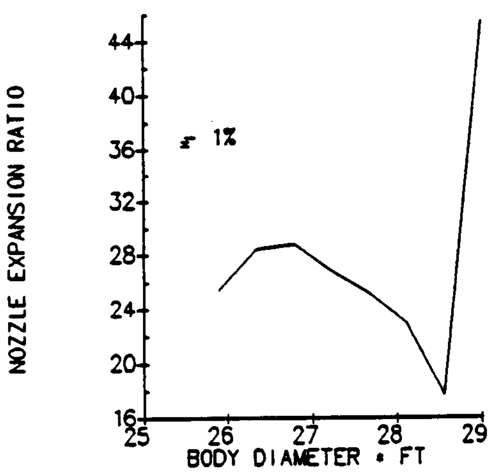
Configuration 2.H Sensitivity Studies (Con:inued)



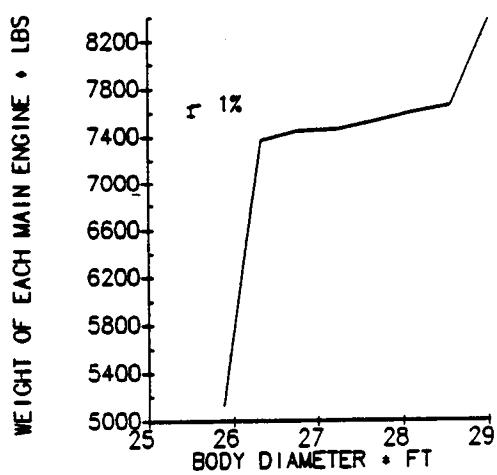
(h-13) Engine-out Lift Off Acceleration Versus Body Diameter



(h-14) Nominal Lift Off Acceleration Versus Body Diameter

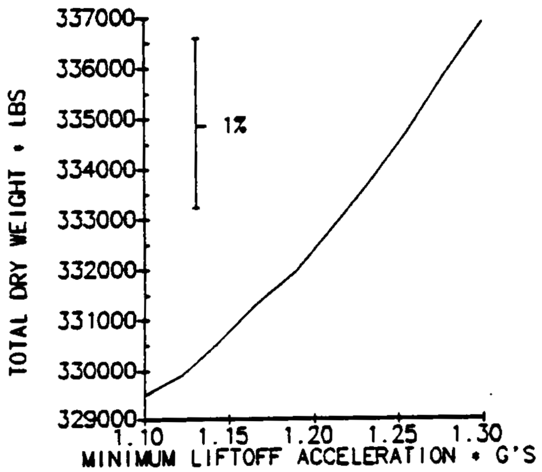


(h-15) Nozzle Expansion Ratio Versus Body Diameter

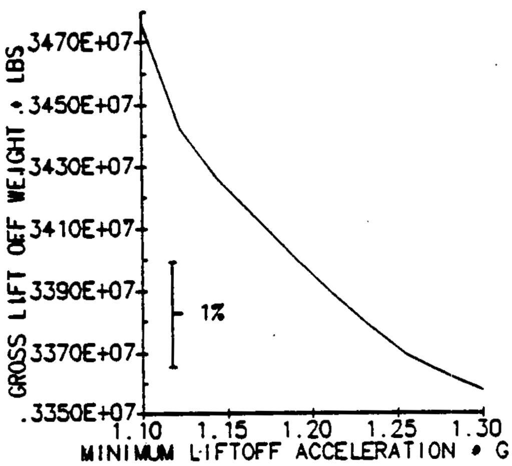


(h-16) Booster Engine Weight Versus Body Diameter

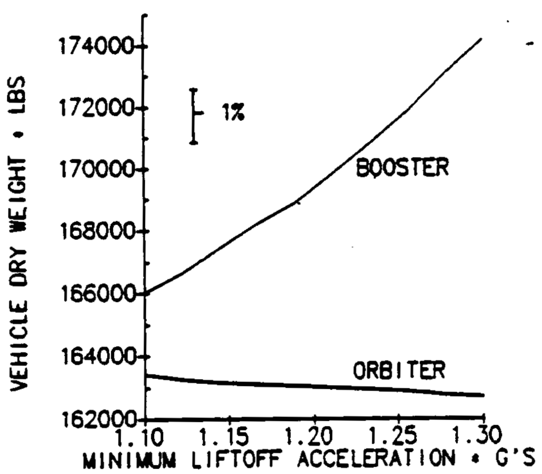
Configuration 2.H Sensitivity Studies (Continued)



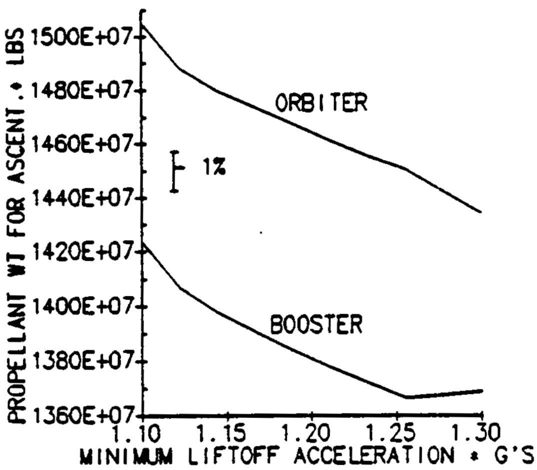
(h-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(h-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

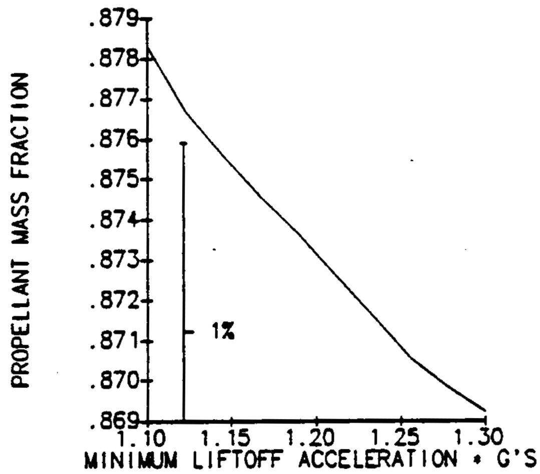


(h-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

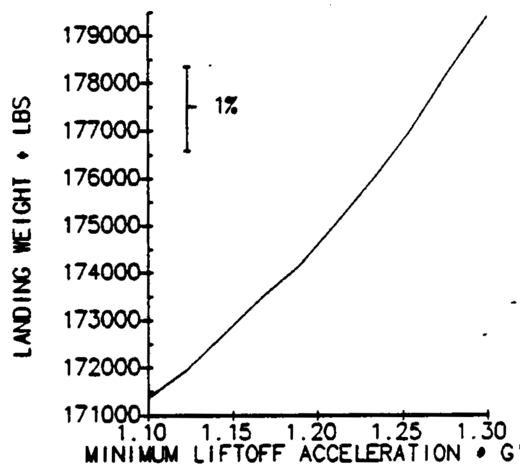


(h-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

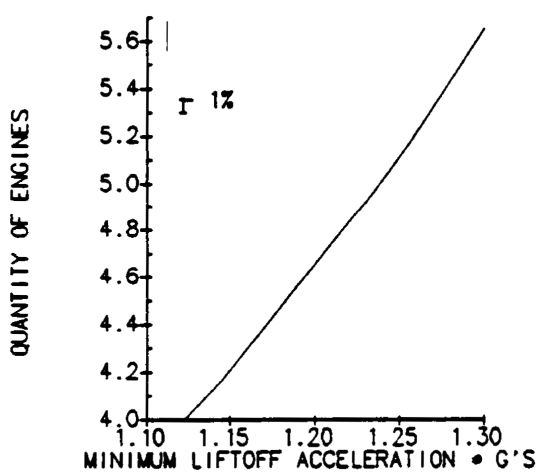
Configuration 2.H Sensitivity Studies (Continued)



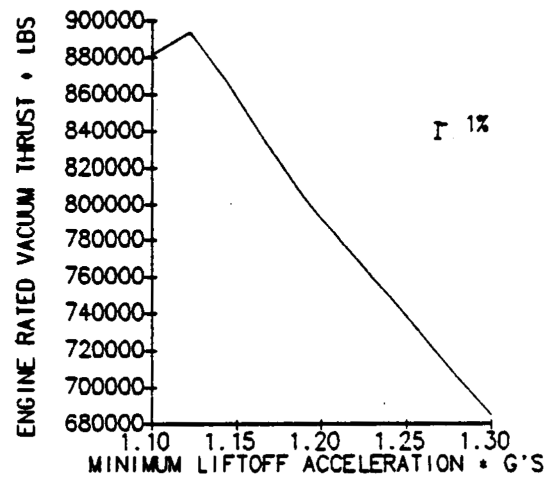
(h-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(h-22) Landing Weight Versus Engine-out Lift Off Acceleration

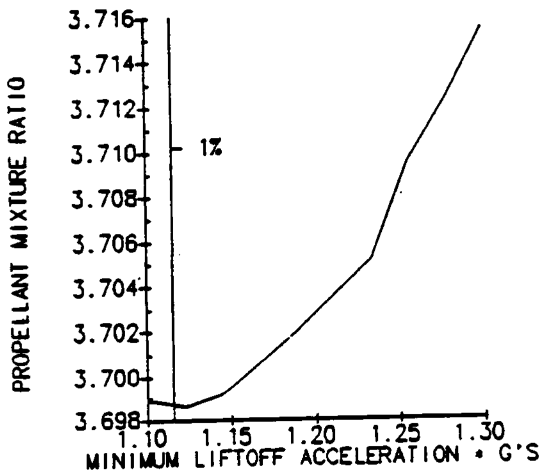


(h-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

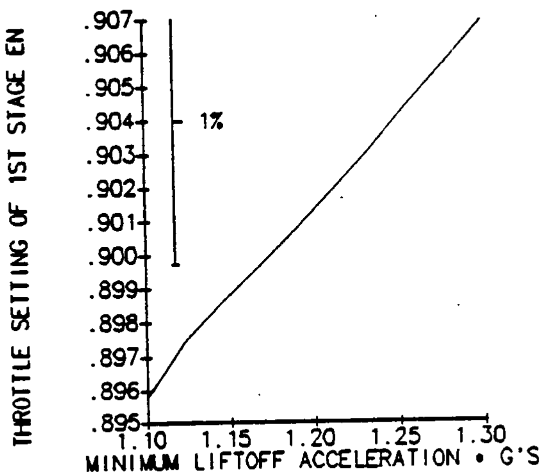


(h-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

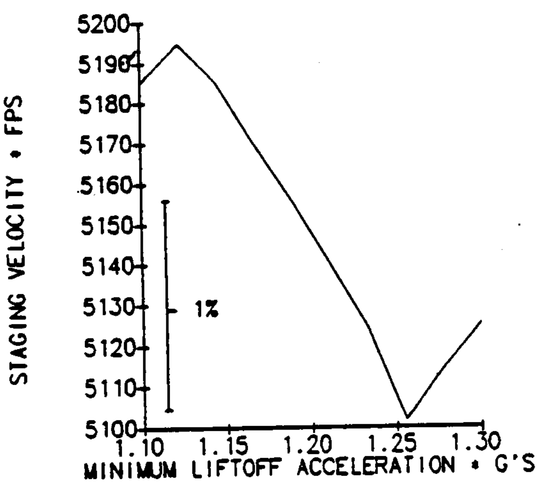
Configuration 2.H Sensitivity Studies (Continued)



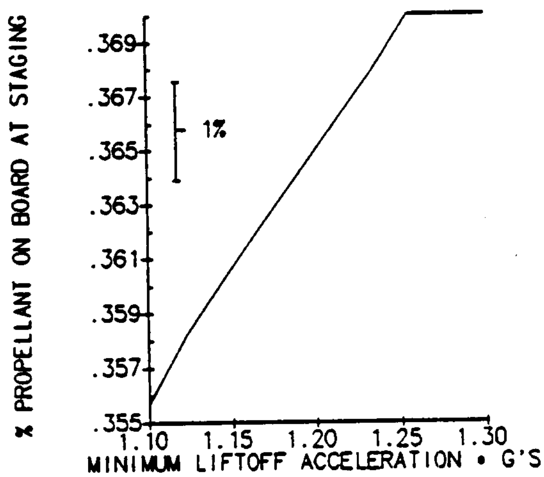
(h-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(h-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

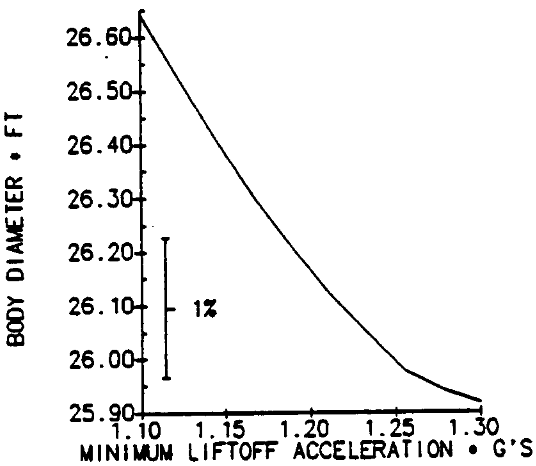


(h-27) Staging Velocity Versus Engine-out Lift Off Acceleration

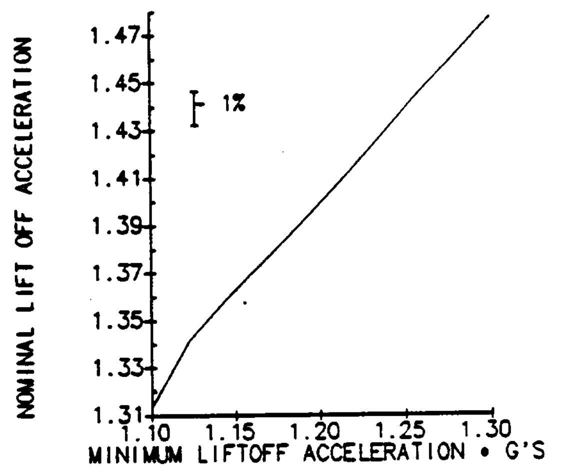


(h-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

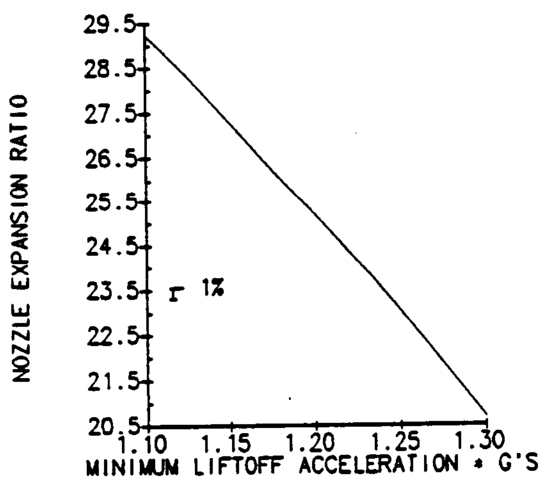
Configuration 2.H Sensitivity Studies (Continued)



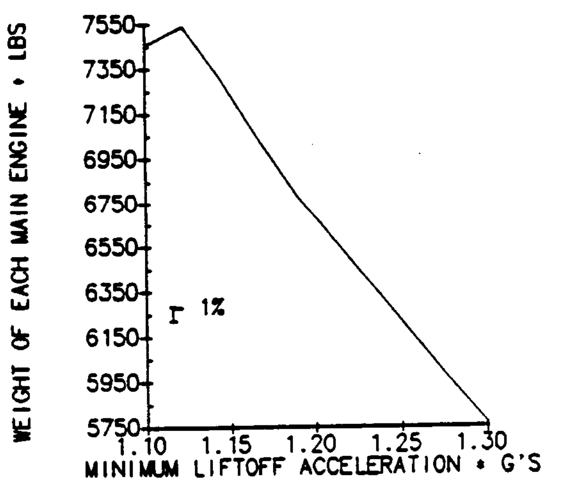
(h-29) Body Diameter Versus Engine-out Lift Off Acceleration



(h-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

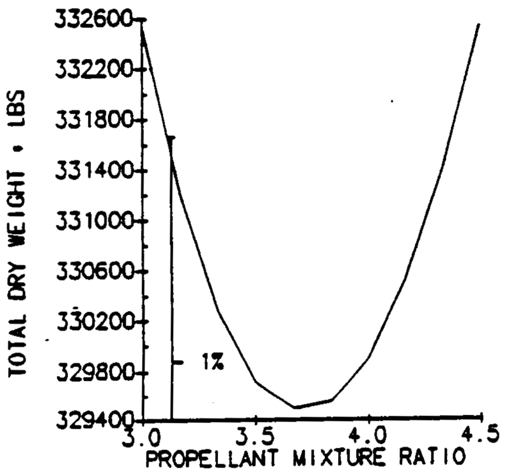


(h-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

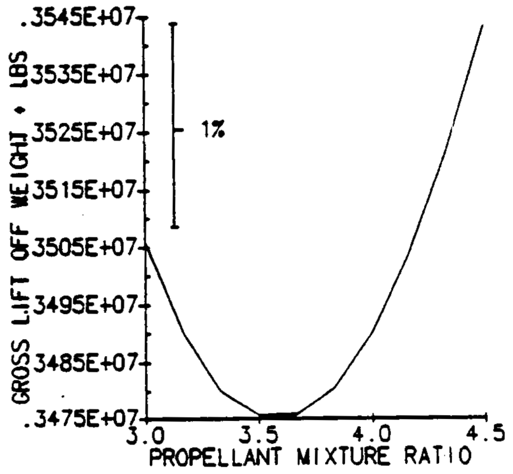


(h-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

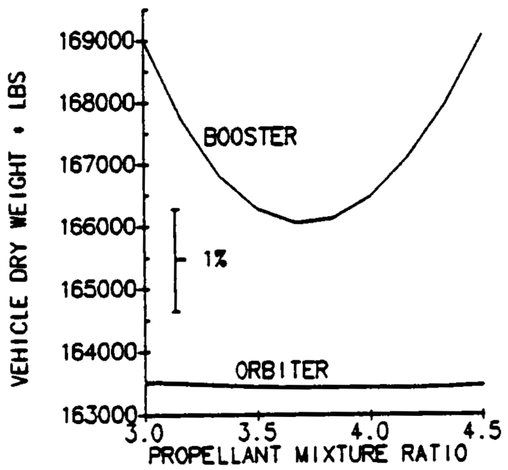
Configuration 2.H Sensitivity Studies (Continued)



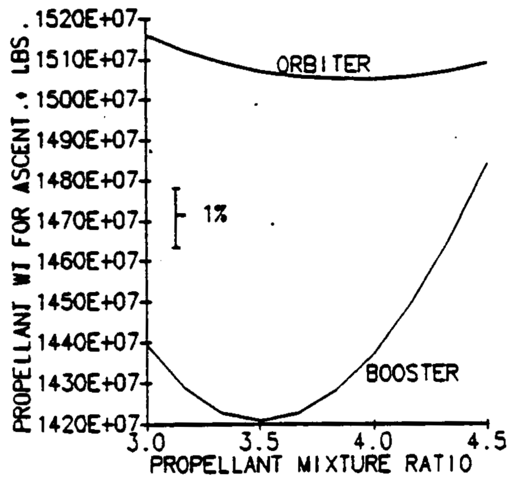
(h-33) Total Dry Weight Versus Propellant Mixture Ratio



(h-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

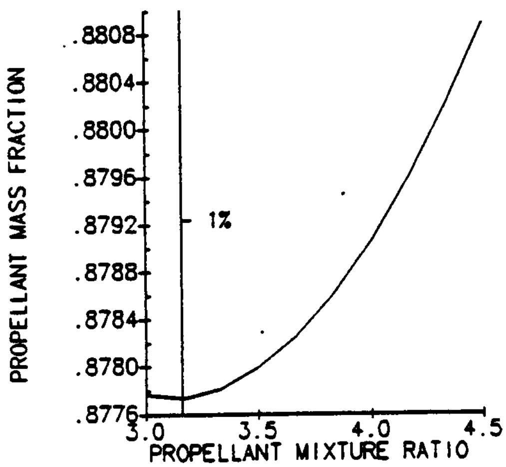


(h-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

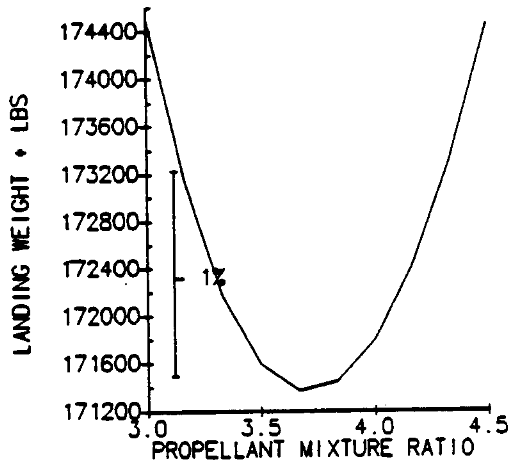


(h-36) Propellant Consumed Versus Propellant Mixture Ratio

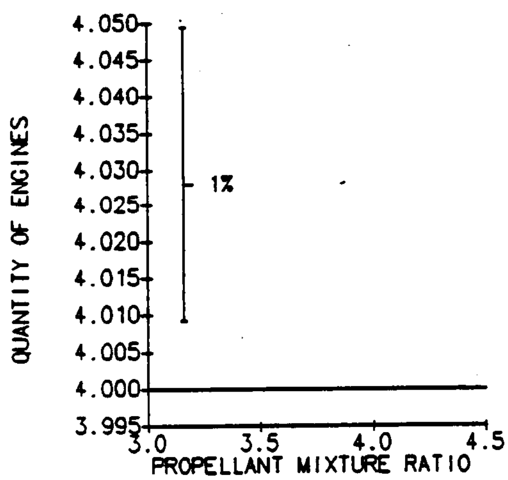
Configuration 2.H Sensitivity Studies (Continued)



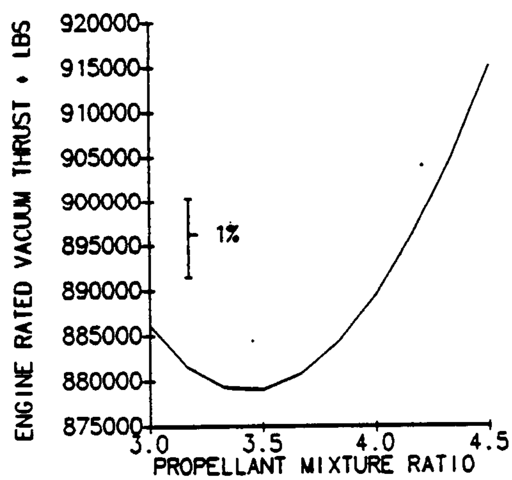
(h-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(h-38) Landing Weight Versus Propellant Mixture Ratio

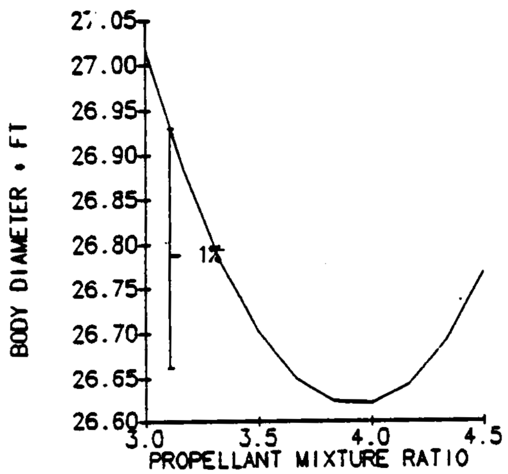


(h-39) Number of Booster Engines Versus Propellant Mixture Ratio

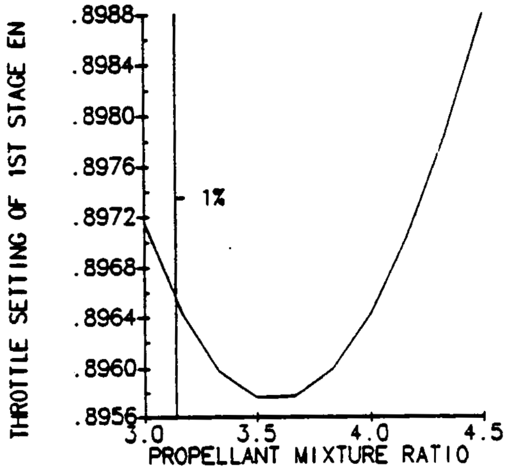


(h-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

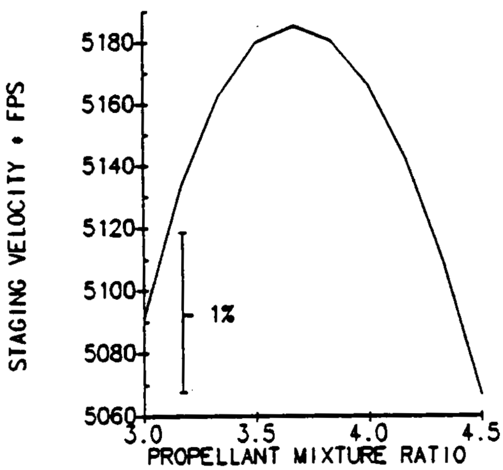
Configuration 2.H Sensitivity Studies (Continued)



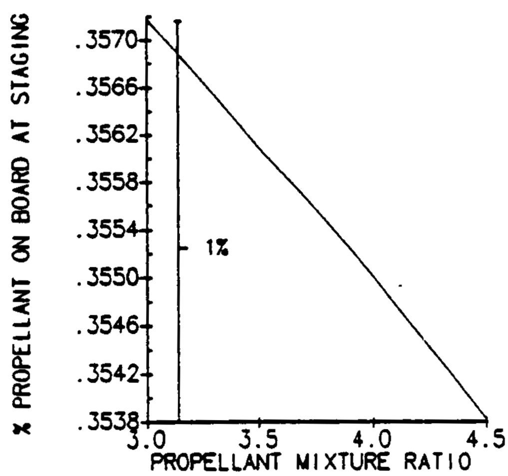
(h-41) Body Diameter Versus Propellant Mixture Ratio



(h-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

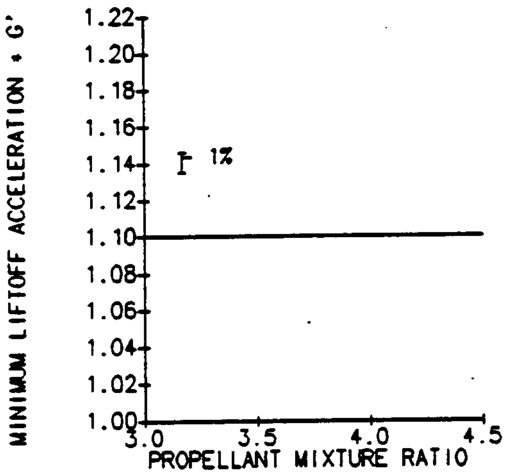


(h-43) Staging Velocity Versus Propellant Mixture Ratio

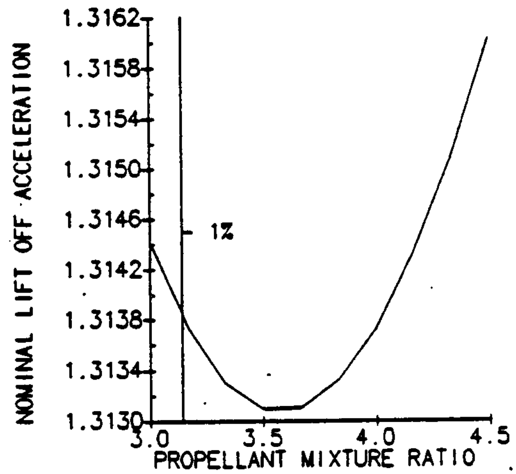


(h-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

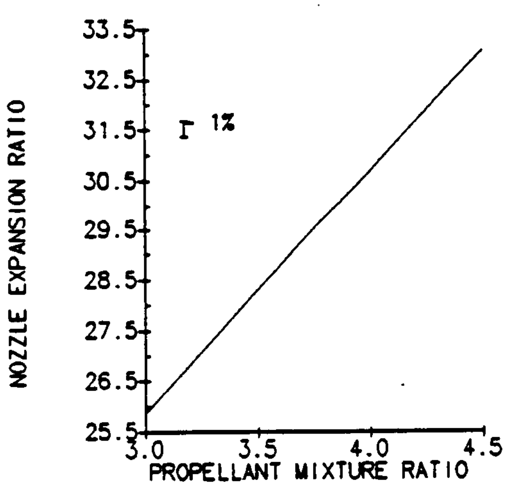
Configuration 2.H Sensitivity Studies (Continued)



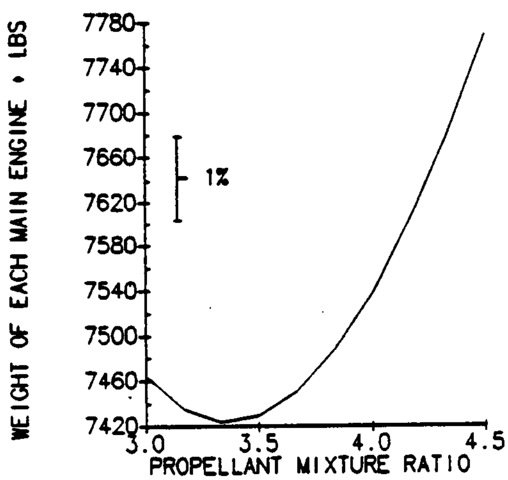
(h-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(h-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

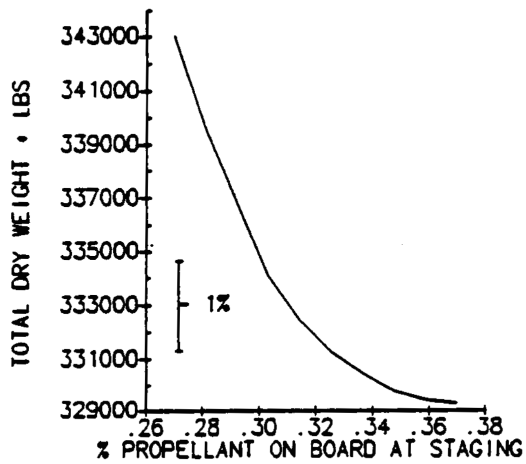


(h-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

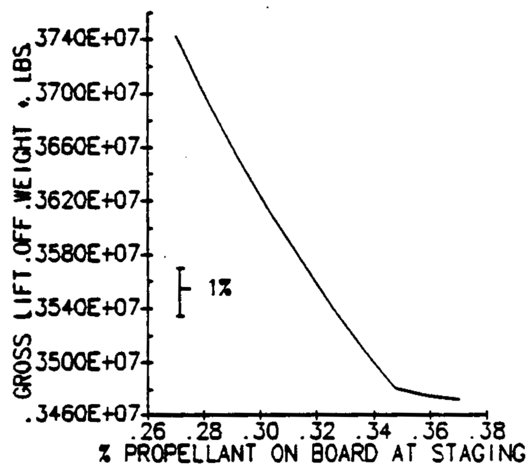


(h-48) Booster Engine Weight Versus Propellant Mixture Ratio

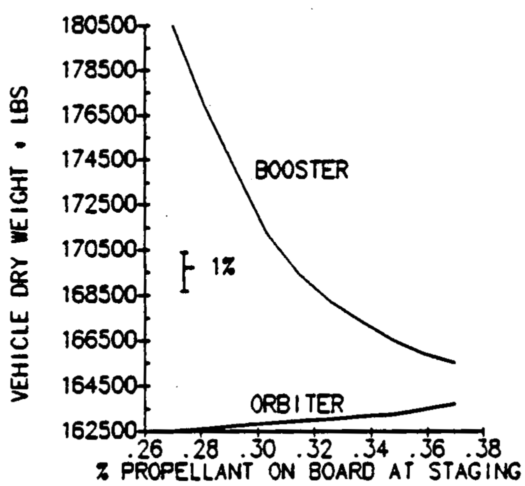
Configuration 2.H Sensitivity Studies (Continued)



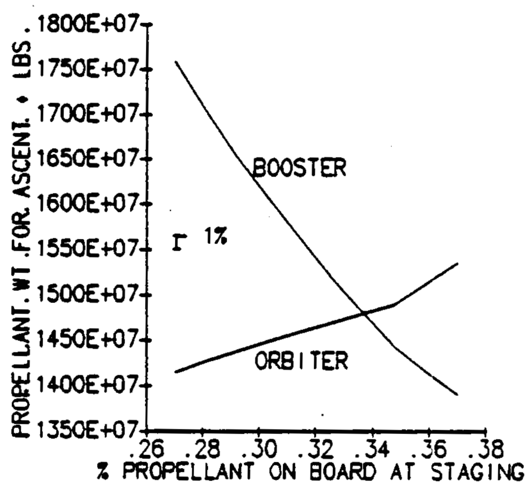
(h-49) Total Dry Weight Versus Orbiter Propellant at Staging



(h-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

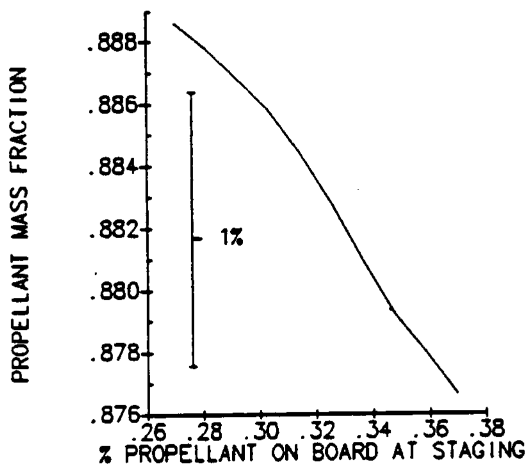


(h-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

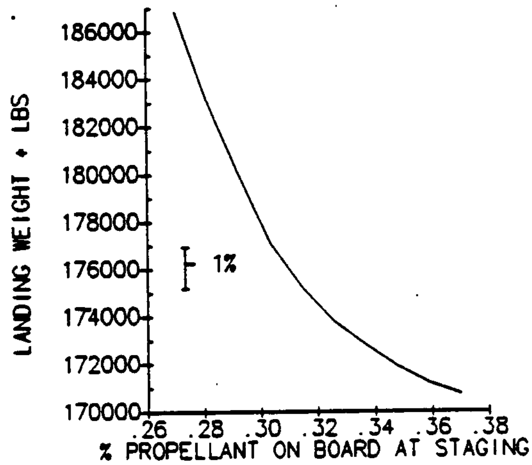


(h-52) Propellant Consumed Versus Orbiter Propellant at Staging

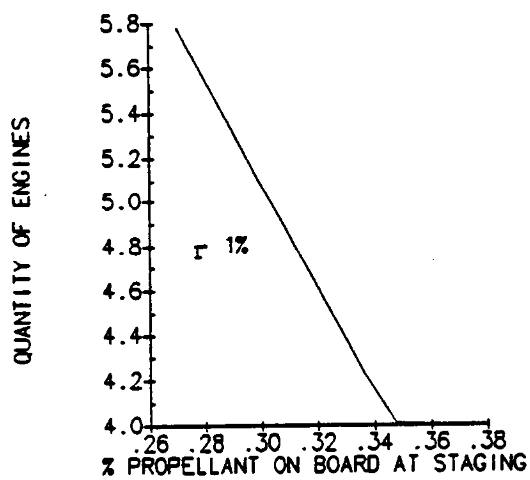
Configuration 2.H Sensitivity Studies (Continued)



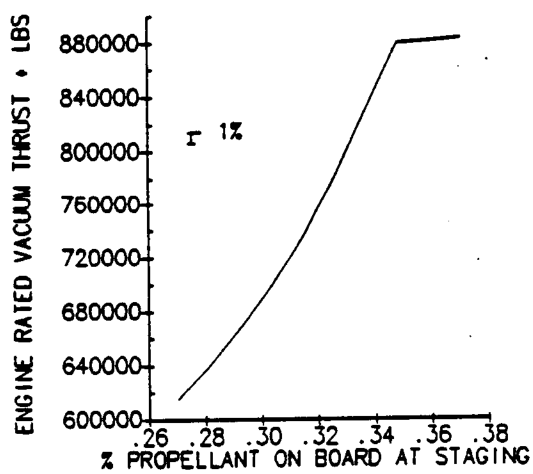
(h-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(h-54) Landing Weight Versus Orbiter Propellant at Staging

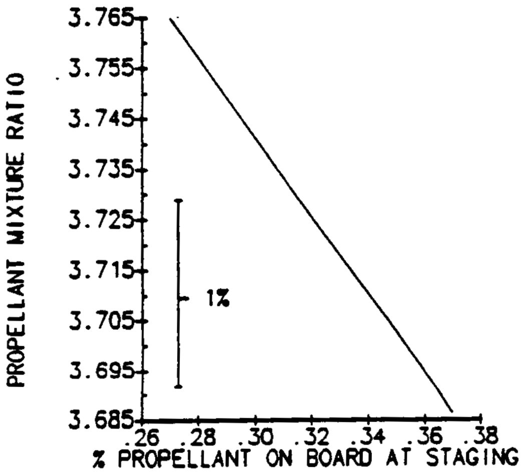


(h-55) Number of Booster Engines Versus Orbiter Propellant at Staging

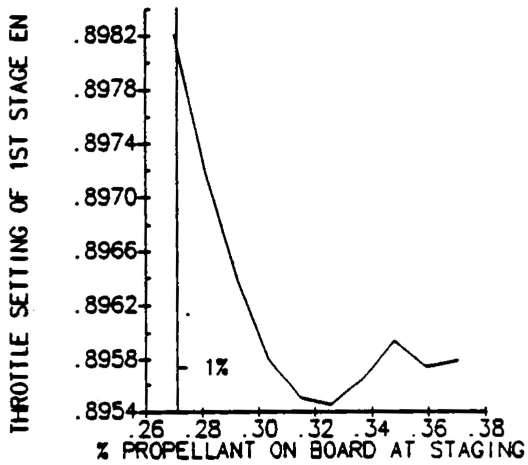


(h-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

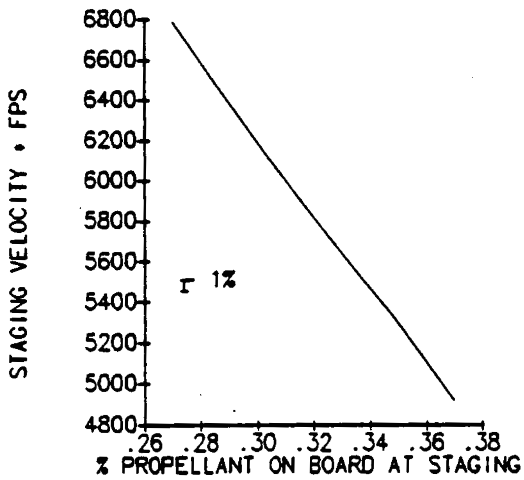
Configuration 2.H Sensitivity Studies (Continued)



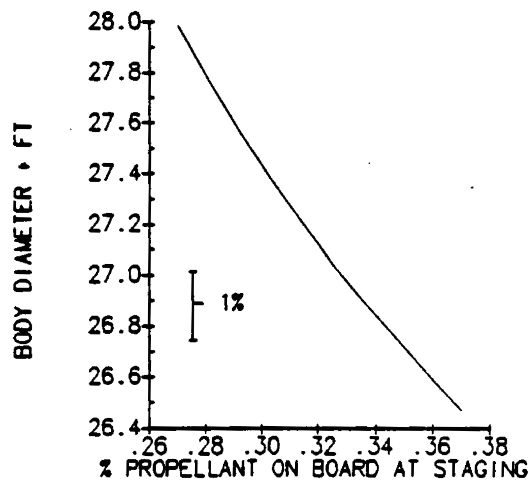
(h-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(h-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

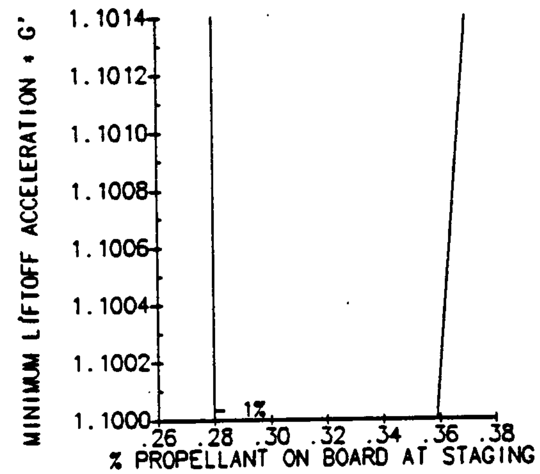


(h-59) Staging Velocity Versus Orbiter Propellant at Staging

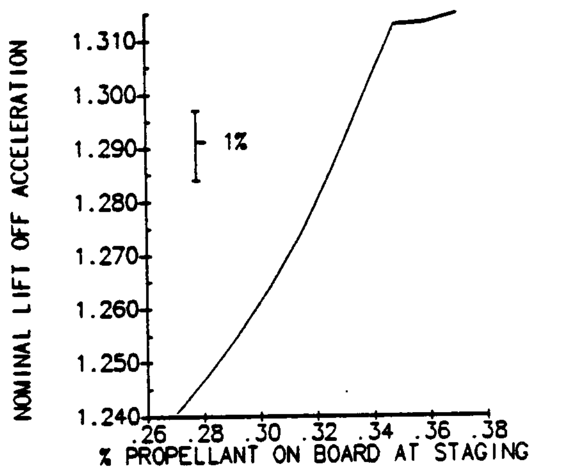


(h-60) Body Diameter Versus Orbiter Propellant at Staging

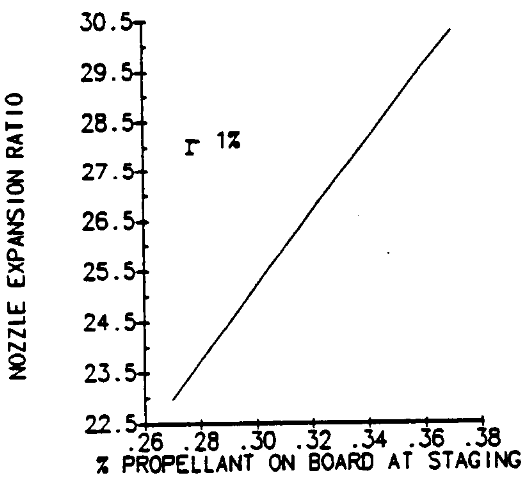
Configuration 2.H Sensitivity Studies (Continued)



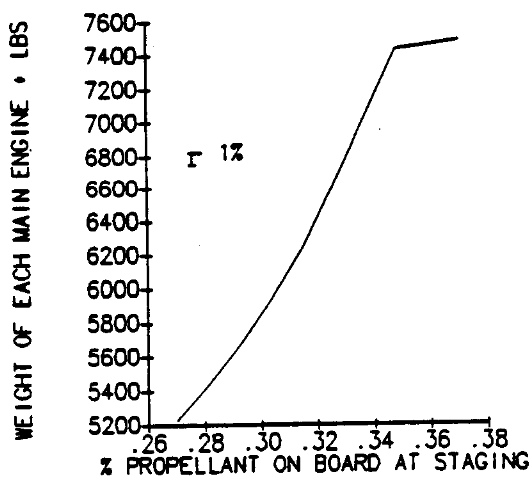
(h-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(h-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

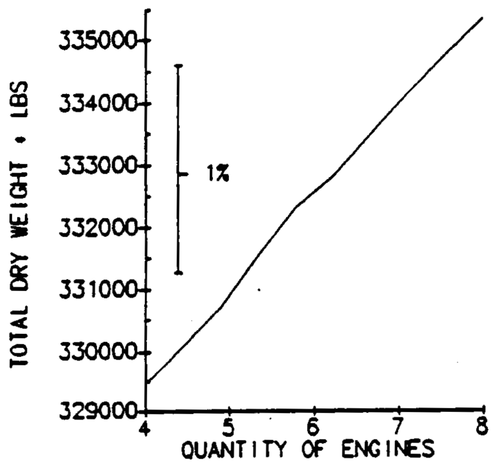


(h-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

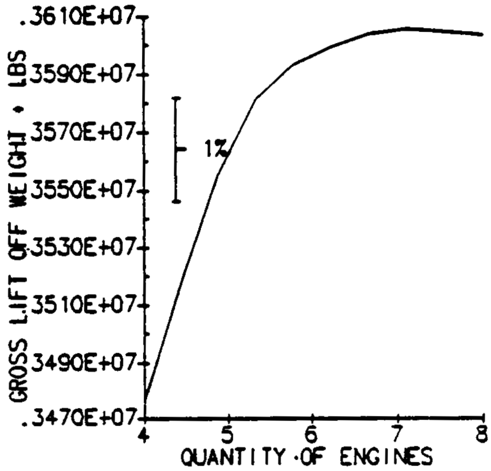


(h-64) Booster Engine Weight Versus Orbiter Propellant at Staging

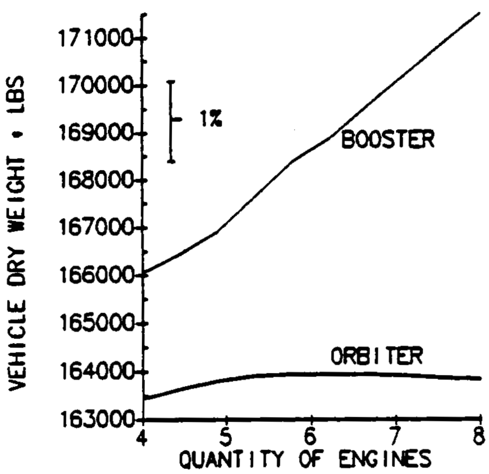
Configuration 2.H Sensitivity Studies (Continued)



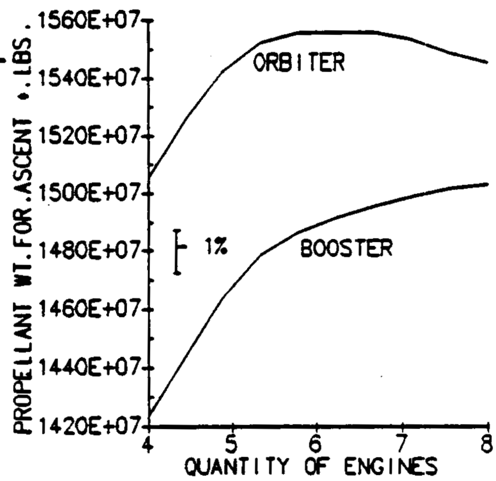
(h-65) Total Dry Weight Versus Number of Booster Engines



(h-66) Gross Lift Off Weight Versus Number of Booster Engines

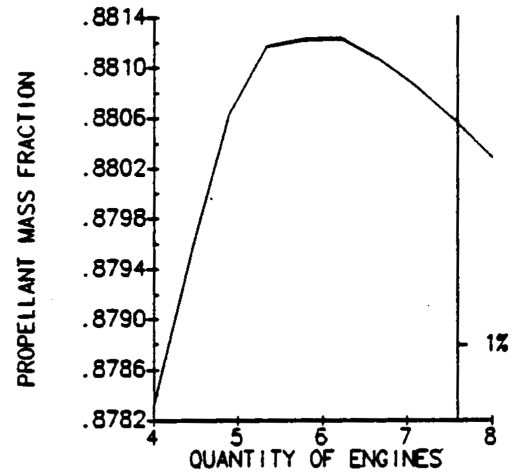


(h-67) Vehicle Dry Weight Versus Number of Booster Engines

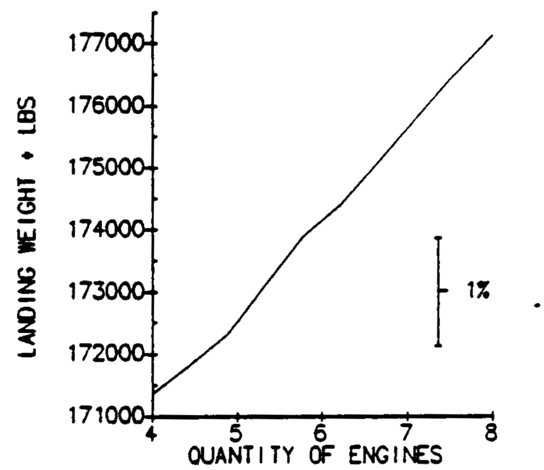


(h-68) Propellant Consumed Versus Number of Booster Engines

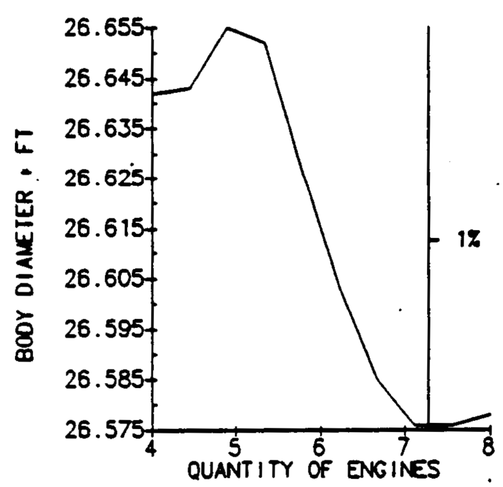
Configuration 2.H Sensitivity Studies (Continued)



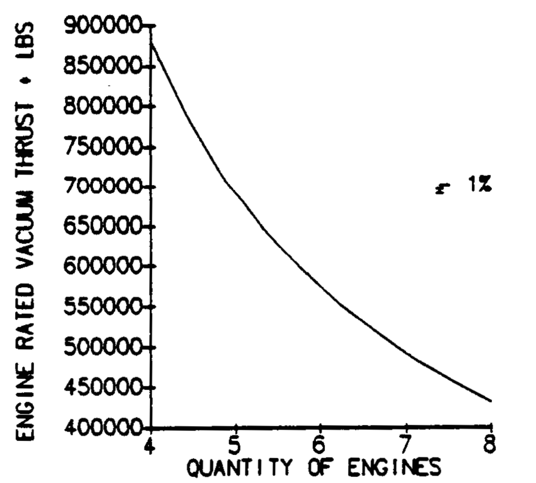
(h-69) Propellant Mass Fraction Versus Number of Booster Engines



(h-70) Landing Weight Versus Number of Booster Engines

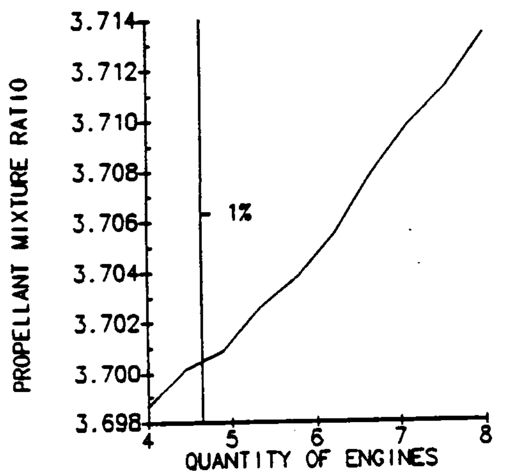


(h-71) Body Diameter Versus Number of Booster Engines

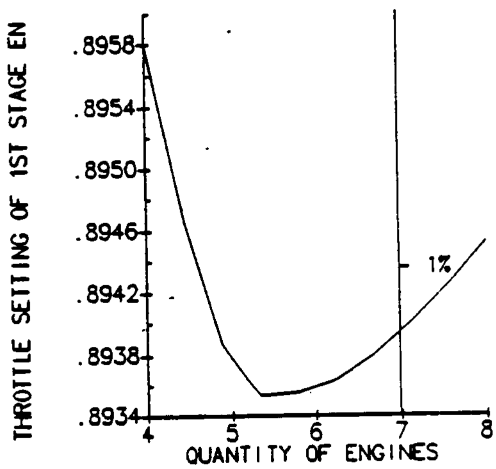


(h-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

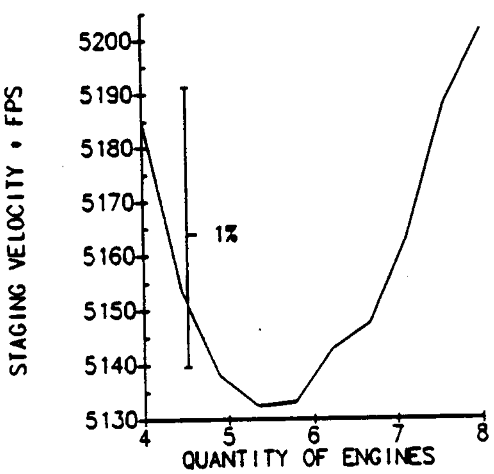
Configuration 2.H Sensitivity Studies (Continued)



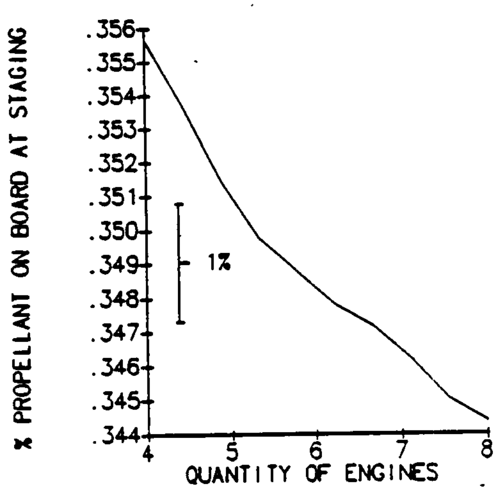
(h-73) Propellant Mixture Ratio Versus Number of Booster Engines



(h-74) Initial Booster Throttle Setting Versus Number of Booster Engines

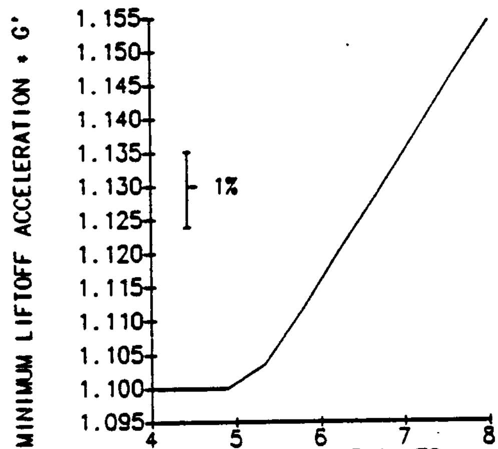


(h-75) Staging Velocity Versus Number of Booster Engines

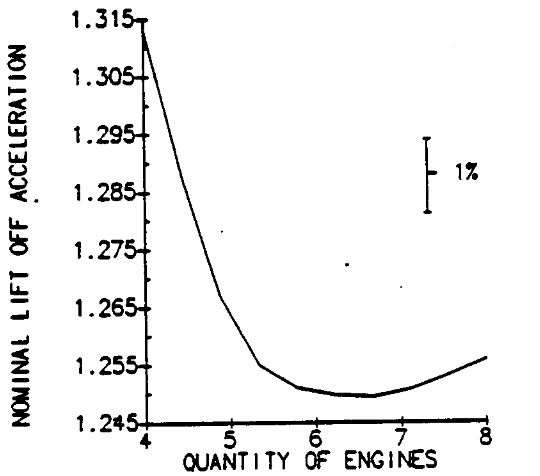


(h-76) Orbiter Propellant at Staging Versus Number of Booster Engines

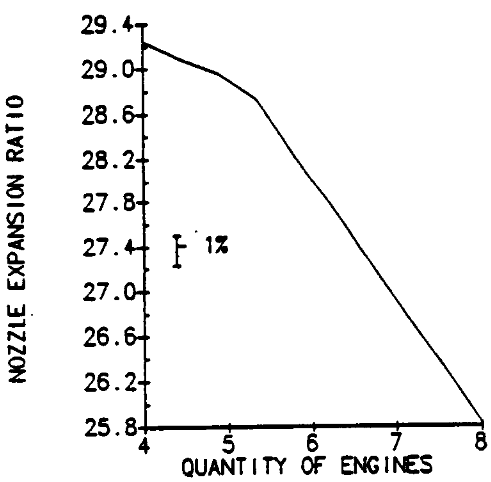
Configuration 2.H Sensitivity Studies (Continued)



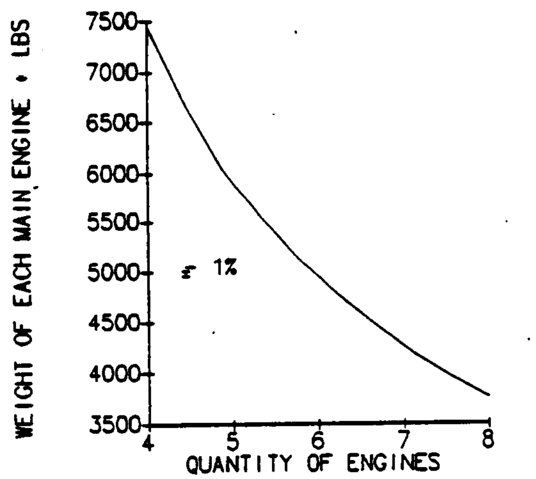
(h-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(h-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

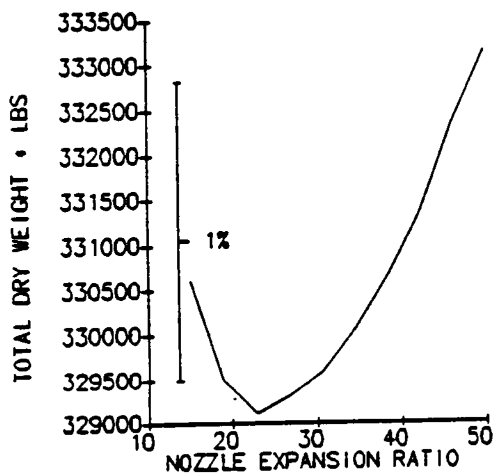


(h-79) Nozzle Expansion Ratio Versus Number of Booster Engines

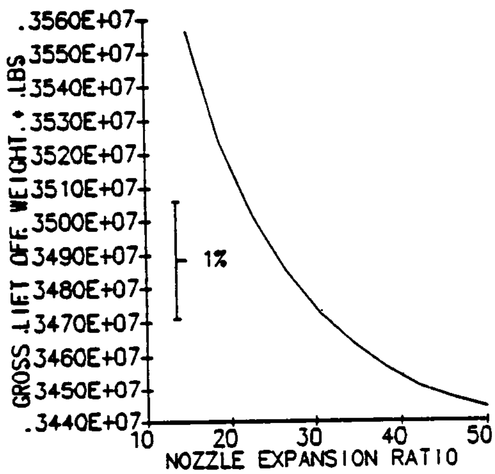


(h-80) Booster Engine Weight Versus Number of Booster Engines

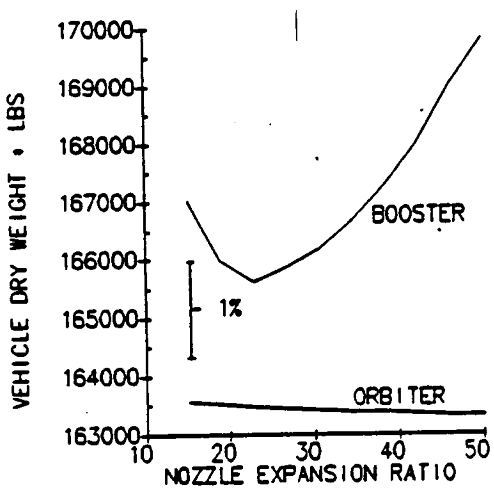
Configuration 2.H Sensitivity Studies (Continued)



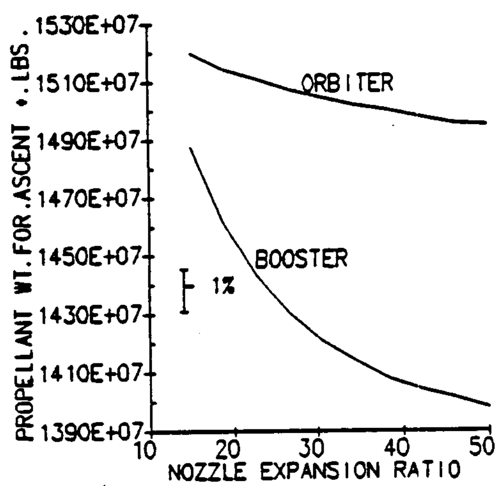
(h-81) Total Dry Weight Versus Nozzle Expansion Ratio



(h-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

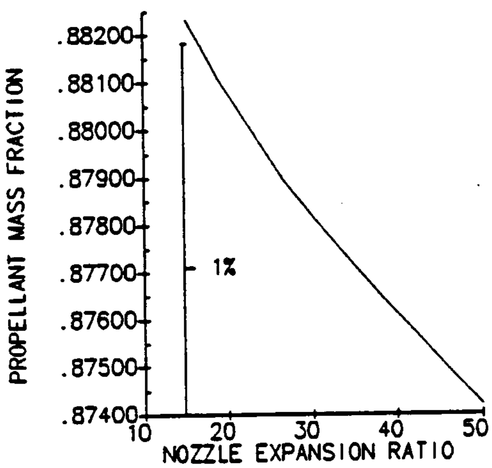


(h-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

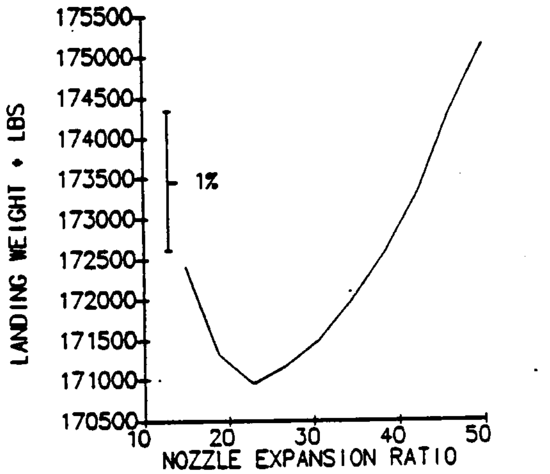


(h-84) Propellant Consumed Versus Nozzle Expansion Ratio

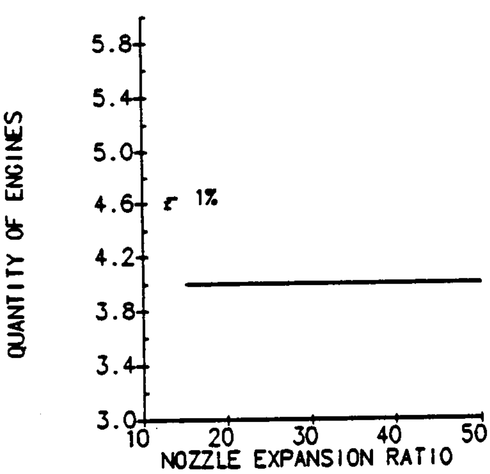
Configuration 2.H Sensitivity Studies (Continued)



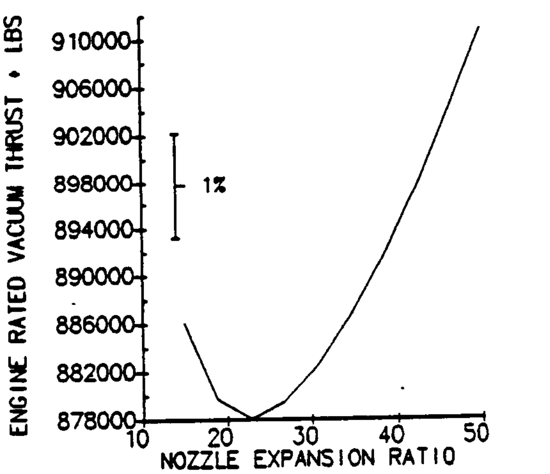
(h-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(h-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

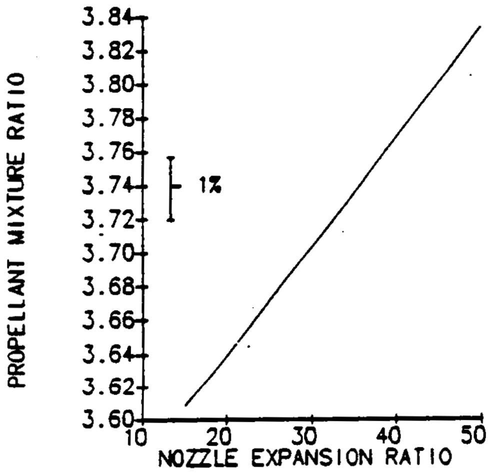


(h-87) Number of Booster Engines Versus Nozzle Expansion Ratio

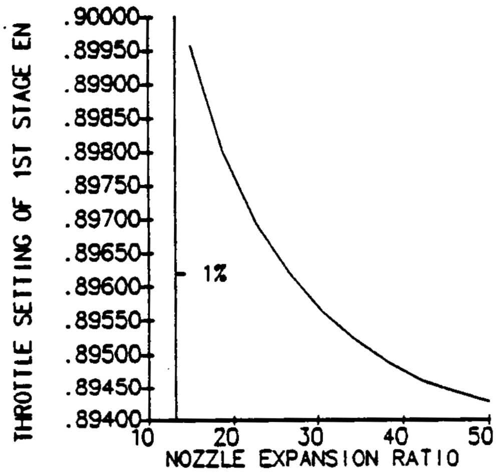


(h-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

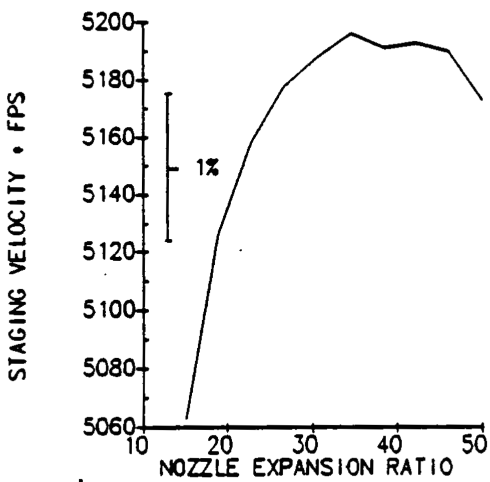
Configuration 2.H Sensitivity Studies (Continued)



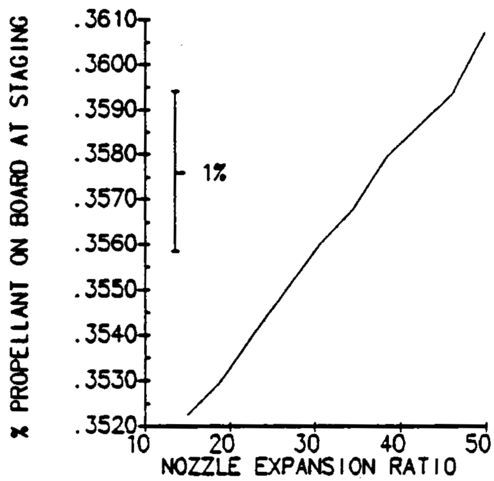
(h-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(h-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

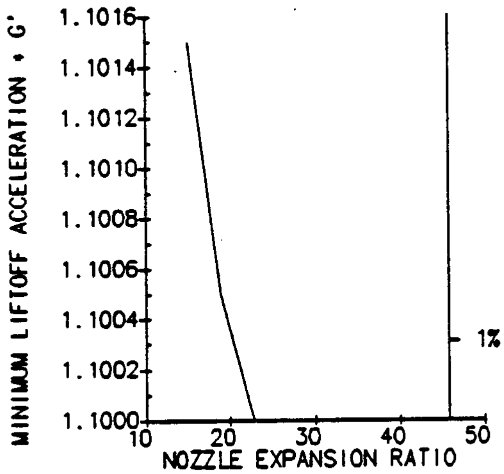


(h-91) Staging Velocity Versus Nozzle Expansion Ratio

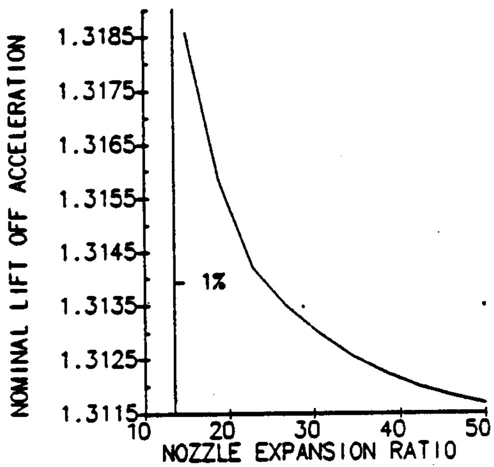


(h-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

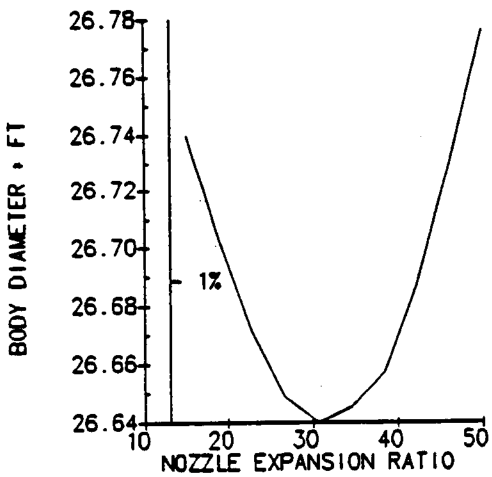
Configuration 2.H Sensitivity Studies (Continued)



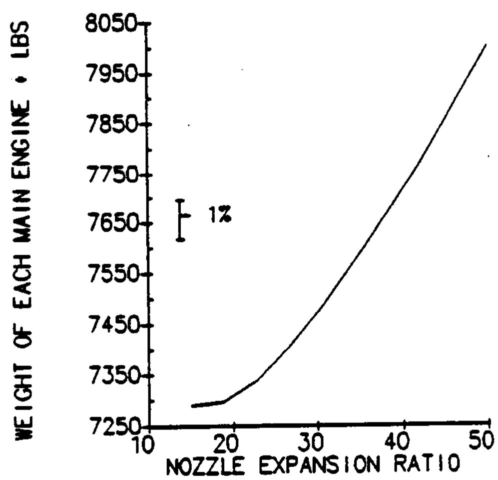
(h-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(h-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

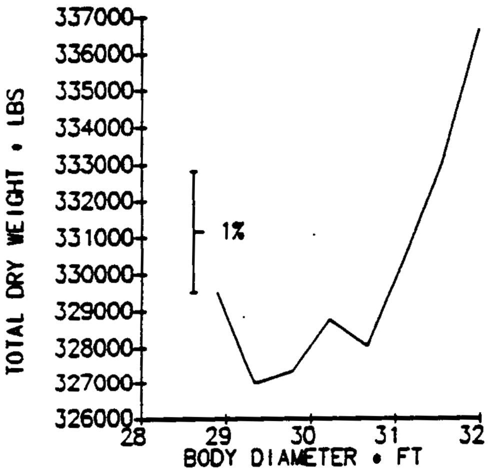


(h-95) Body Diameter Versus Nozzle Expansion Ratio

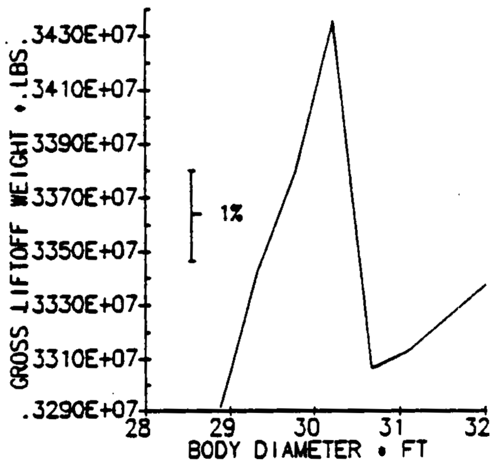


(h-96) Booster Engine Weight Versus Nozzle Expansion Ratio

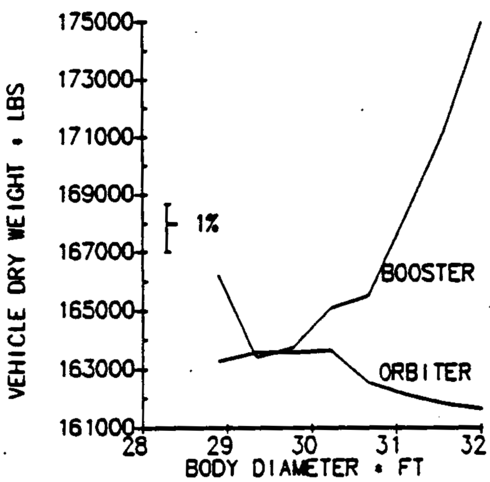
Configuration 2.H Sensitivity Studies (Continued)



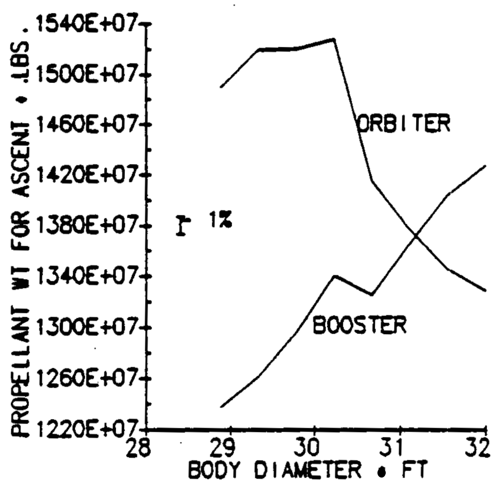
(i-1) **Total Dry Weight Versus Body Diameter**



(i-2) **Gross Lift Off Weight Versus Body Diameter**

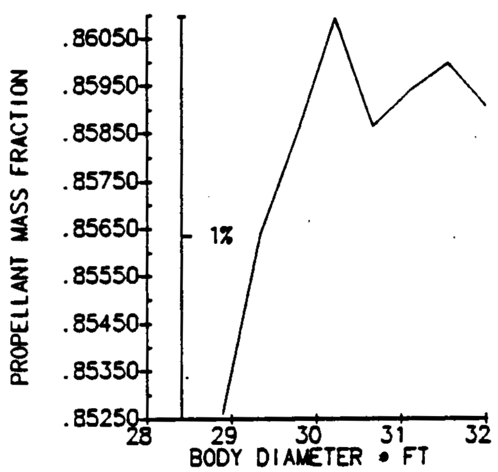


(i-3) **Vehicle Dry Weight Versus Body Diameter**

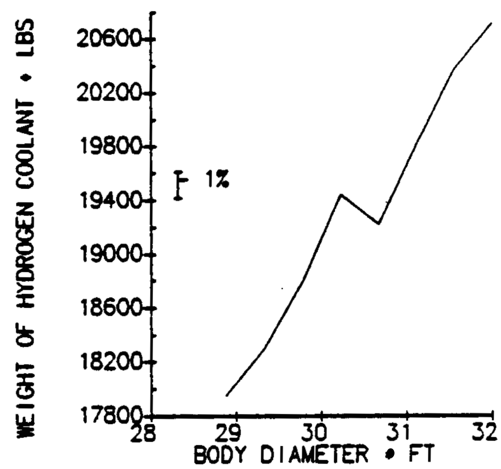


(i-4) **Propellant Consumed Versus Body Diameter**

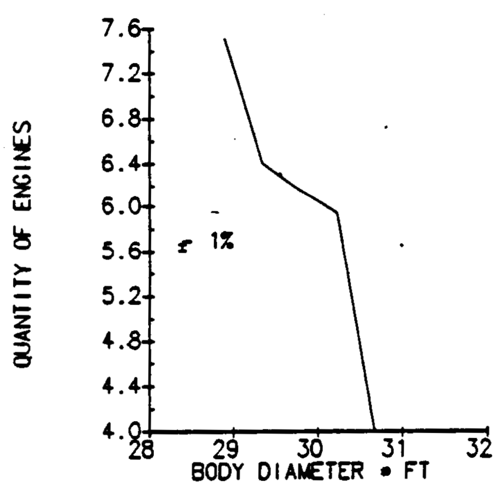
Configuration 2.1 Sensitivity Studies



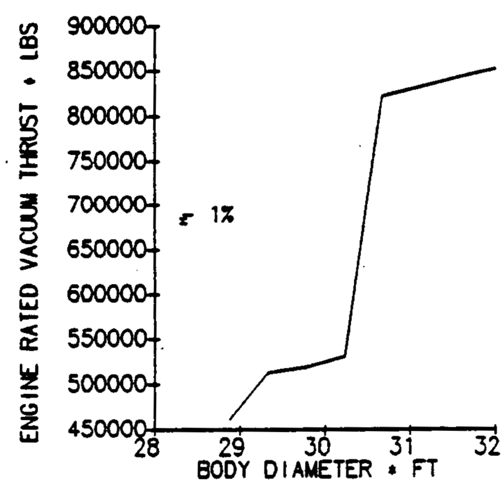
(i-5) **Propellant Mass Fraction Versus Body Diameter**



(i-6) **Weight of Hydrogen Coolant Versus Body Diameter**

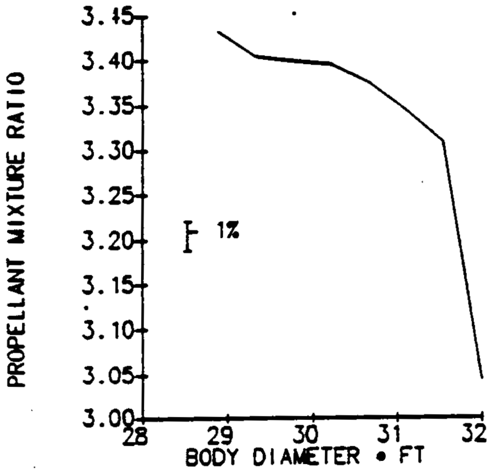


(i-7) **Number of Booster Engines Versus Body Diameter**

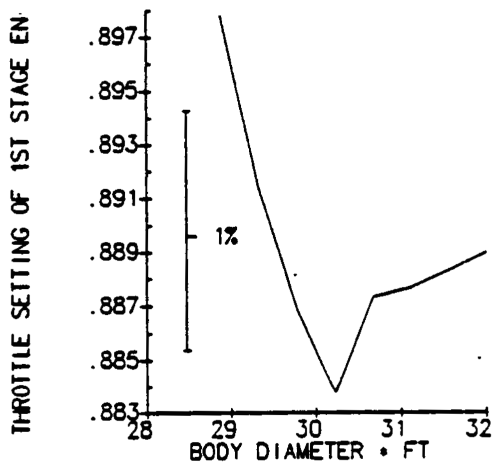


(i-8) **Engine Rated Vacuum Thrust Versus Body Diameter**

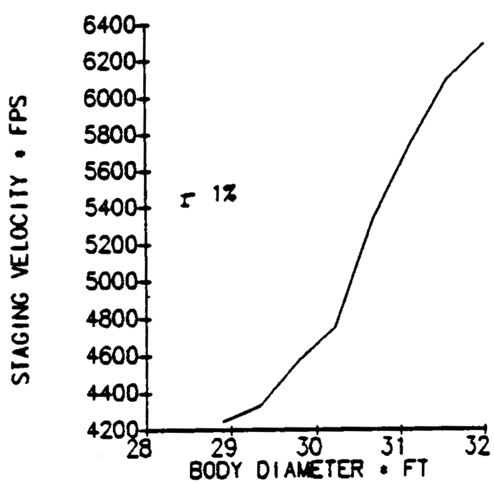
Configuration 2.1 Sensitivity Studies (Continued)



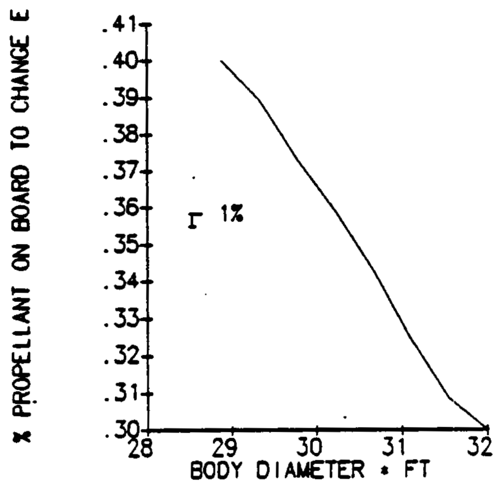
(i-9) **Propellant Mixture Ratio Versus Body Diameter**



(i-10) **Initial Booster Throttle Setting Versus Body Diameter**

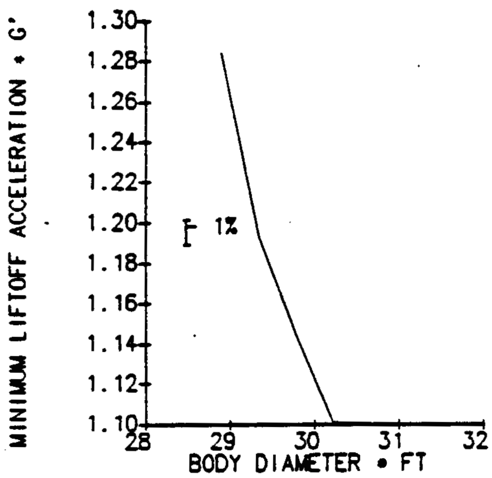


(i-11) **Staging Velocity Versus Body Diameter**

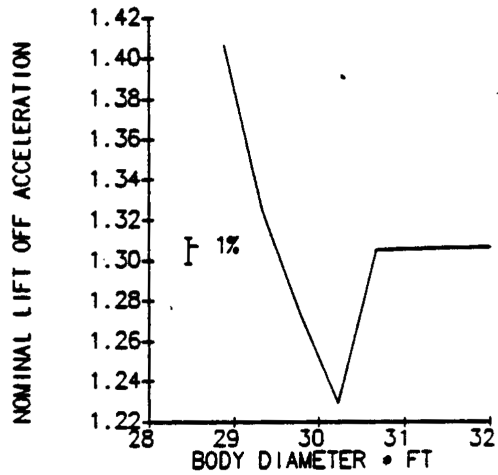


(i-12) **Orbiter Propellant at Staging Versus Body Diameter**

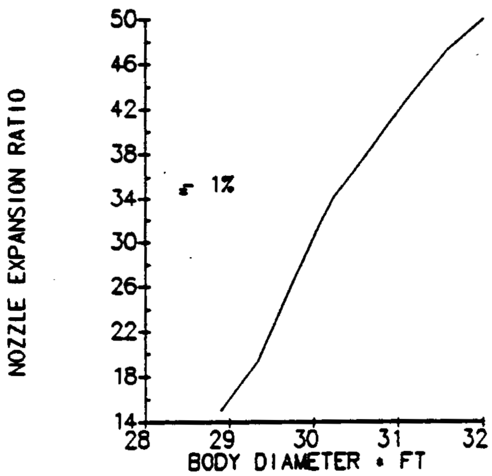
Configuration 2.1 Sensitivity Studies (Continued)



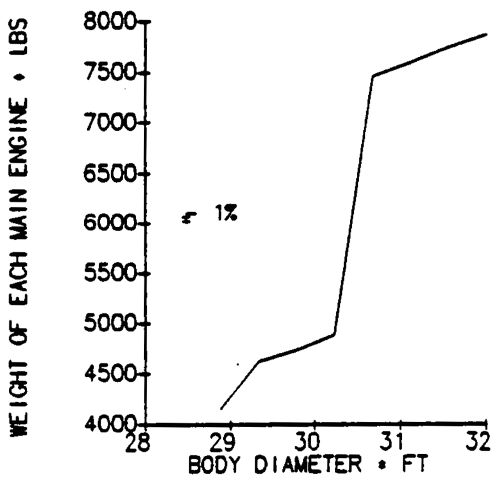
(i-13) **Engine-out Lift Off Acceleration Versus Body Diameter**



(i-14) **Nominal Lift Off Acceleration Versus Body Diameter**

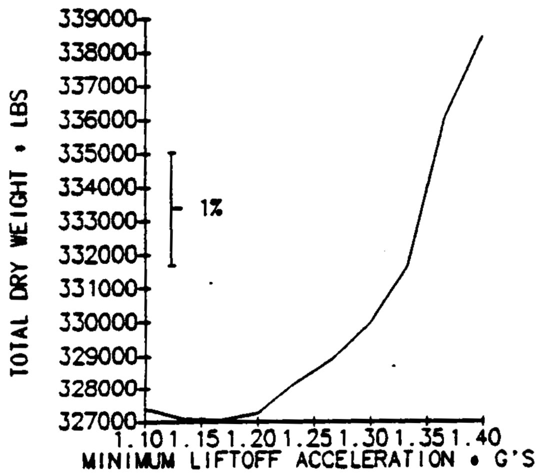


(i-15) **Nozzle Expansion Ratio Versus Body Diameter**

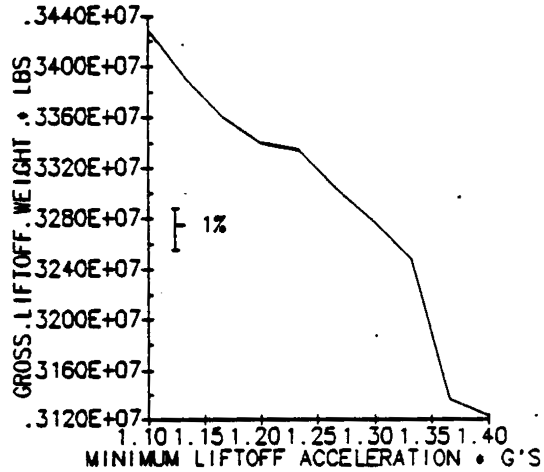


(i-16) **Booster Engine Weight Versus Body Diameter**

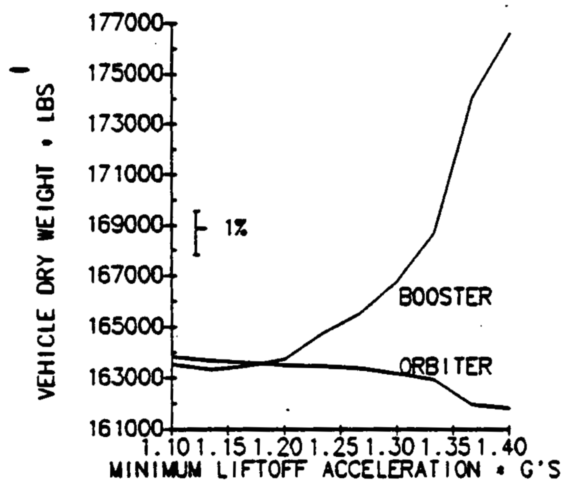
Configuration 2.1 Sensitivity Studies (Continued)



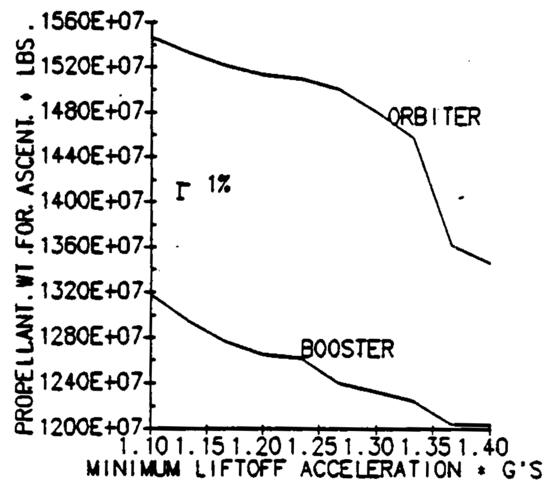
(I-17) **Total Dry Weight Versus Engine-out Lift Off Acceleration**



(I-18) **Gross Lift Off Weight Versus Engine-out Lift Off Acceleration**

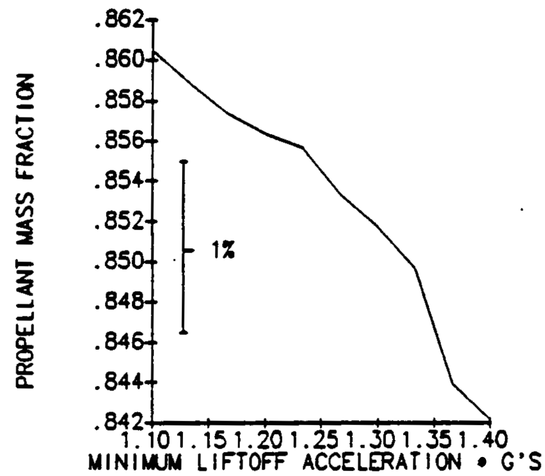


(I-19) **Vehicle Dry Weight Versus Engine-out Lift Off Acceleration**

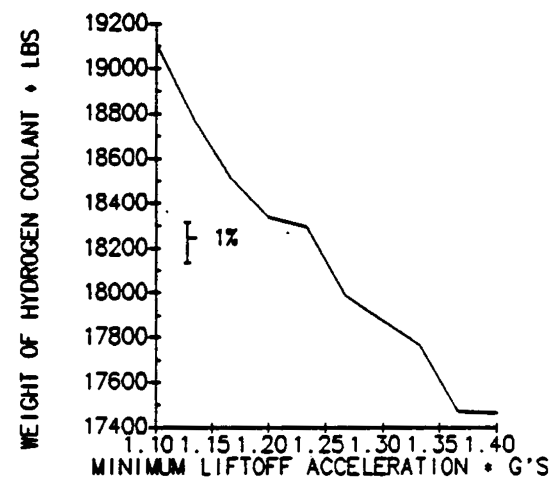


(I-20) **Propellant Consumed Versus Engine-out Lift Off Acceleration**

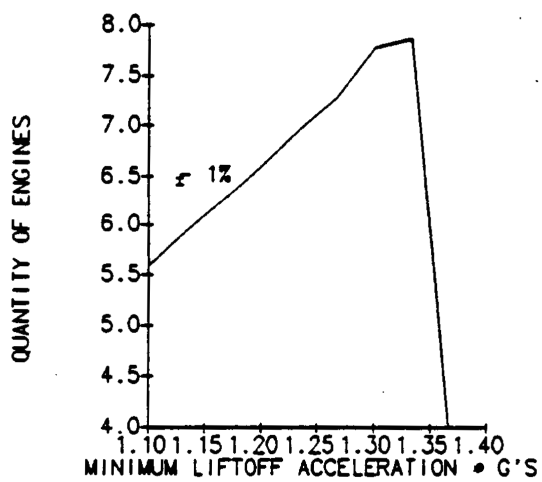
Configuration 2.1 Sensitivity Studies (Continued)



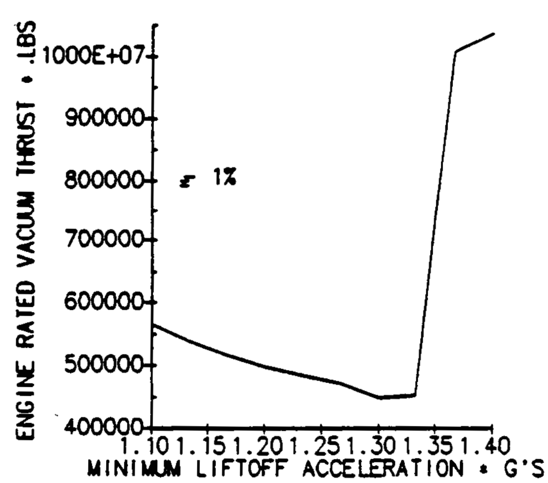
(i-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(i-22) Weight of Hydrogen Coolant Versus Engine-out Lift Off Acceleration

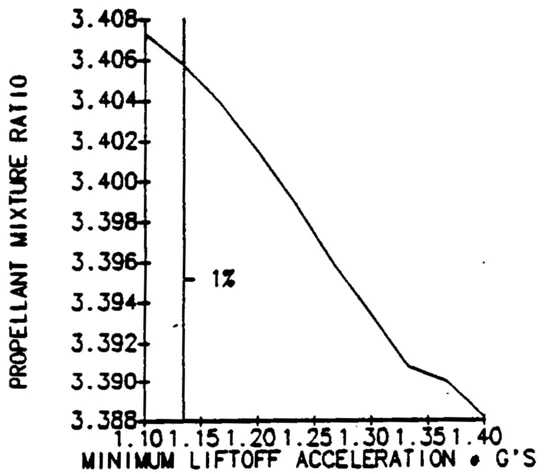


(i-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

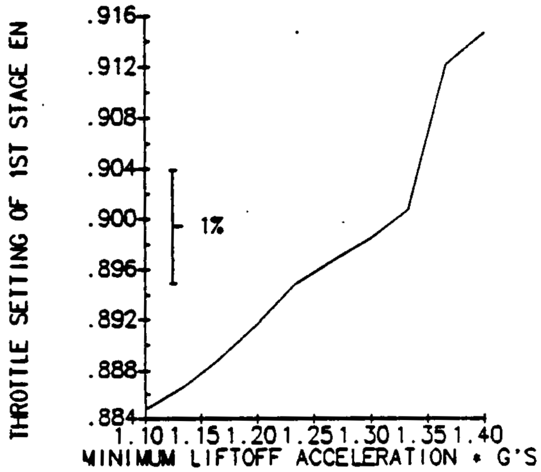


(i-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

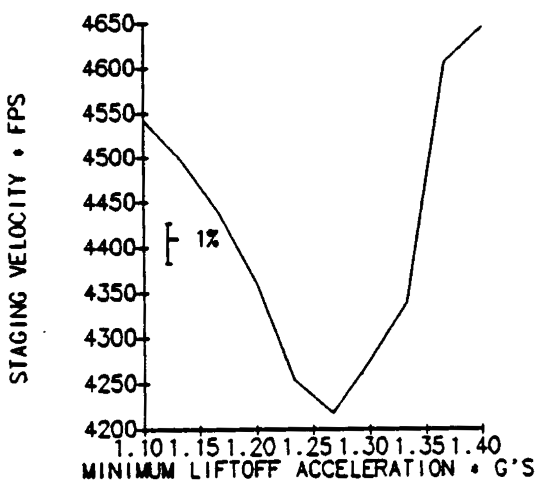
Configuration 2.1 Sensitivity Studies (Continued)



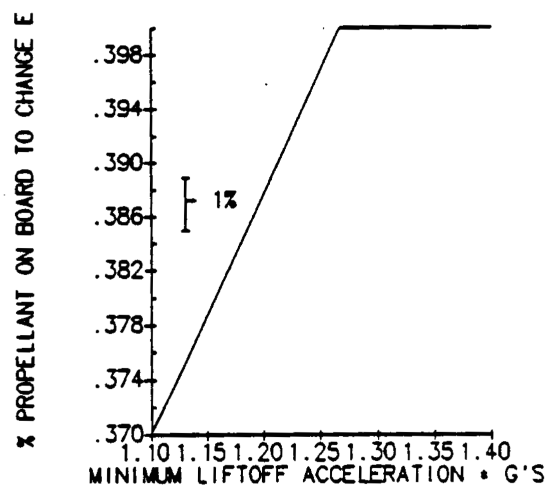
(i-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(i-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

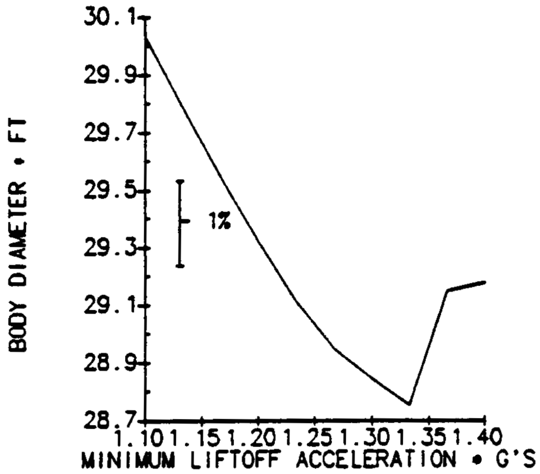


(i-27) Staging Velocity Versus Engine-out Lift Off Acceleration

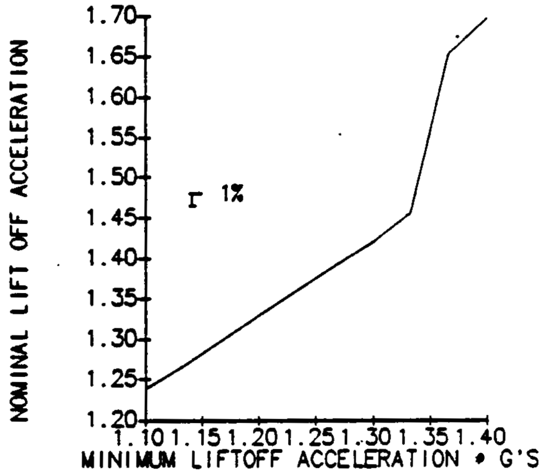


(i-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

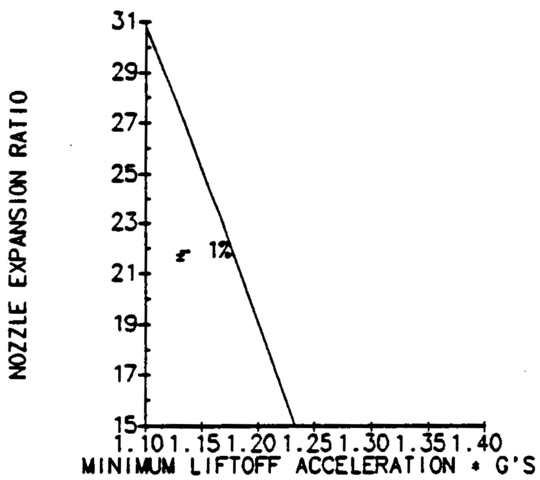
Configuration 2.1 Sensitivity Studies (Continued)



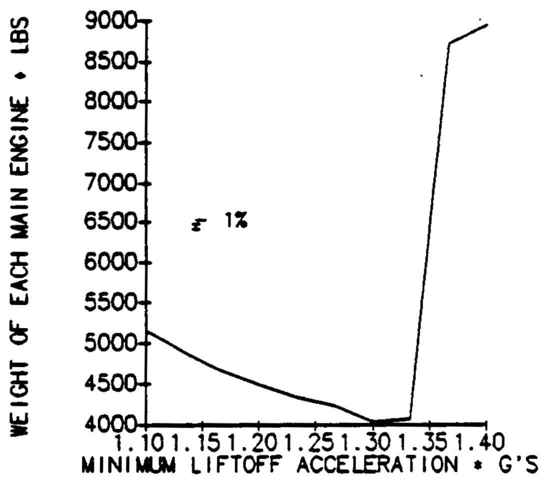
(i-29) **Body Diameter Versus Engine-out Lift Off Acceleration**



(i-30) **Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration**



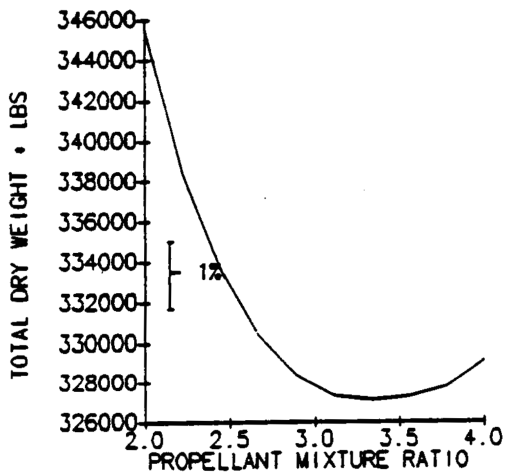
(i-31) **Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration**



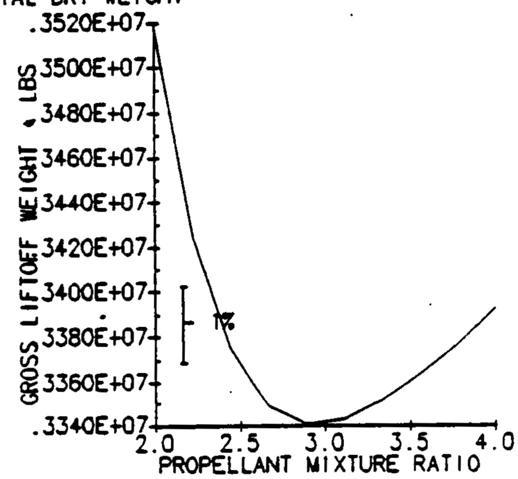
(i-32) **Booster Engine Weight Versus Engine-out Lift Off Acceleration**

Configuration 2.1 Sensitivity Studies (Continued)

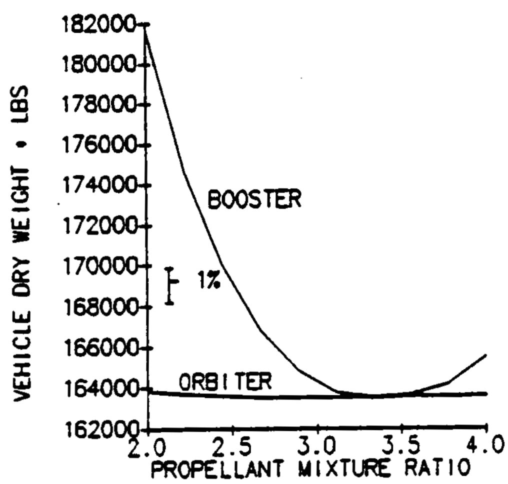
BPVIS TWO STAGE LOX/NBP PROPANE, HYDROGEN COOLED
BOOSTER LENGTH/DIAMETER = 4.535
MIMIMUM TOTAL DRY WEIGHT



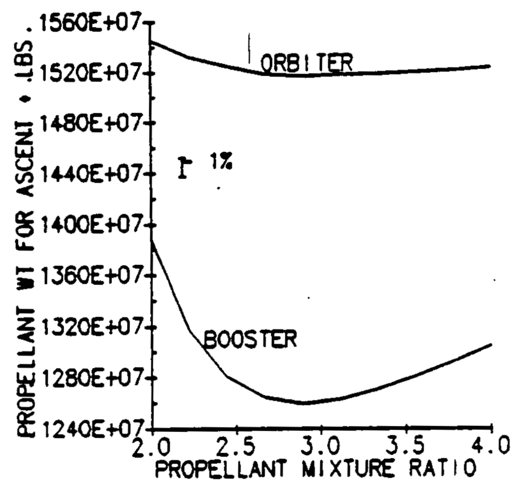
(i-33) Total Dry Weight Versus Propellant Mixture Ratio



(i-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

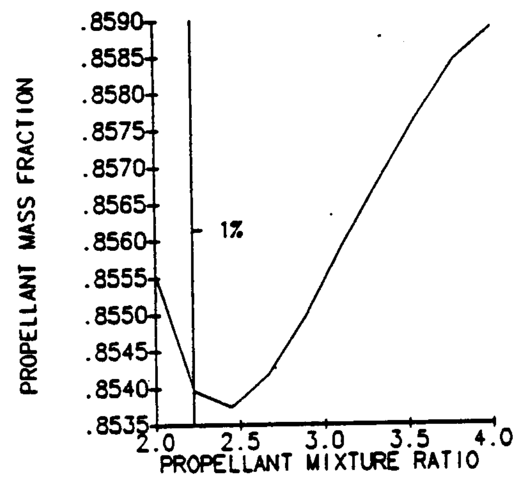


(i-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

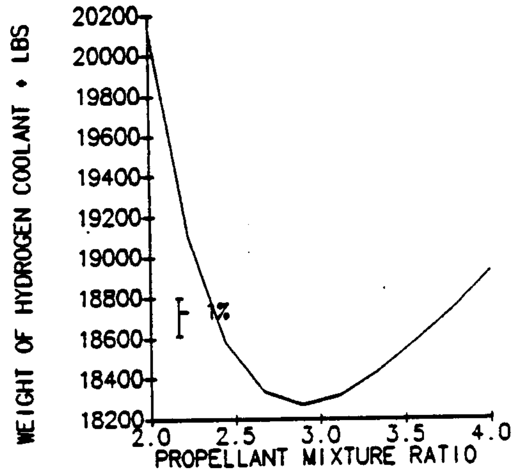


(i-36) Propellant Consumed Versus Propellant Mixture Ratio

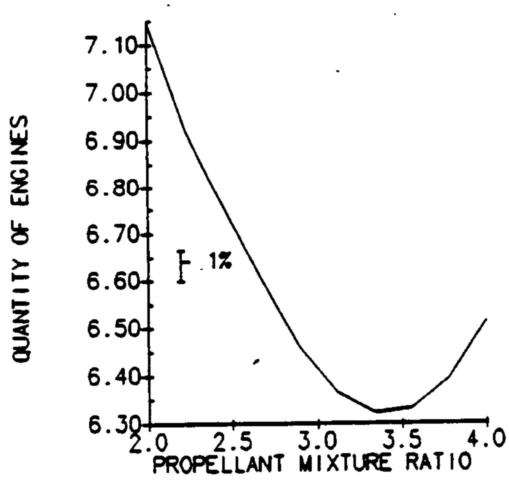
Configuration 2.I Sensitivity Studies (Continued)



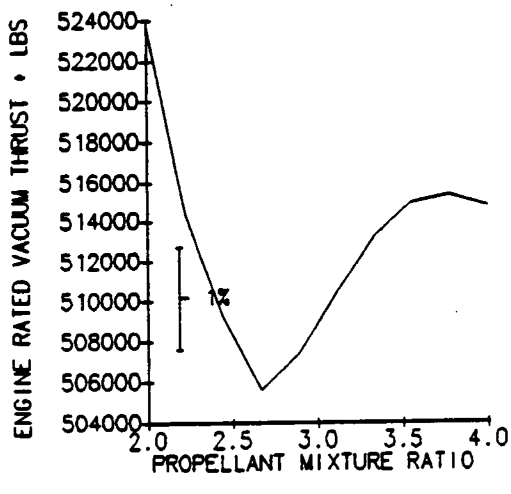
(i-37) **Propellant Mass Fraction Versus Propellant Mixture Ratio**



(i-38) **Weight of Hydrogen Coolant Versus Propellant Mixture Ratio**

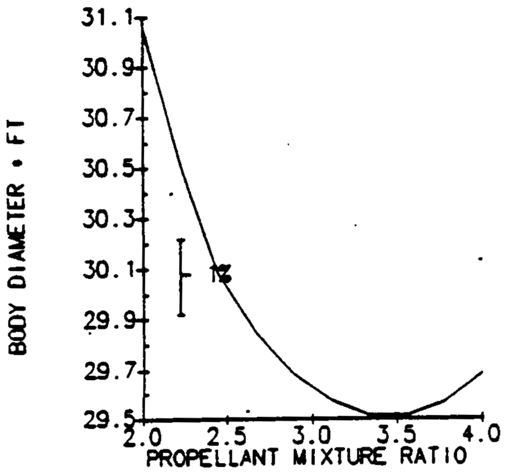


(i-39) **Number of Booster Engines Versus Propellant Mixture Ratio**

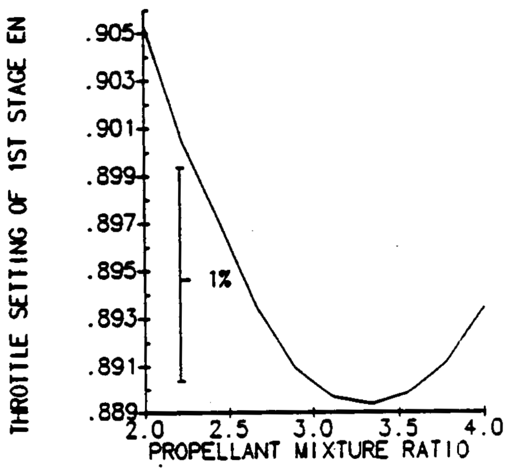


(i-40) **Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio**

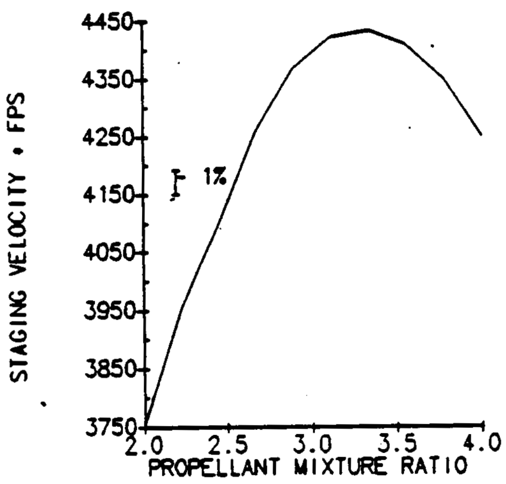
Configuration 2.1 Sensitivity Studies (Continued)



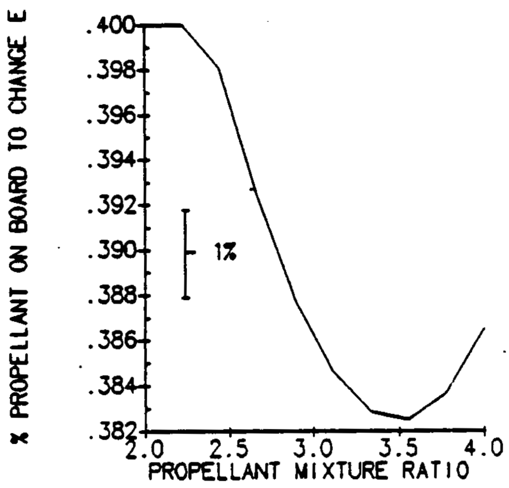
(i-41) Body Diameter Versus Propellant Mixture Ratio



(i-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

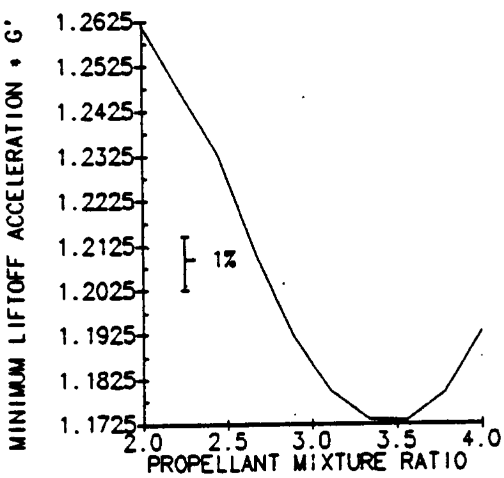


(i-43) Staging Velocity Versus Propellant Mixture Ratio

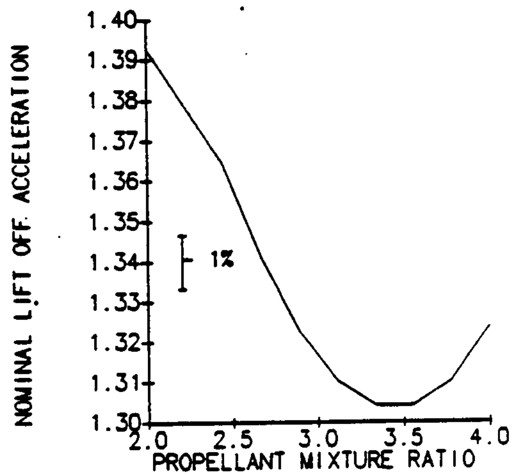


(i-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

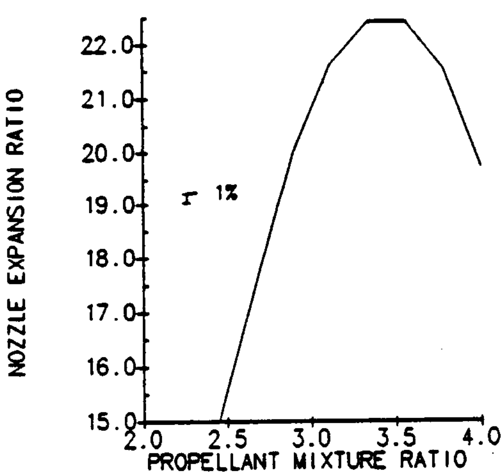
Configuration 2.1 Sensitivity Studies (Continued)



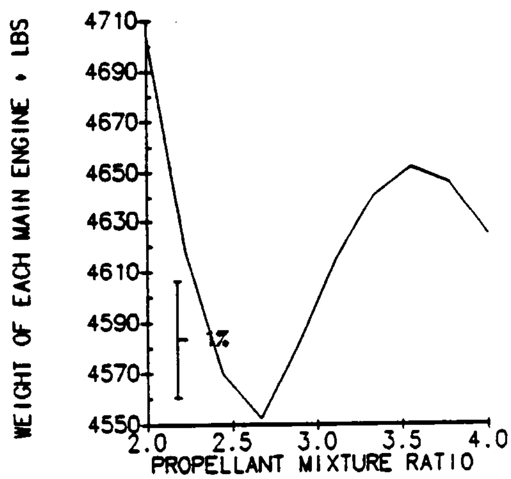
(i-45) **Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio**



(i-46) **Nominal Lift Off Acceleration Versus Propellant Mixture Ratio**

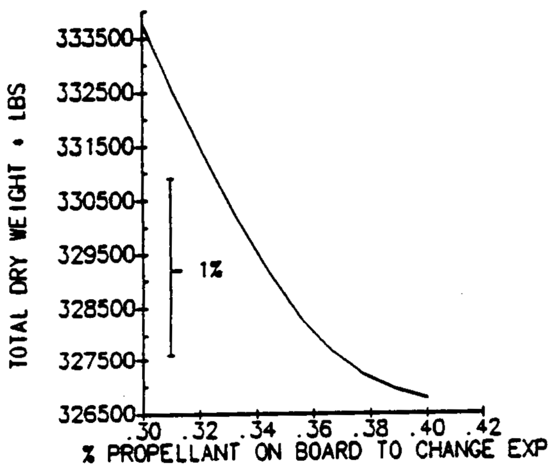


(i-47) **Nozzle Expansion Ratio Versus Propellant Mixture Ratio**

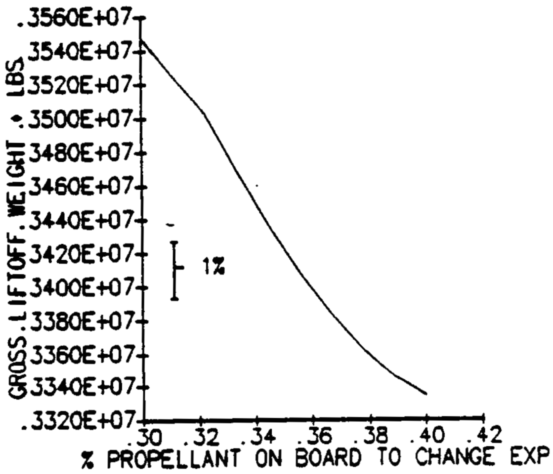


(i-48) **Booster Engine Weight Versus Propellant Mixture Ratio**

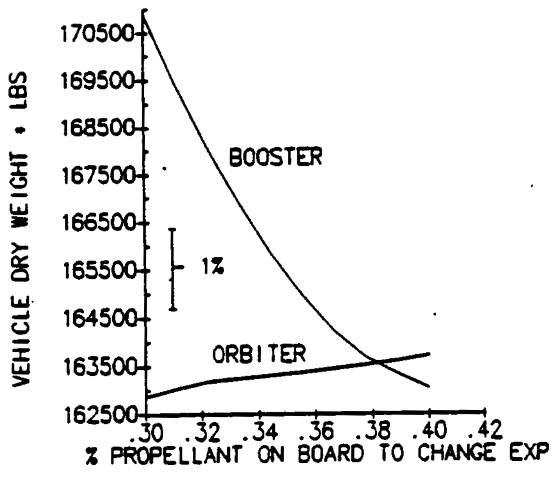
Configuration 2.1 Sensitivity Studies (Continued)



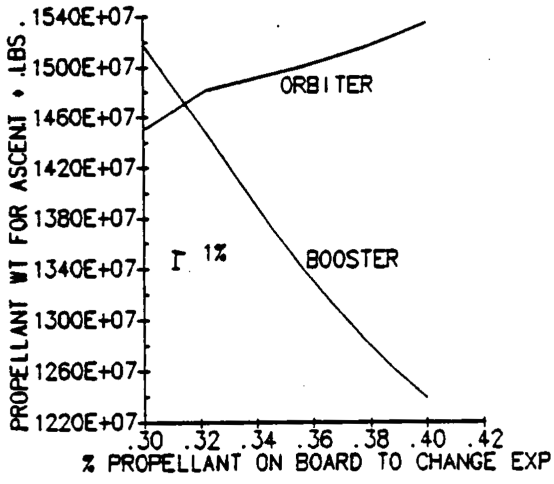
(i-49) Total Dry Weight Versus Orbiter Propellant at Staging



(i-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

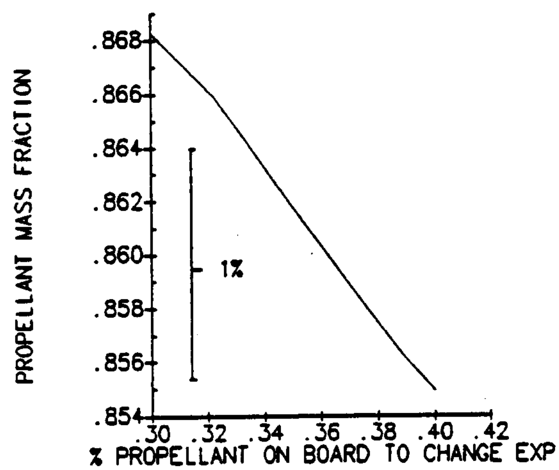


(i-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

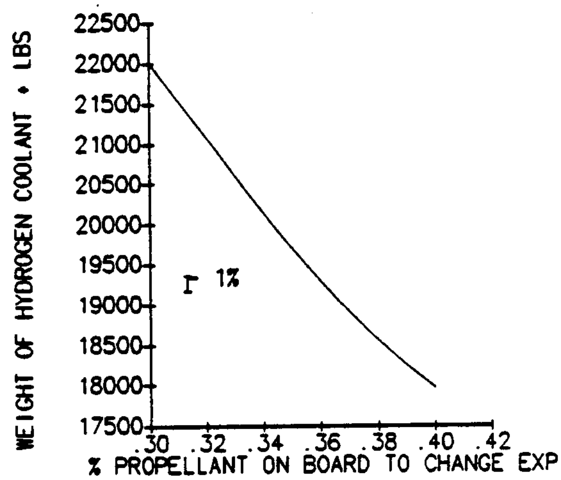


(i-52) Propellant Consumed Versus Orbiter Propellant at Staging

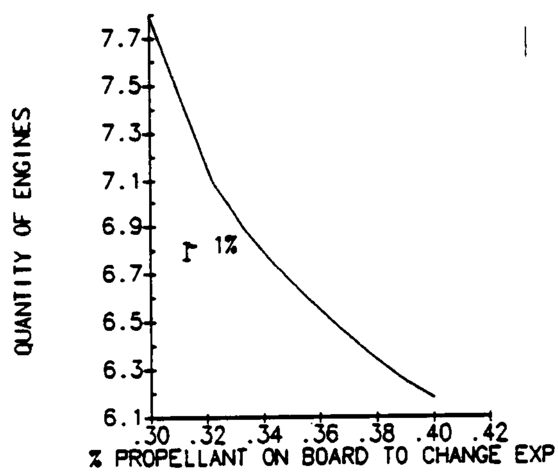
Configuration 2.1 Sensitivity Studies (Continued)



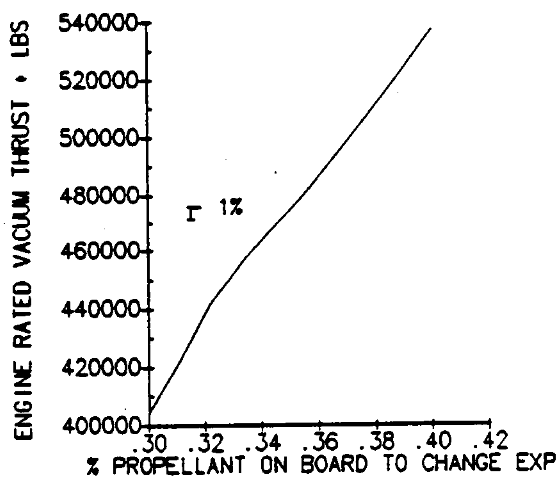
(i-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(i-54) Weight of Hydrogen Coolant Versus Orbiter Propellant at Staging

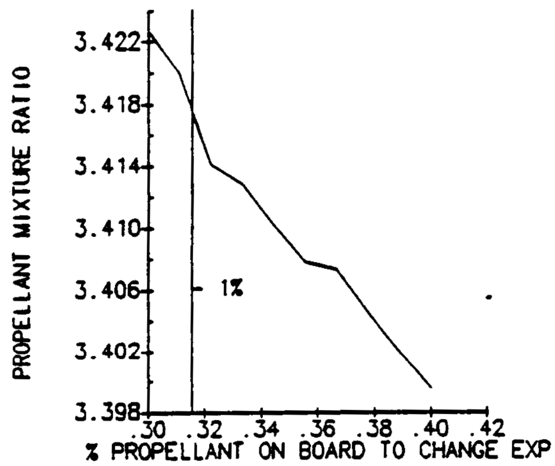


(i-55) Number of Booster Engines Versus Orbiter Propellant at Staging

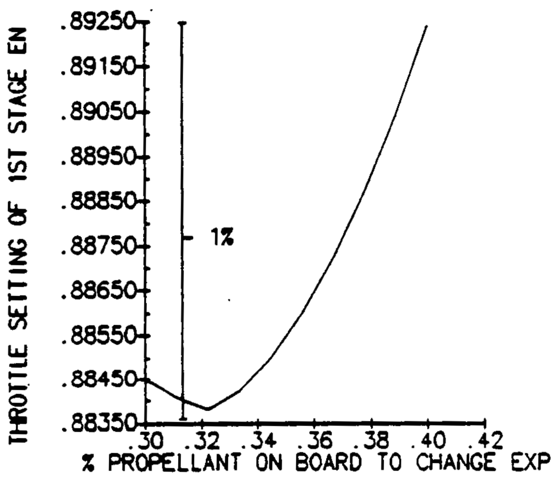


(i-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

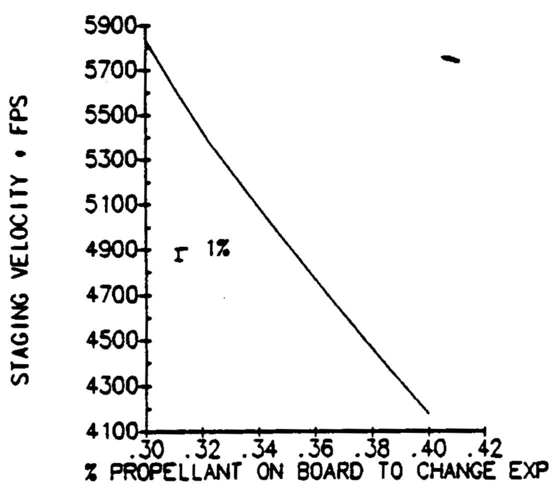
Configuration 2.1 Sensitivity Studies (Continued)



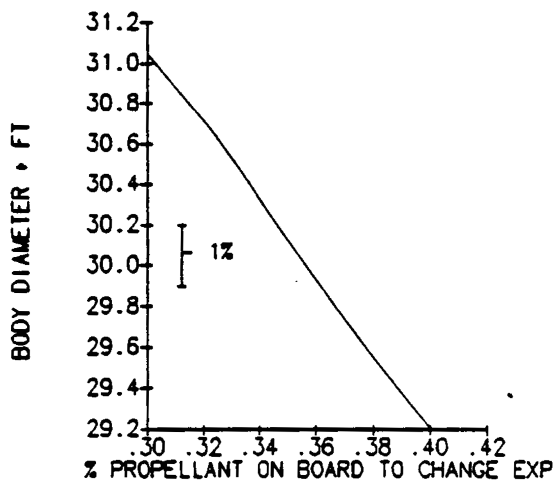
(i-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(i-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

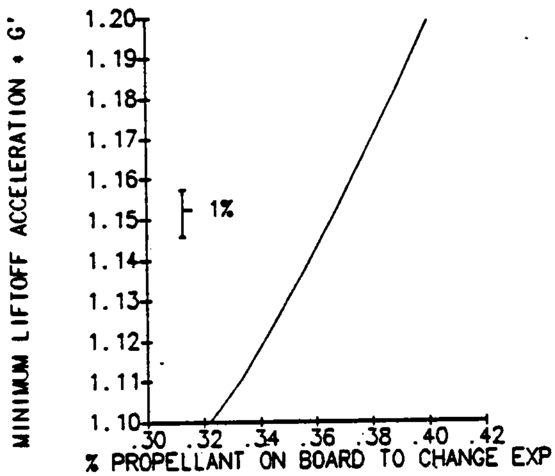


(i-59) Staging Velocity Versus Orbiter Propellant at Staging

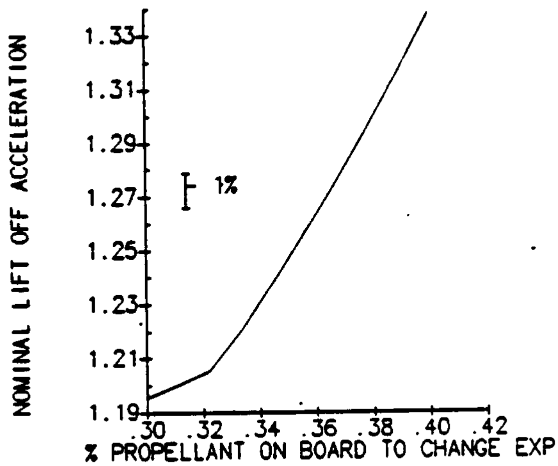


(i-60) Body Diameter Versus Orbiter Propellant at Staging

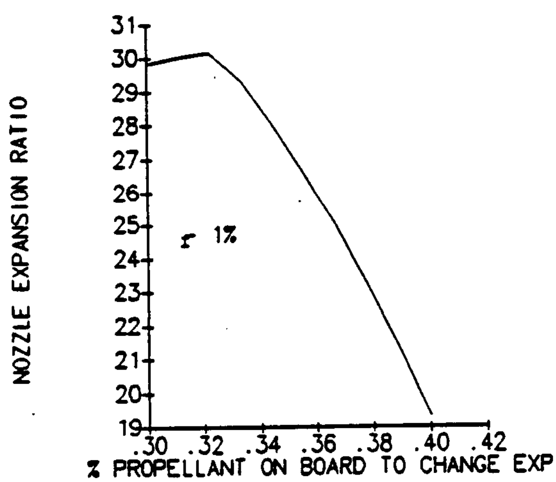
Configuration 3.1 Sensitivity Studies (Continued)



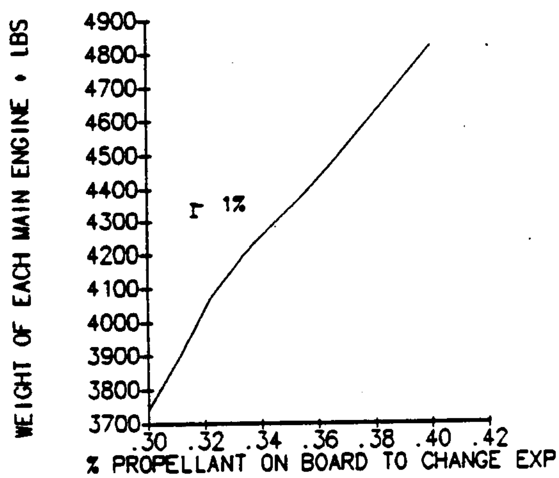
(i-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(i-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

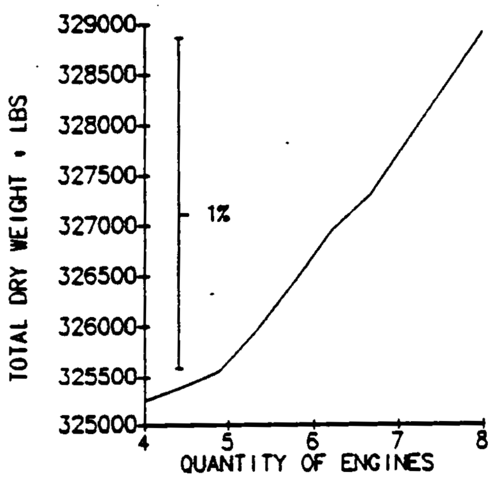


(i-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

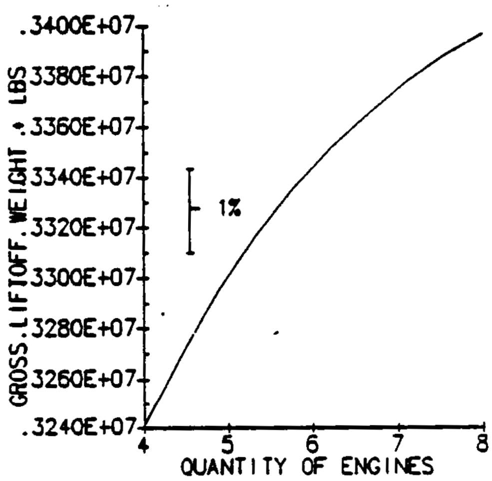


(i-64) Booster Engine Weight Versus Orbiter Propellant at Staging

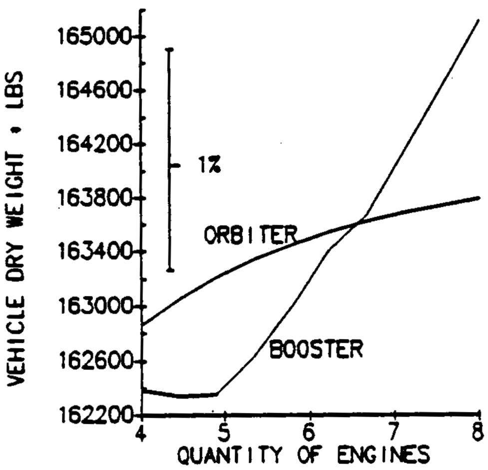
Configuration 2.1 Sensitivity Studies (Continued)



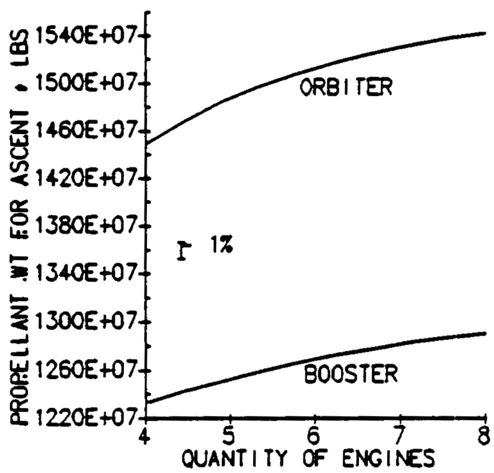
(i-65) Total Dry Weight Versus Number of Booster Engines



(i-66) Gross Lift Off Weight Versus Number of Booster Engines

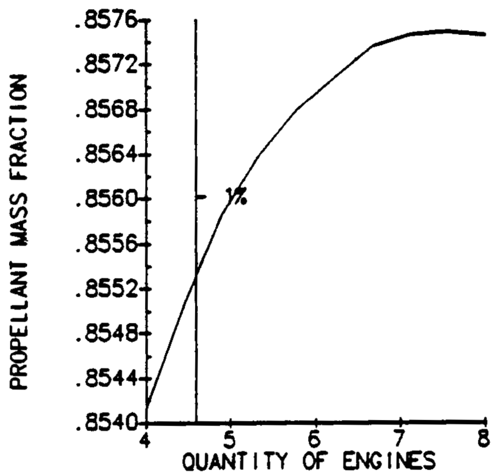


(i-67) Vehicle Dry Weight Versus Number of Booster Engines

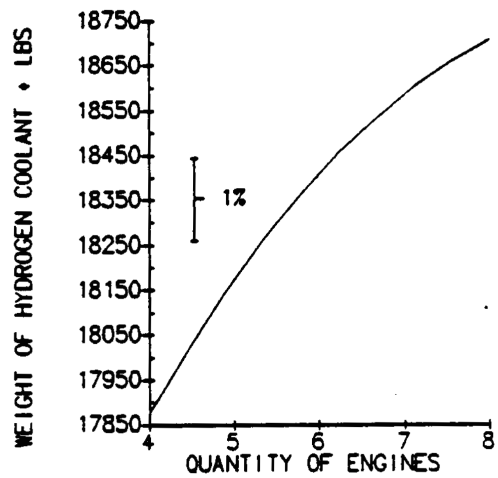


(i-68) Propellant Consumed Versus Number of Booster Engines

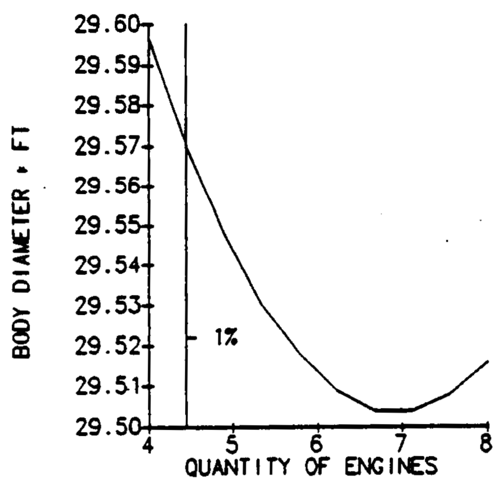
Configuration 2.1 Sensitivity Studies (Continued)



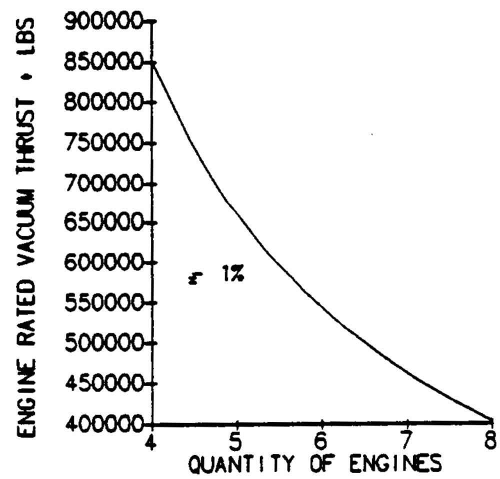
(i-69) Propellant Mass Fraction Versus Number of Booster Engines



(i-70) Weight of Hydrogen Coolant Versus Number of Booster Engines

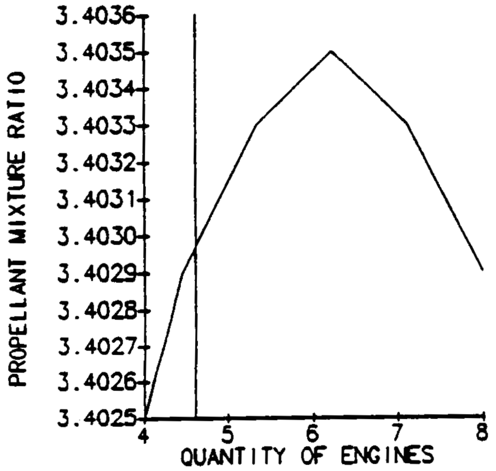


(i-71) Body Diameter Versus Number of Booster Engines

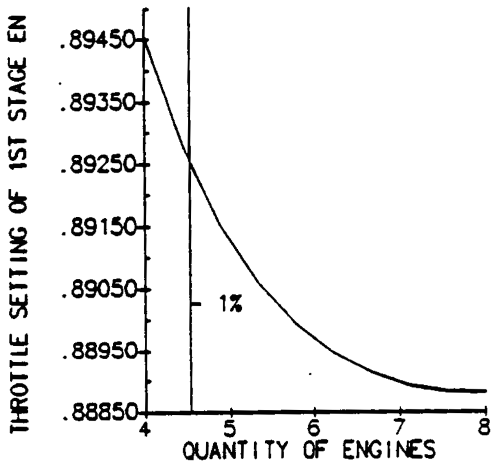


(i-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

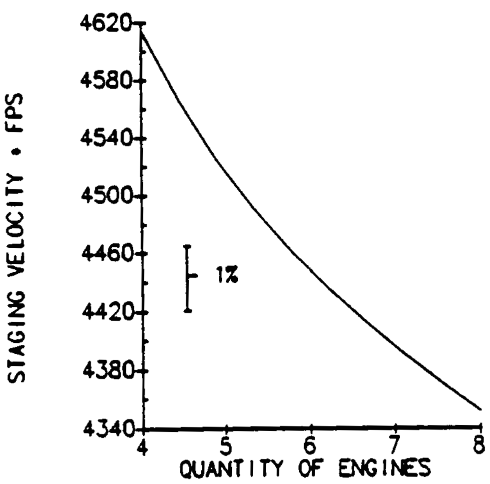
Configuration 2.1 Sensitivity Studies (Continued)



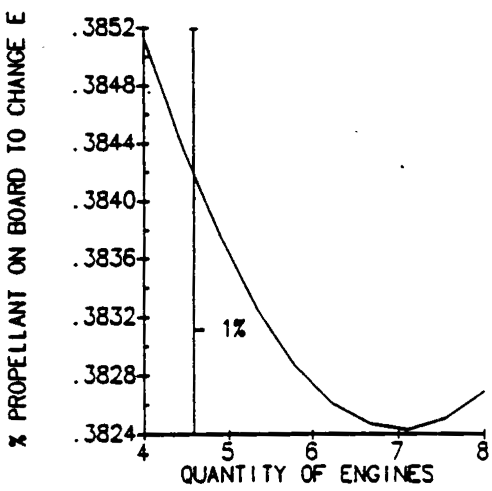
(I-73) **Propellant Mixture Ratio Versus Number of Booster Engines**



(I-74) **Initial Booster Throttle Setting Versus Number of Booster Engines**

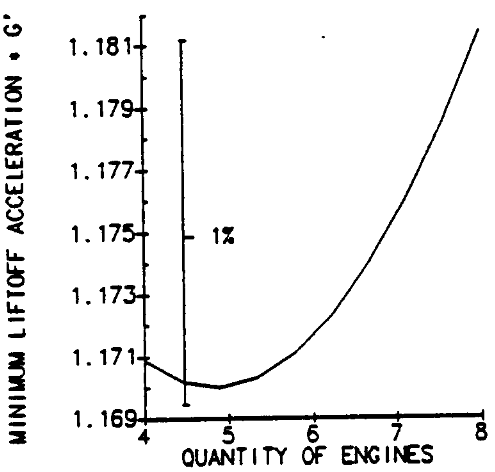


(I-75) **Staging Velocity Versus Number of Booster Engines**

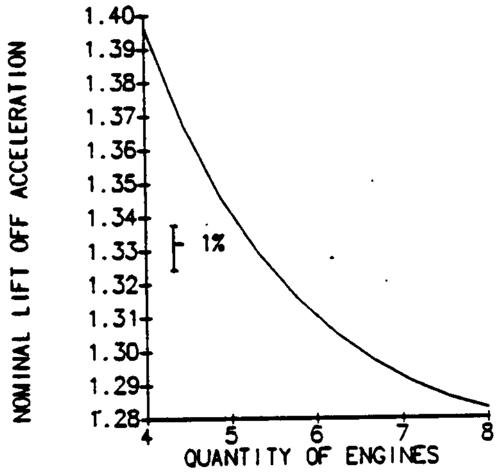


(I-76) **Orbiter Propellant at Staging Versus Number of Booster Engines**

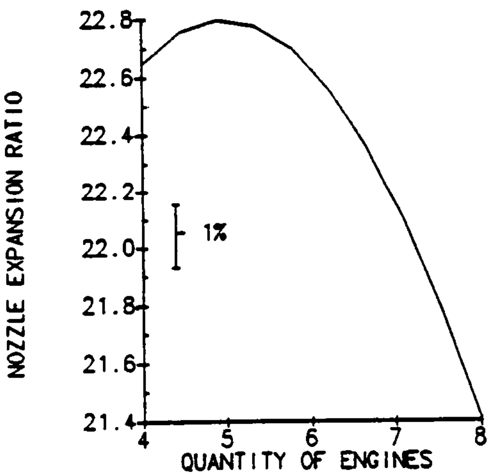
Configuration 2.1 Sensitivity Studies (Continued)



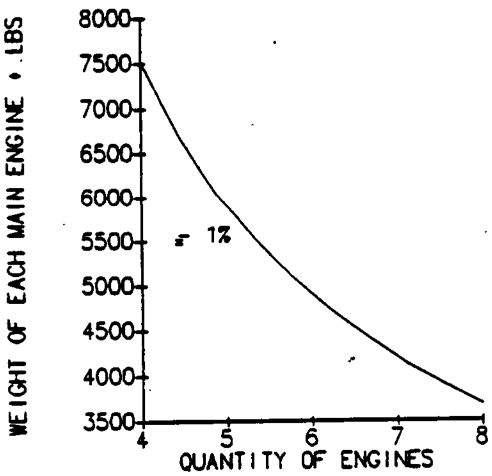
(I-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(I-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

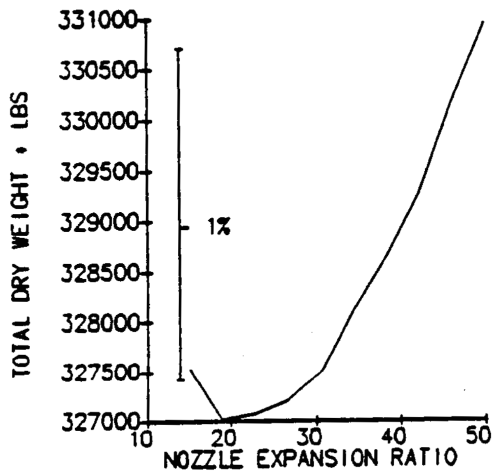


(I-79) Nozzle Expansion Ratio Versus Number of Booster Engines

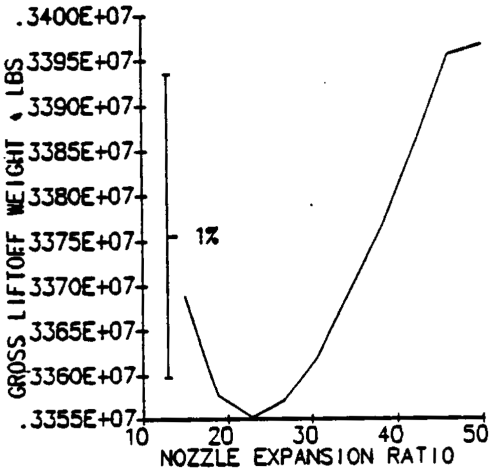


(I-80) Booster Engine Weight Versus Number of Booster Engines

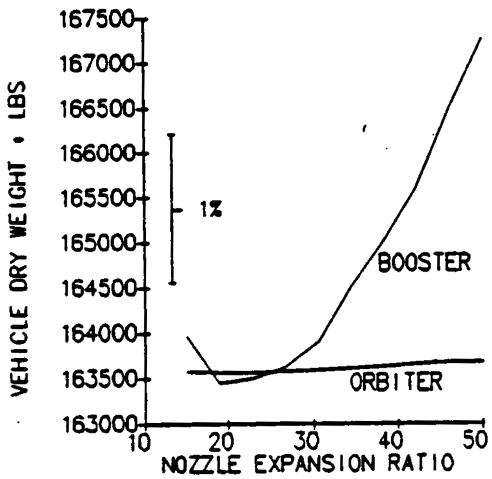
Configuration 2.1 Sensitivity Studies (Continued)



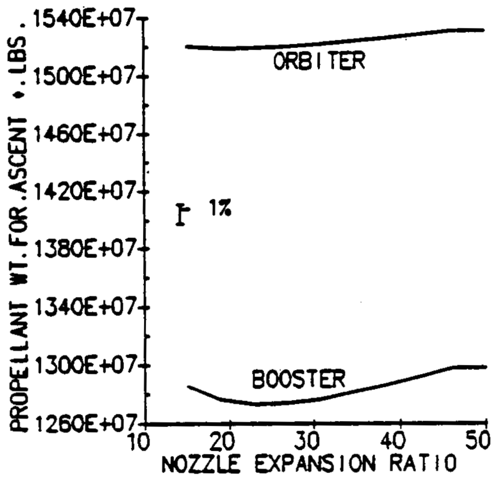
(I-81) Total Dry Weight Versus Nozzle Expansion Ratio



(I-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

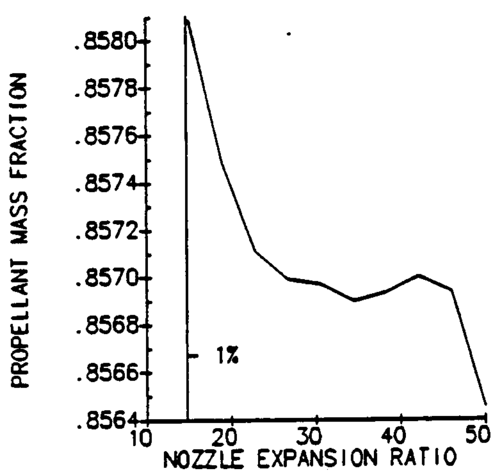


(I-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

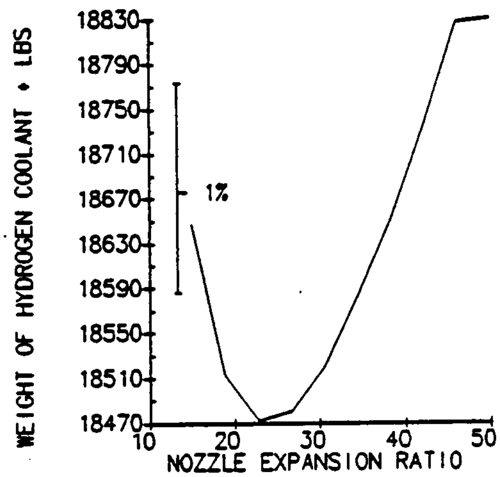


(I-84) Propellant Consumed Versus Nozzle Expansion Ratio

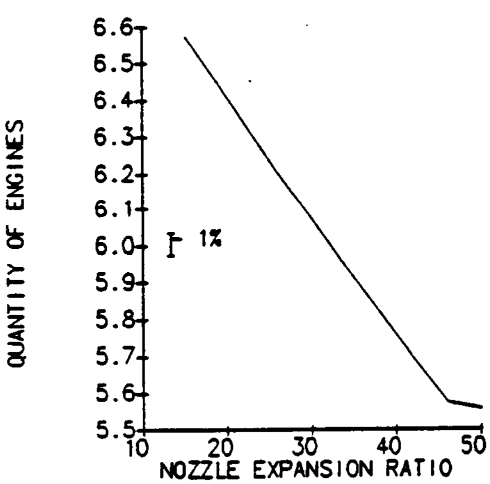
Configuration 2.1 Sensitivity Studies (Continued)



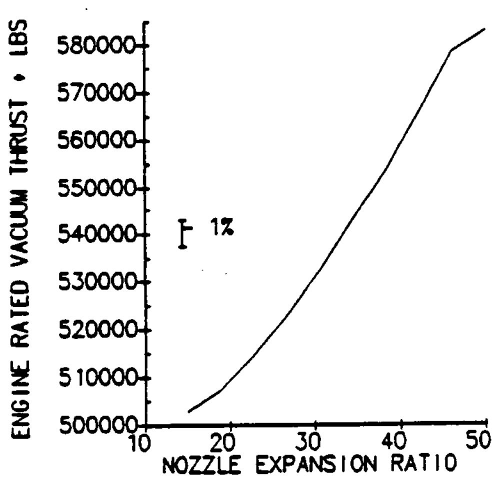
(i-85) **Propellant Mass Fraction Versus Nozzle Expansion Ratio**



(i-86) **Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio**

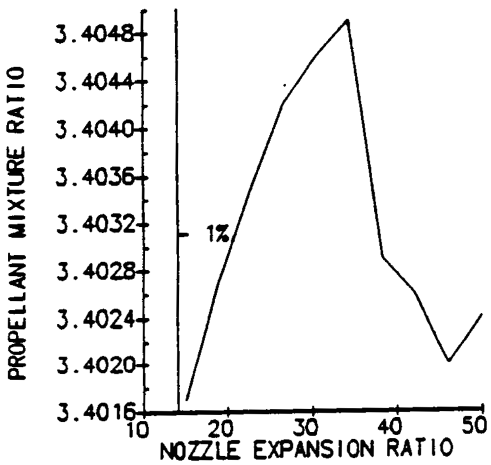


(i-87) **Number of Booster Engines Versus Nozzle Expansion Ratio**

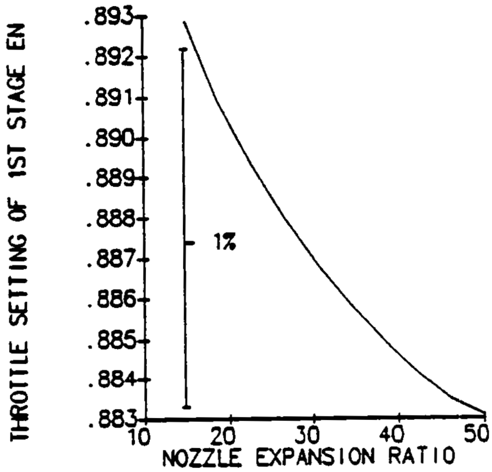


(i-88) **Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio**

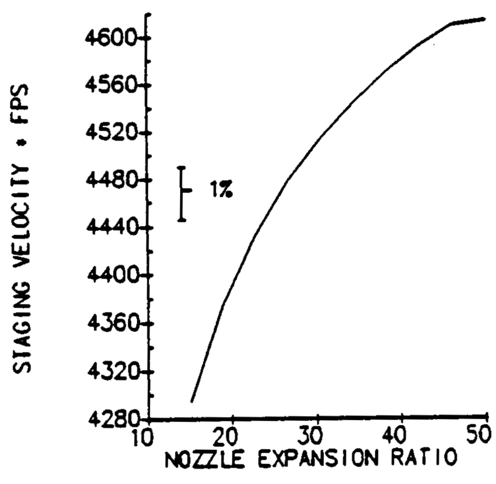
Configuration 2.1 Sensitivity Studies (Continued)



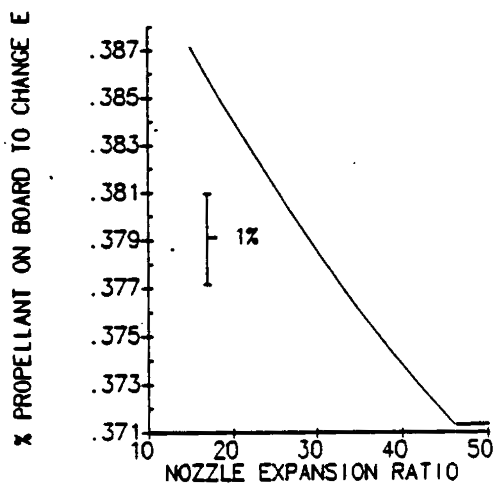
(i-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(i-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

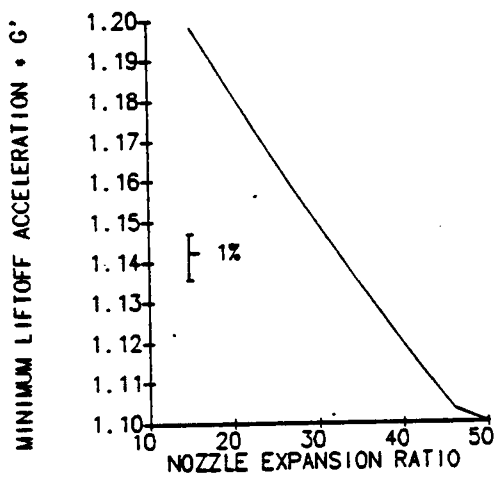


(i-91) Staging Velocity Versus Nozzle Expansion Ratio

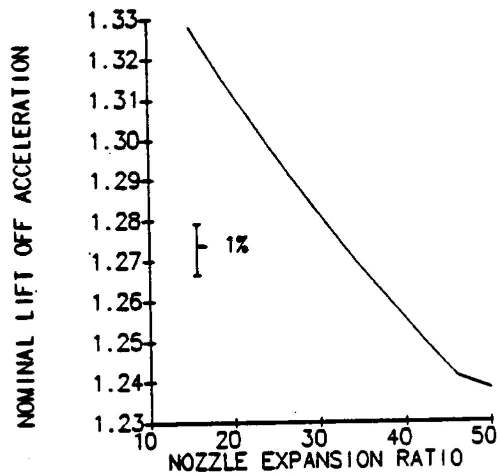


(i-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

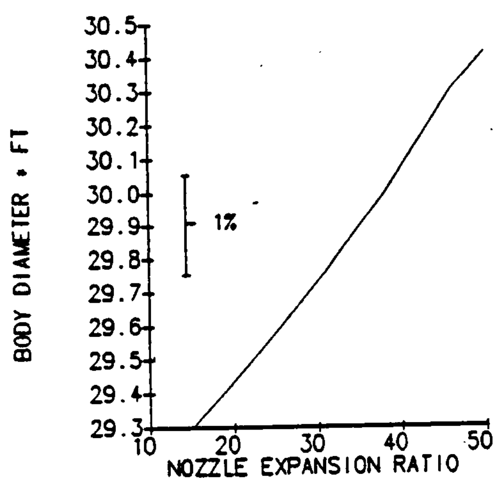
Configuration 2.1 Sensitivity Studies (Continued)



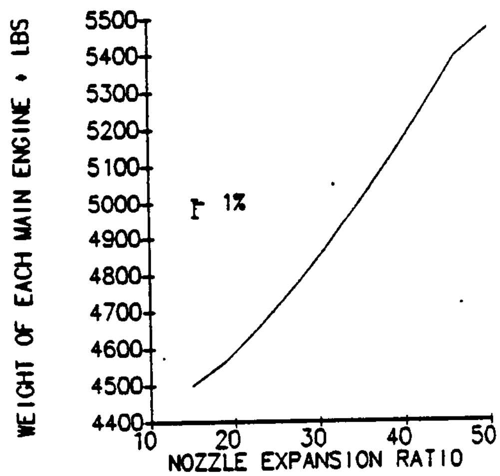
(i-93) **Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio**



(i-94) **Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio**

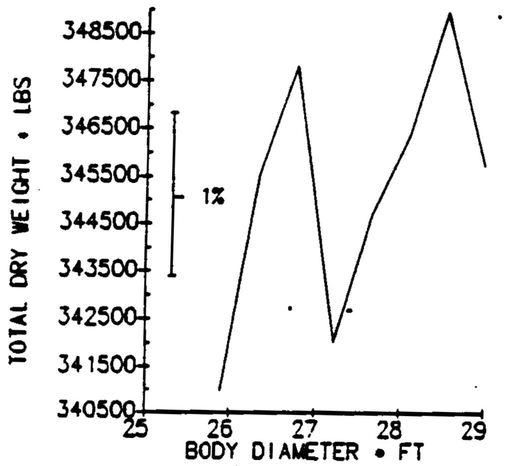


(i-95) **Body Diameter Versus Nozzle Expansion Ratio**

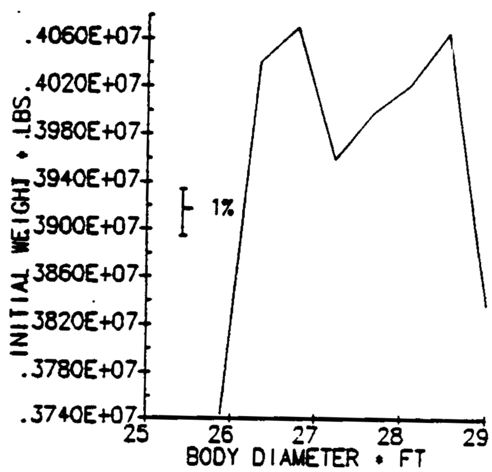


(i-96) **Booster Engine Weight Versus Nozzle Expansion Ratio**

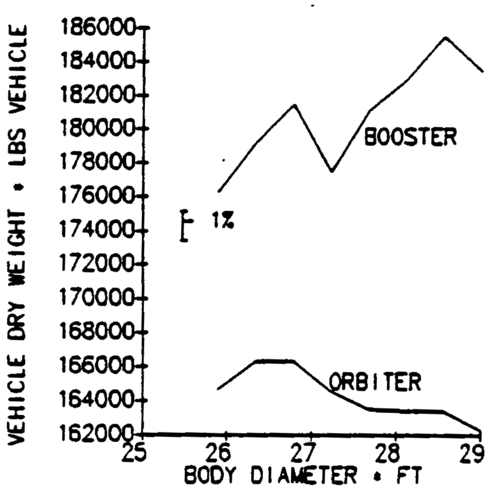
Configuration 2.1 Sensitivity Studies (Continued)



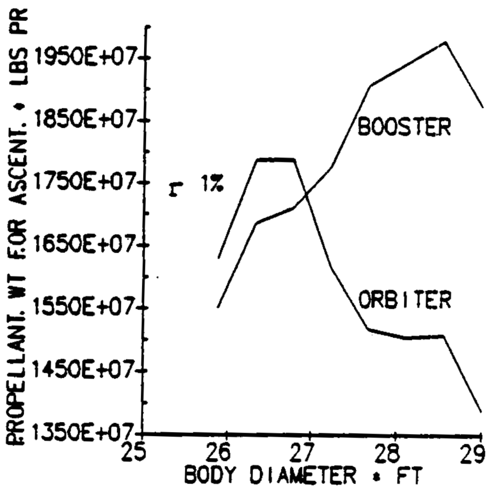
(J-1) Total Dry Weight Versus Body Diameter



(J-2) Gross Lift Off Weight Versus Body Diameter

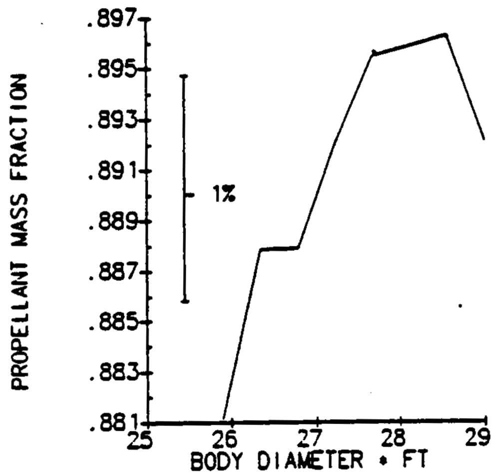


(J-3) Vehicle Dry Weight Versus Body Diameter

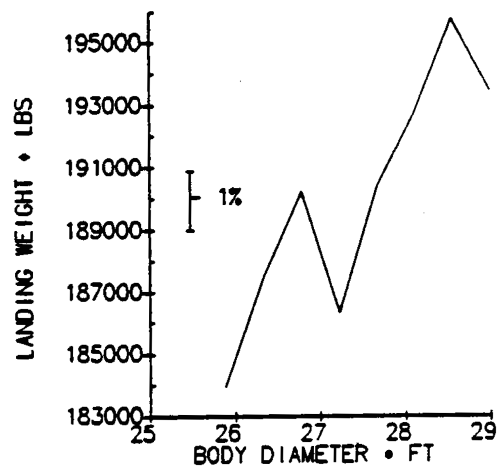


(J-4) Propellant Consumed Versus Body Diameter

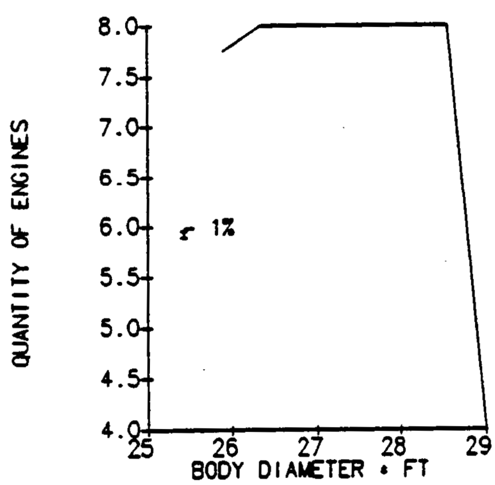
Configuration 2J Sensitivity Studies



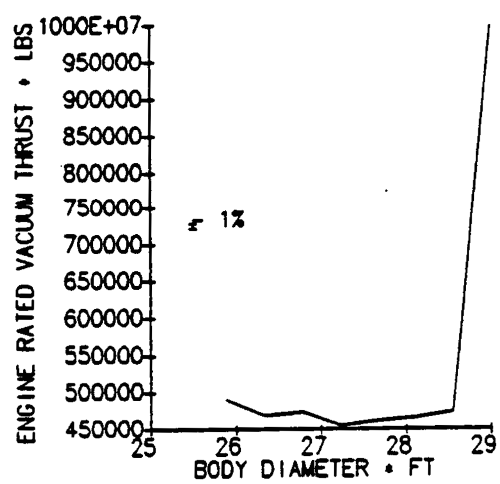
(J-5) **Propellant Mass Fraction Versus Body Diameter**



(J-6) **Landing Weight Versus Body Diameter**

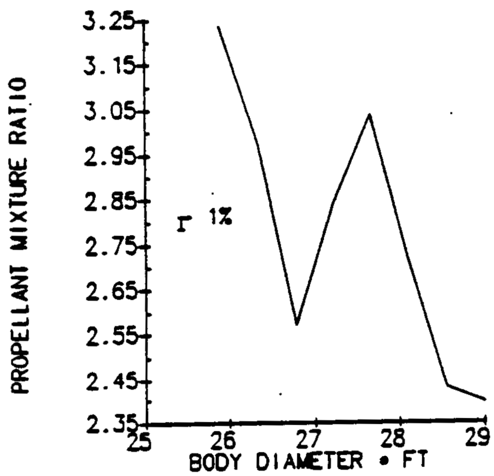


(J-7) **Number of Booster Engines Versus Body Diameter**

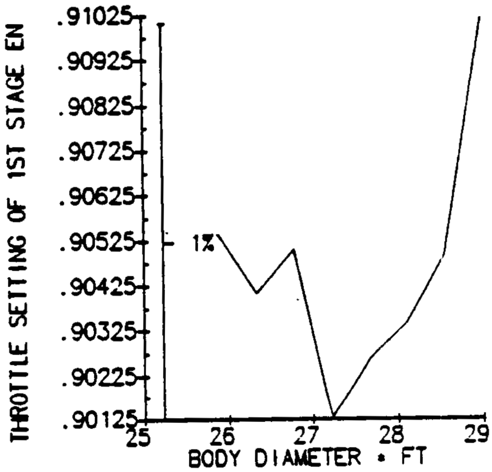


(J-8) **Engine Rated Vacuum Thrust Versus Body Diameter**

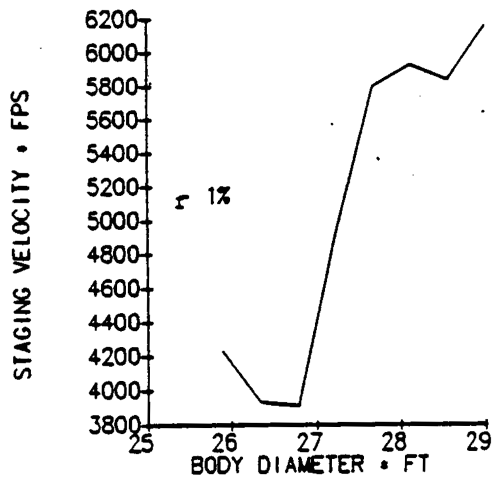
Configuration 2.J Sensitivity Studies (Continued)



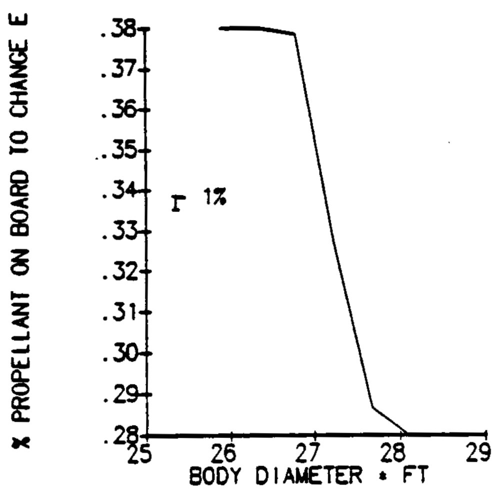
(J-9) Propellant Mixture Ratio Versus Body Diameter



(J-10) Initial Booster Throttle Setting Versus Body Diameter

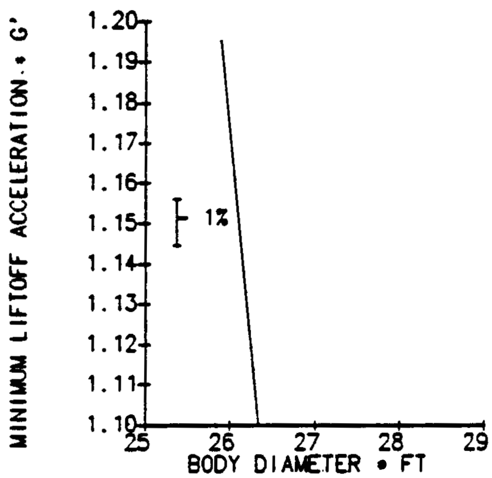


(J-11) Staging Velocity Versus Body Diameter

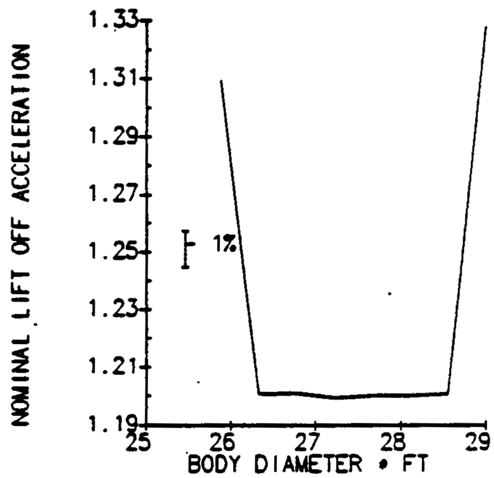


(J-12) Orbiter Propellant at Staging Versus Body Diameter

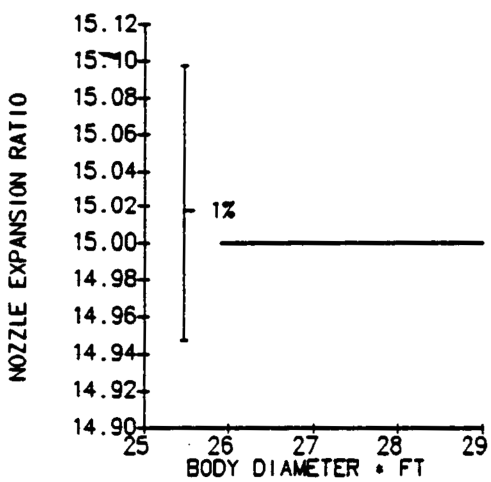
Configuration 2.J Sensitivity Studies (Continued)



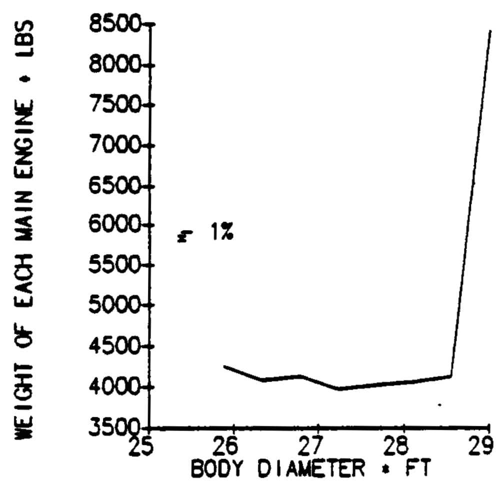
(J-13) Engine-out Lift Off Acceleration Versus Body Diameter



(J-14) Nominal Lift Off Acceleration Versus Body Diameter

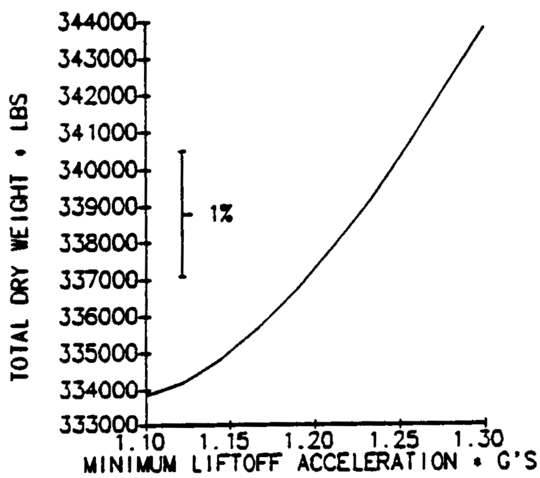


(J-15) Nozzle Expansion Ratio Versus Body Diameter

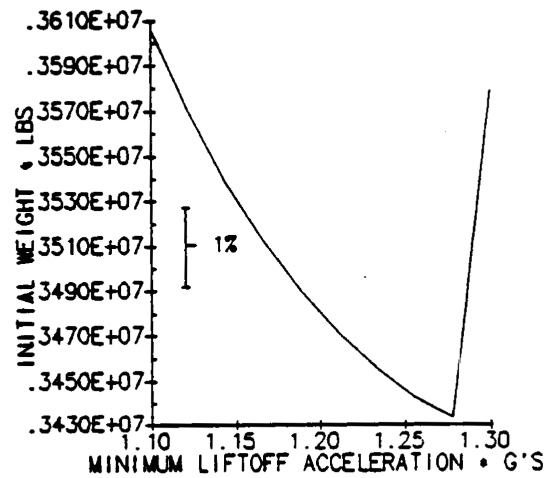


(J-16) Booster Engine Weight Versus Body Diameter

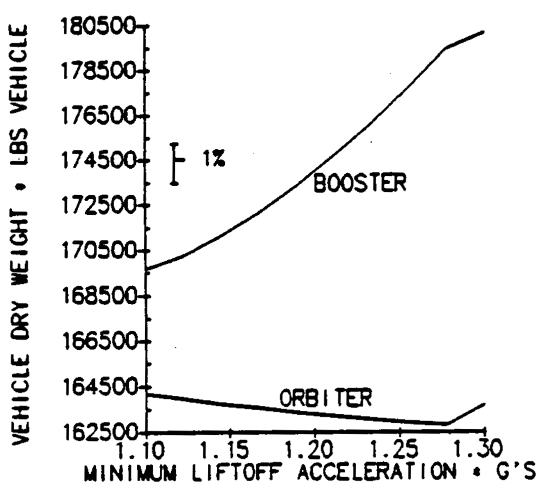
Configuration 2.J Sensitivity Studies (Continued)



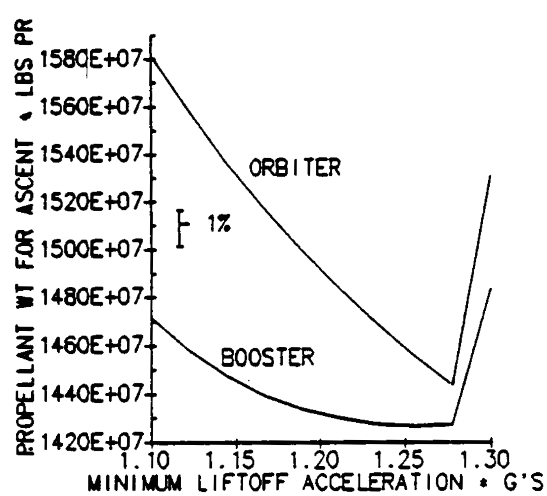
(J-17) **Total Dry Weight Versus Engine-out Lift Off Acceleration**



(J-18) **Gross Lift Off Weight Versus Engine-out Lift Off Acceleration**

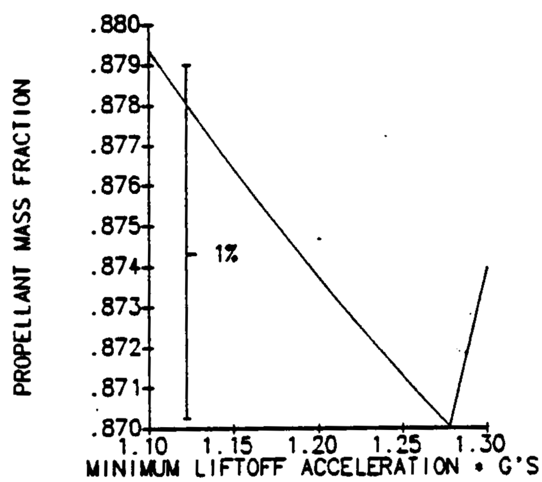


(J-19) **Vehicle Dry Weight Versus Engine-out Lift Off Acceleration**

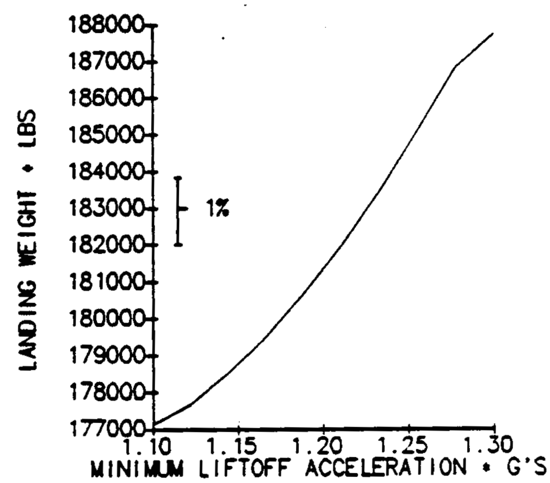


(J-20) **Propellant Consumed Versus Engine-out Lift Off Acceleration**

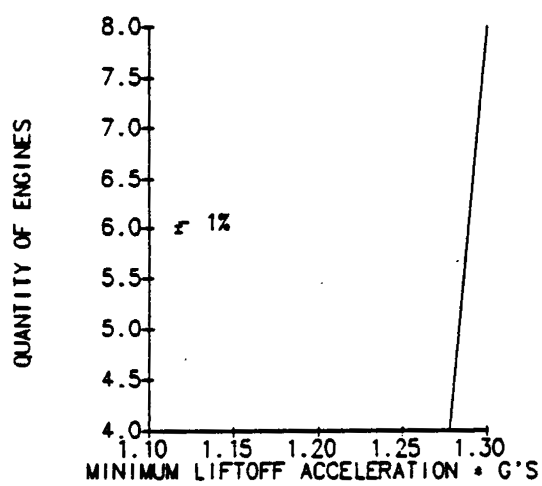
Configuration 2J Sensitivity Studies (Continued)



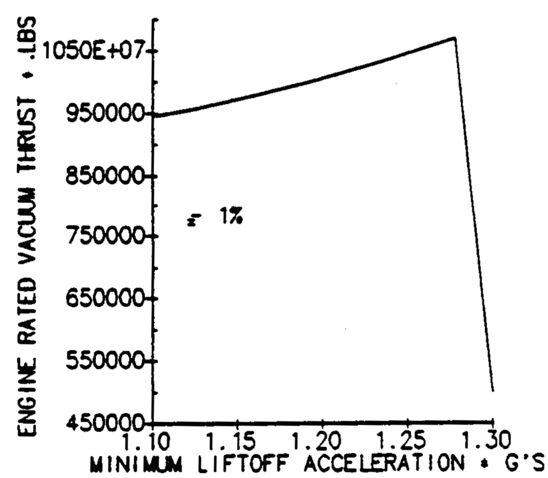
(J-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(J-22) Landing Weight Versus Engine-out Lift Off Acceleration

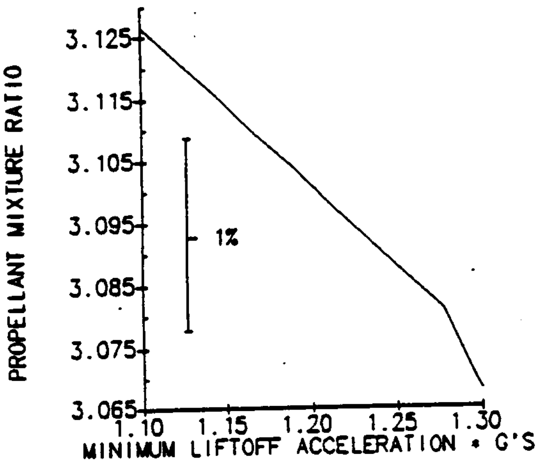


(J-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

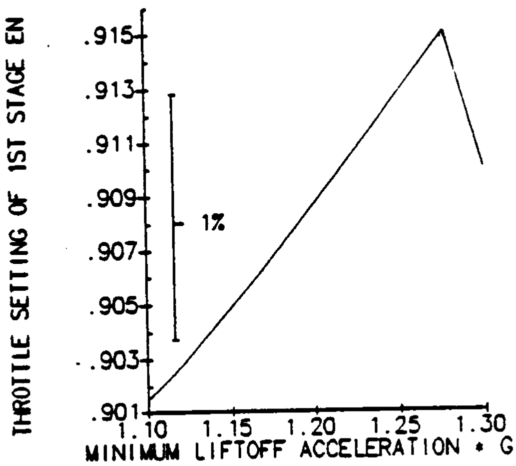


(J-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

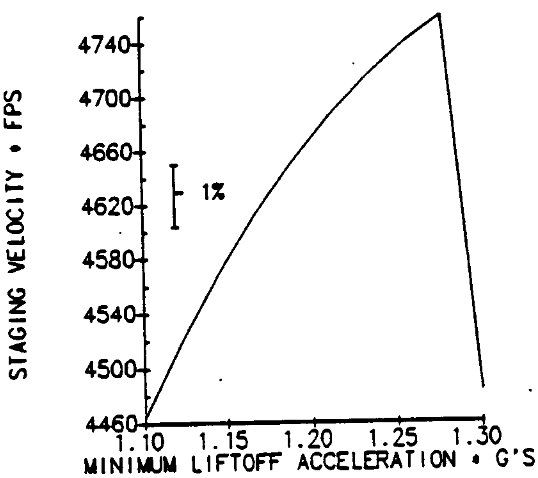
Configuration 2.J Sensitivity Studies (Continued)



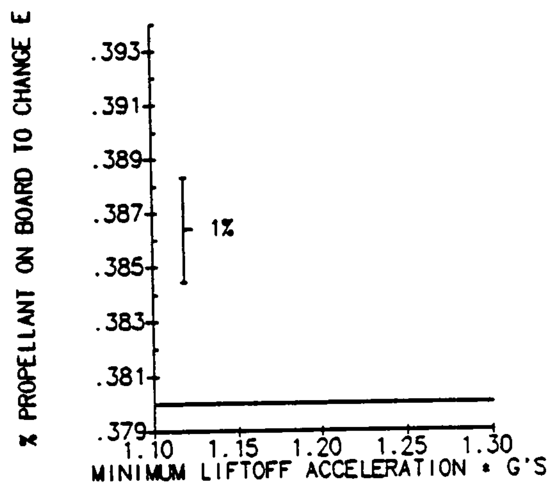
(J-25) **Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration**



(J-26) **Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration**

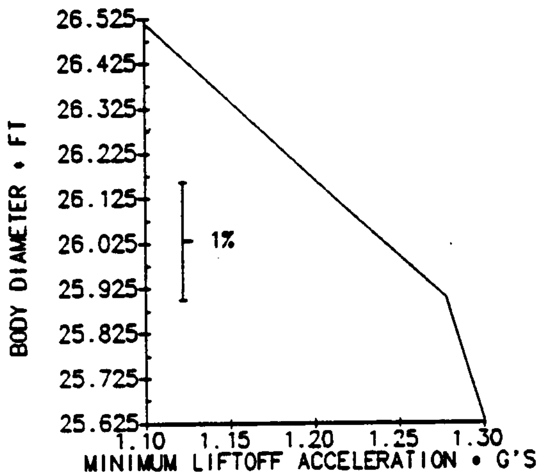


(J-27) **Staging Velocity Versus Engine-out Lift Off Acceleration**

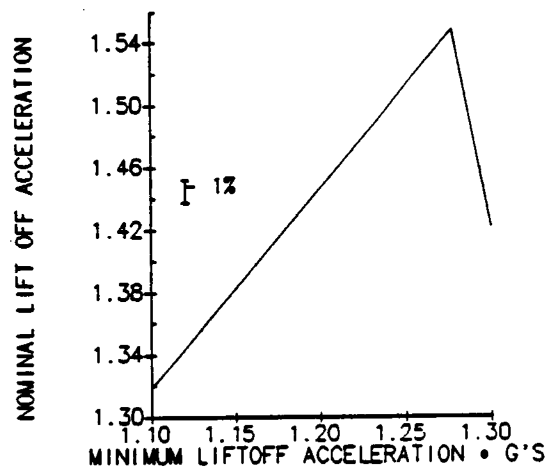


(J-28) **Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration**

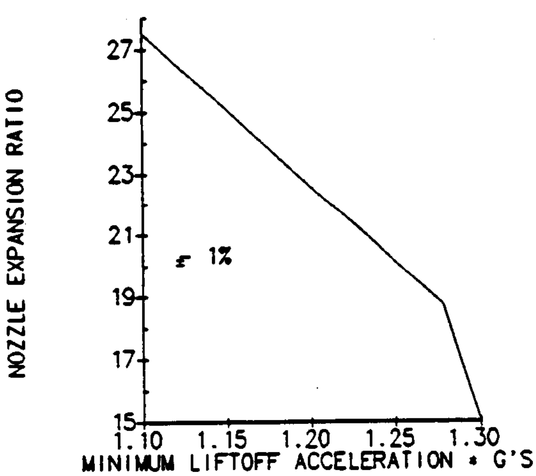
Configuration 2.J Sensitivity Studies (Continued)



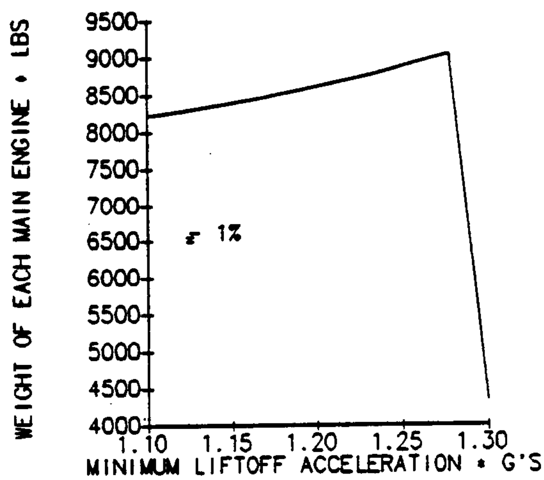
(J-29) Body Diameter Versus Engine-out Lift Off Acceleration



(J-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

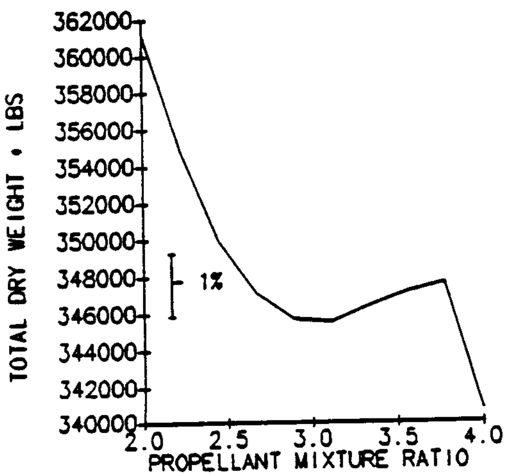


(J-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

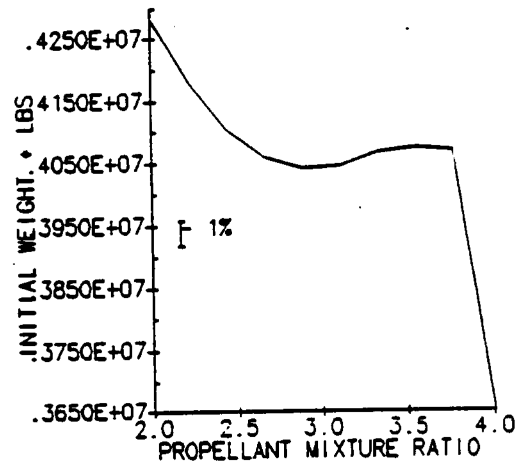


(J-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

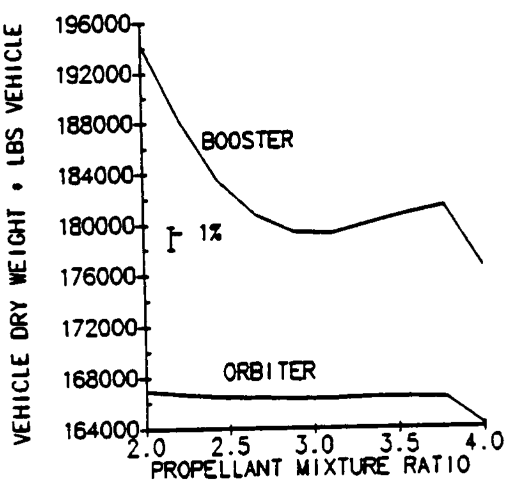
Configuration 2.J Sensitivity Studies (Continued)



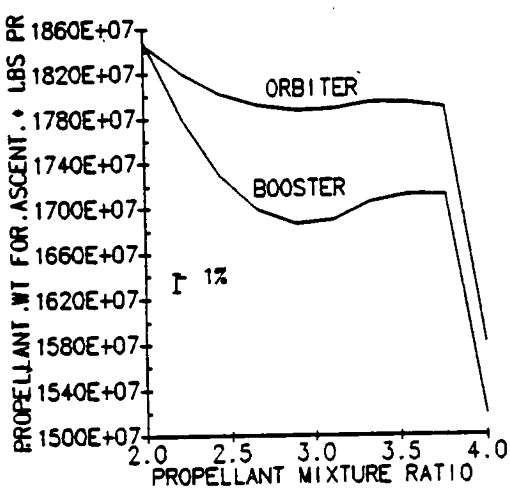
(J-33) Total Dry Weight Versus Propellant Mixture Ratio



(J-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

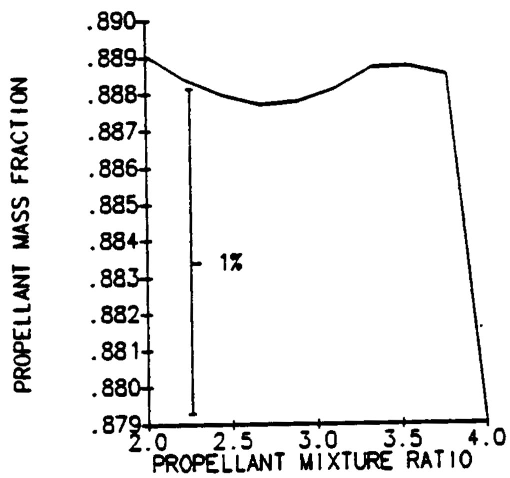


(J-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

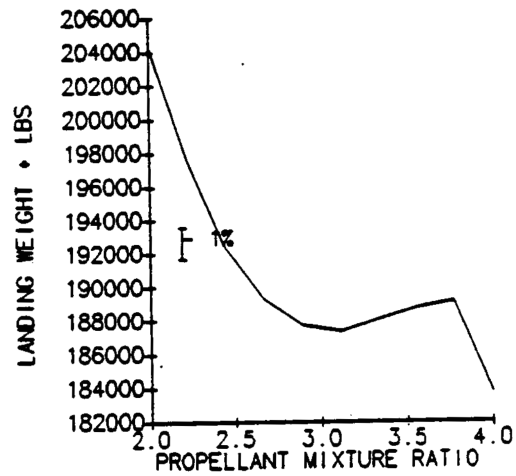


(J-36) Propellant Consumed Versus Propellant Mixture Ratio

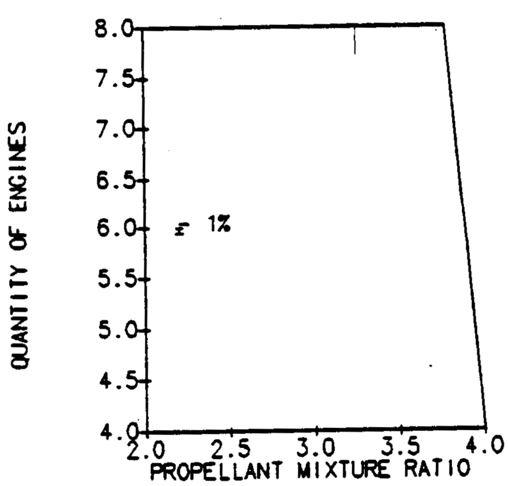
Configuration 2.J Sensitivity Studies (Continued)



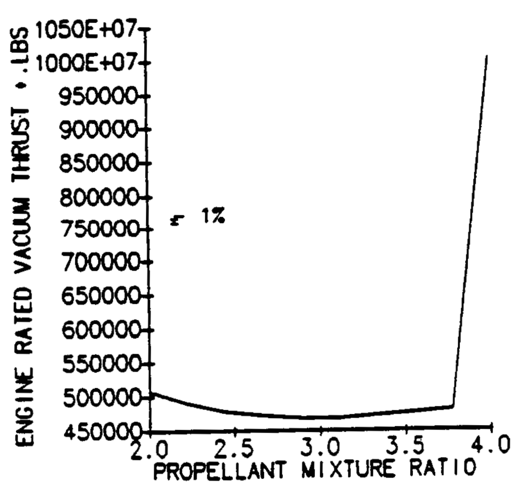
(J-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(J-38) Landing Weight Versus Propellant Mixture Ratio

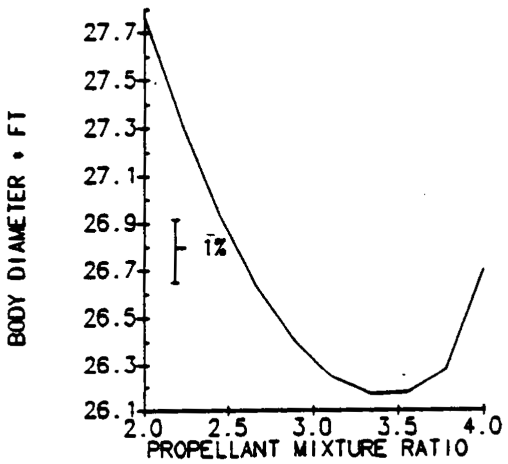


(J-39) Number of Booster Engines Versus Propellant Mixture Ratio

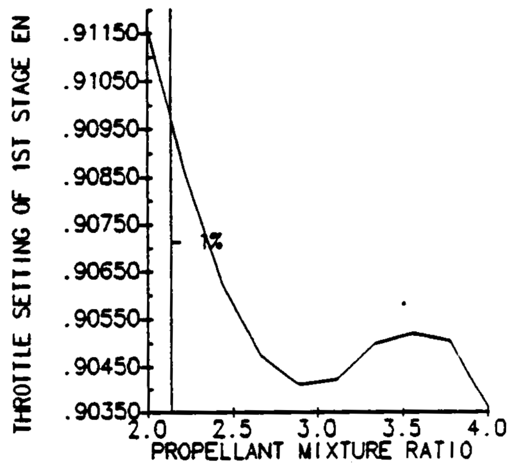


(J-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

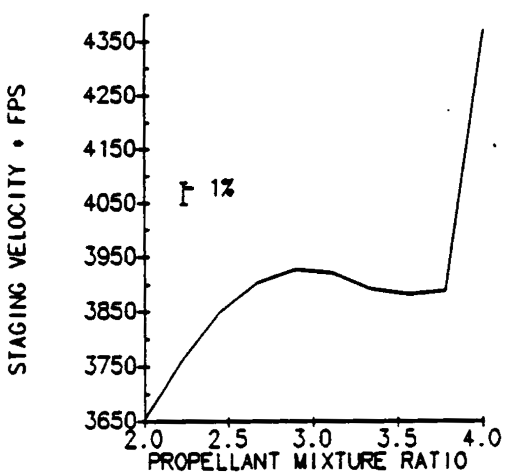
Configuration 2.J Sensitivity Studies (Continued)



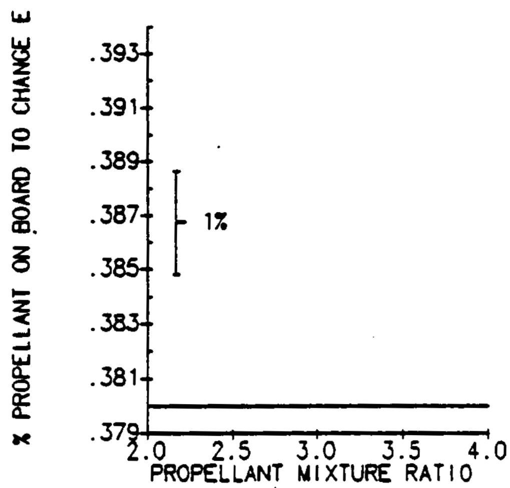
(J-41) Body Diameter Versus Propellant Mixture Ratio



(J-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

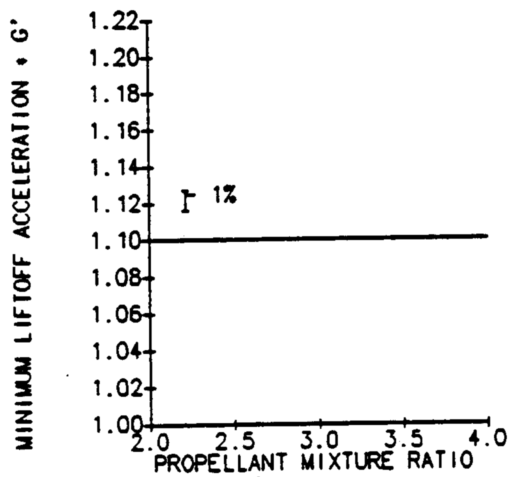


(J-43) Staging Velocity Versus Propellant Mixture Ratio

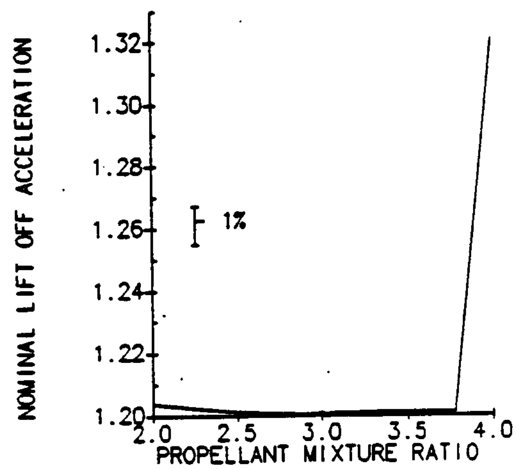


(J-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

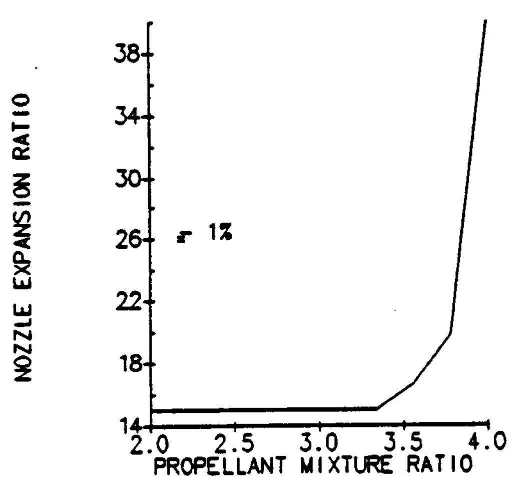
Configuration 2.J Sensitivity Studies (Continued)



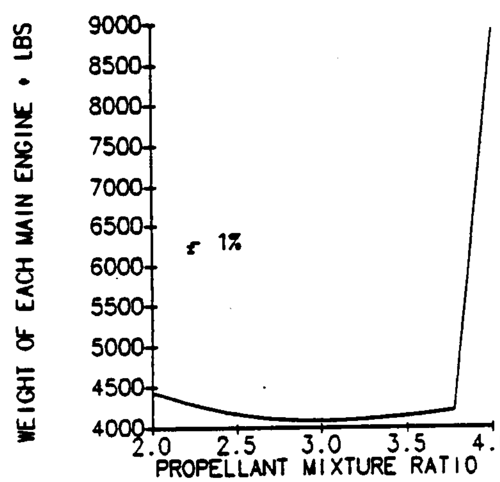
(J-45) **Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio**



(J-46) **Nominal Lift Off Acceleration Versus Propellant Mixture Ratio**

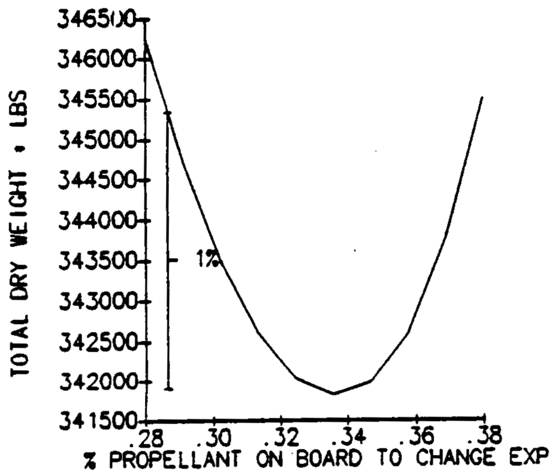


(J-47) **Nozzle Expansion Ratio Versus Propellant Mixture Ratio**

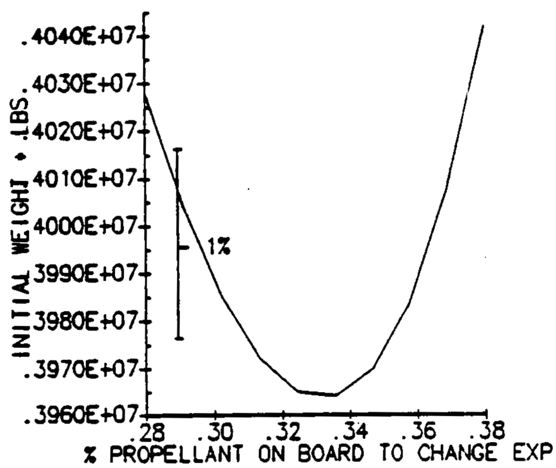


(J-48) **Booster Engine Weight Versus Propellant Mixture Ratio**

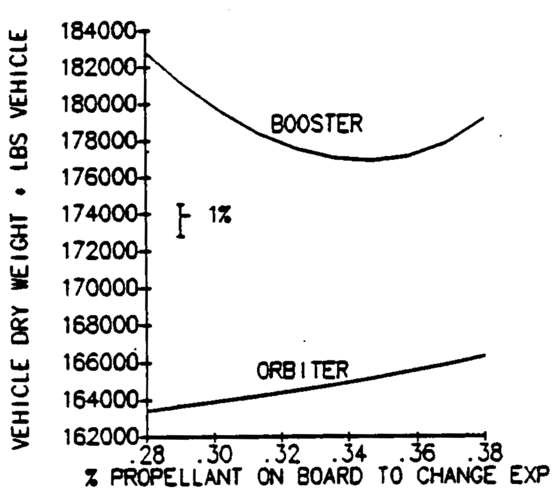
Configuration 2.J Sensitivity Studies (Continued)



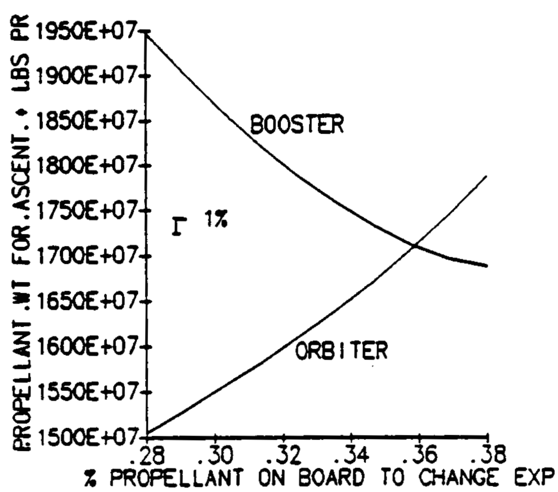
(J-49) **Total Dry Weight Versus Orbiter Propellant at Staging**



(J-50) **Gross Lift Off Weight Versus Orbiter Propellant at Staging**

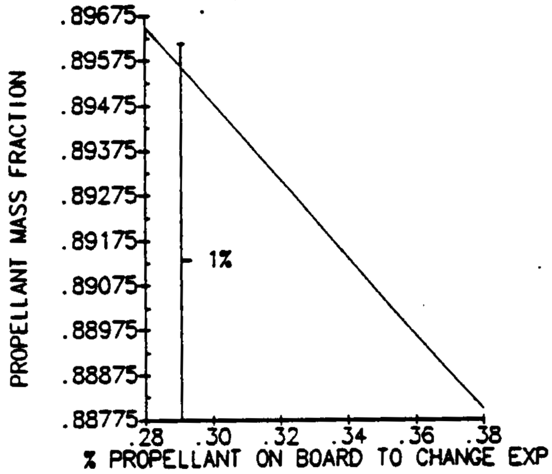


(J-51) **Vehicle Dry Weight Versus Orbiter Propellant at Staging**

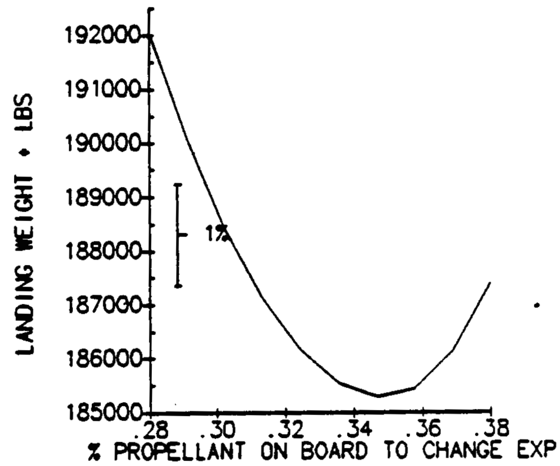


(J-52) **Propellant Consumed Versus Orbiter Propellant at Staging**

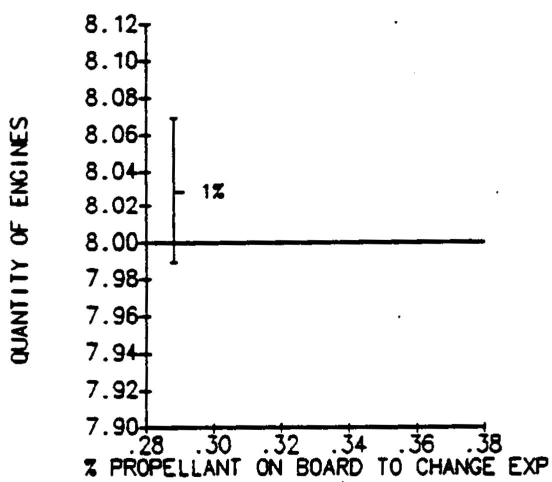
Configuration 2.J Sensitivity Studies (Continued)



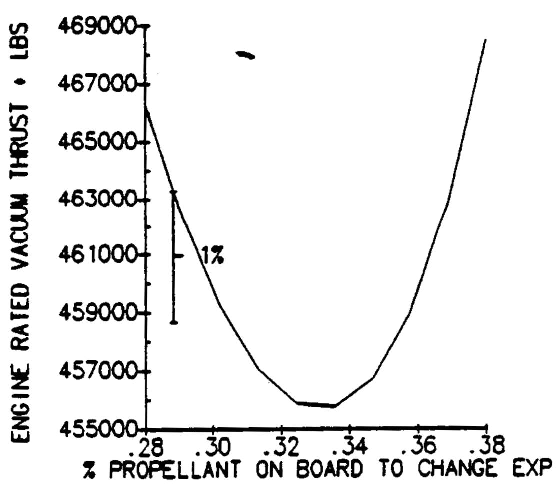
(J-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(J-54) Landing Weight Versus Orbiter Propellant at Staging

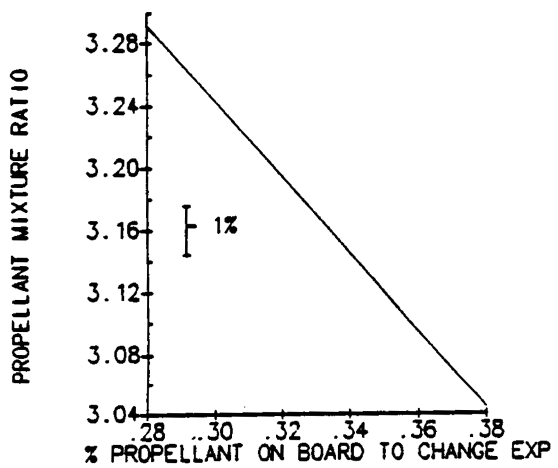


(J-55) Number of Booster Engines Versus Orbiter Propellant at Staging

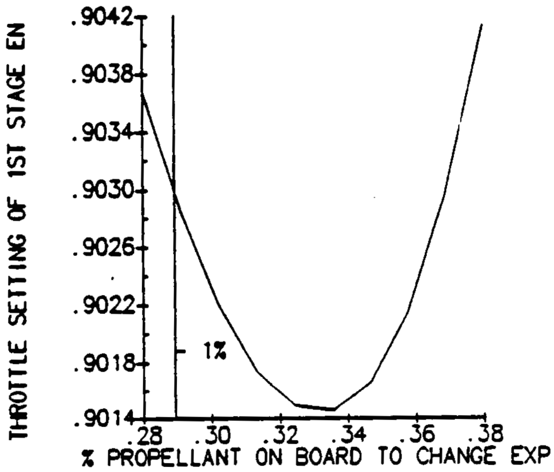


(J-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

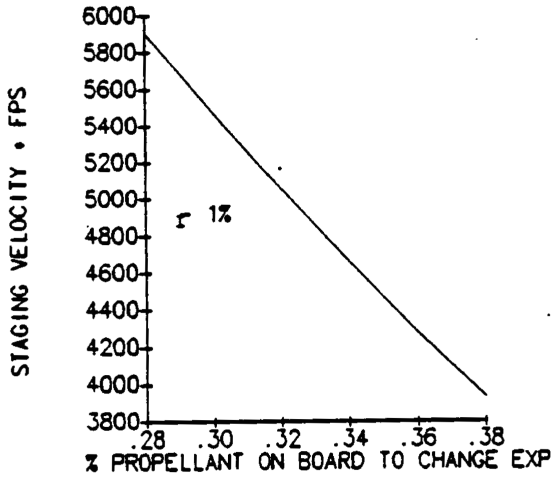
Configuration 2J Sensitivity Studies (Continued)



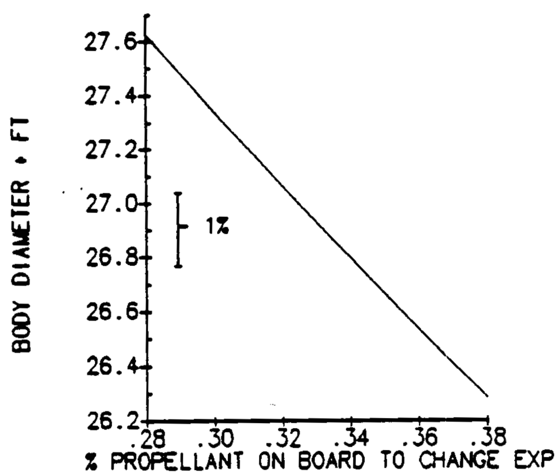
(J-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(J-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

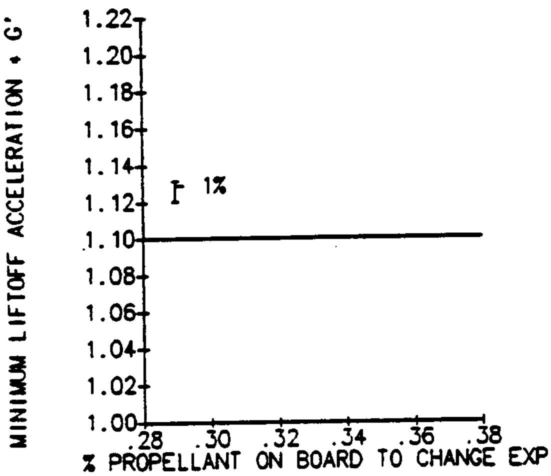


(J-59) Staging Velocity Versus Orbiter Propellant at Staging

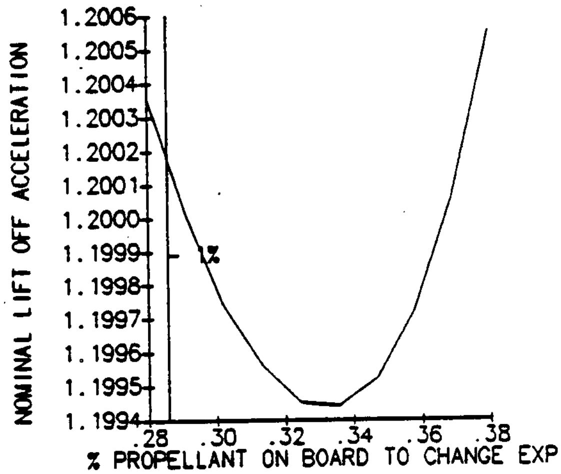


(J-60) Body Diameter Versus Orbiter Propellant at Staging –

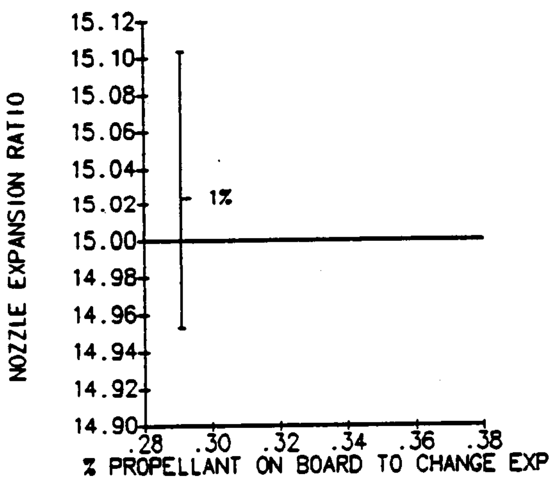
Configuration 2.J Sensitivity Studies (Continued)



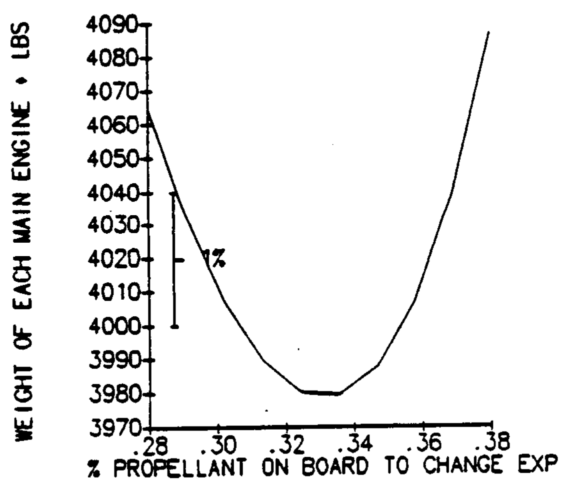
(J-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(J-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

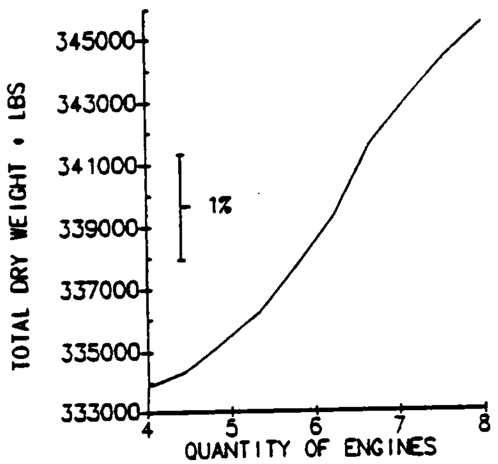


(J-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

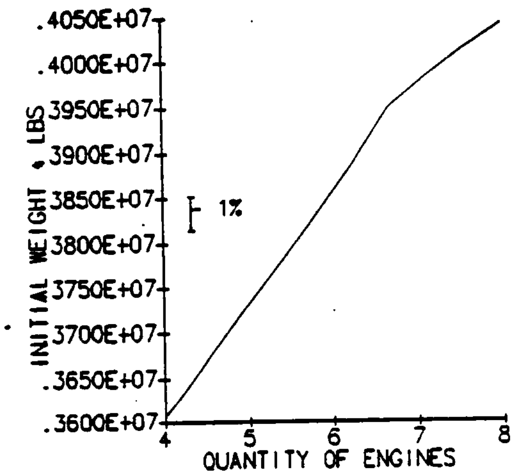


(J-64) Booster Engine Weight Versus Orbiter Propellant at Staging

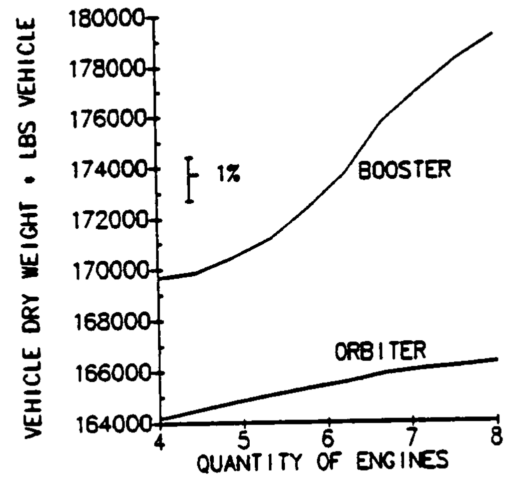
Configuration 2.J Sensitivity Studies (Continued)



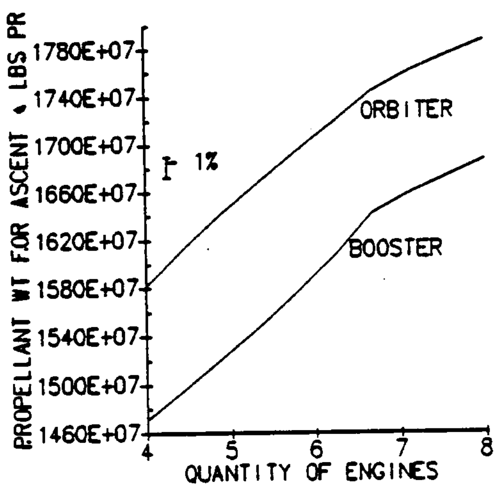
(J-65) Total Dry Weight Versus Number of Booster Engines



(J-66) Gross Lift Off Weight Versus Number of Booster Engines

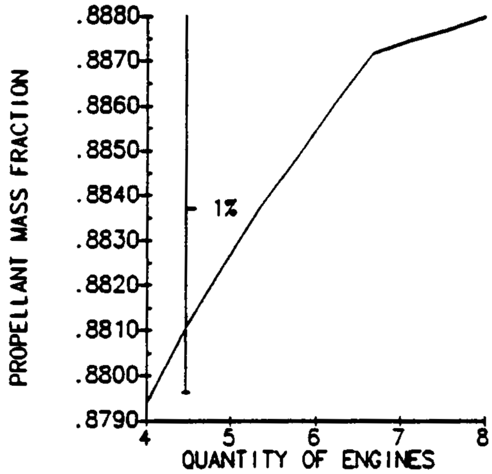


(J-67) Vehicle Dry Weight Versus Number of Booster Engines

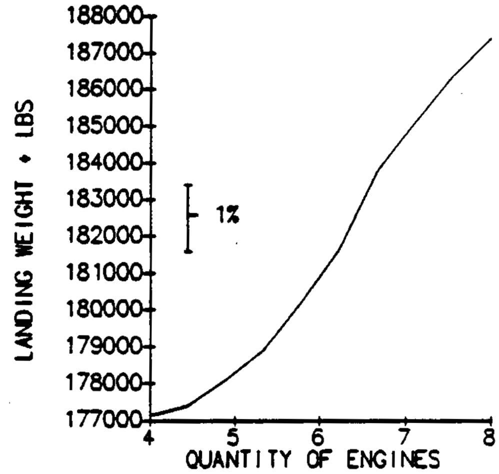


(J-68) Propellant Consumed Versus Number of Booster Engines

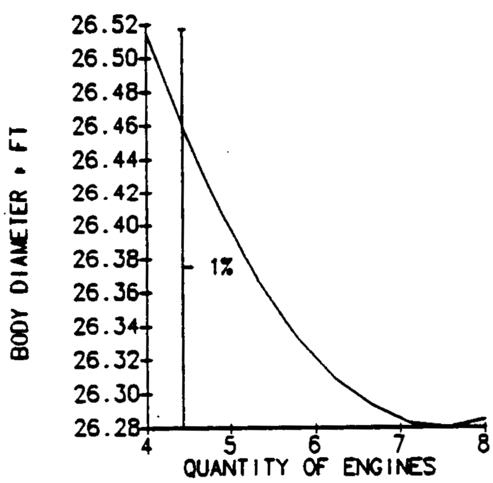
Configuration 2.J Sensitivity Studies (Continued)



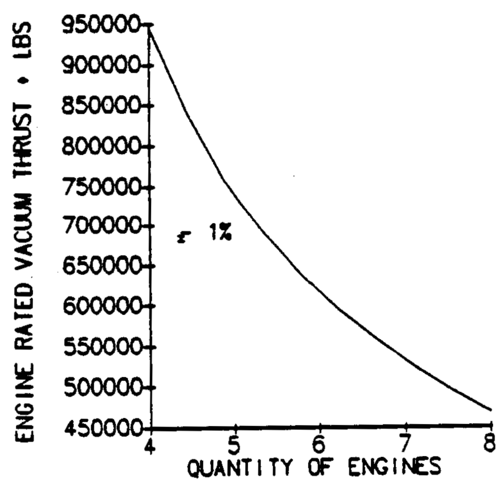
(J-69) **Propellant Mass Fraction Versus Number of Booster Engines**



(J-70) **Landing Weight Versus Number of Booster Engines**

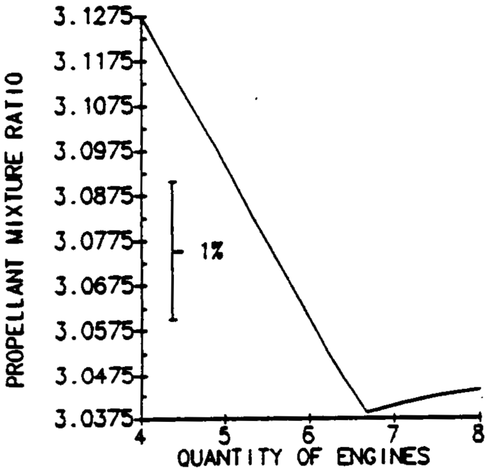


(J-71) **Body Diameter Versus Number of Booster Engines**

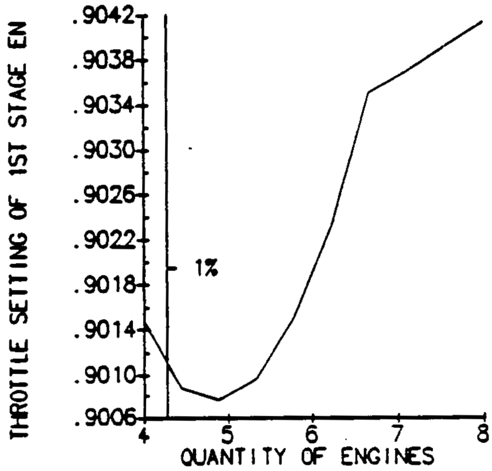


(J-72) **Engine Rated Vacuum Thrust Versus Number of Booster Engines**

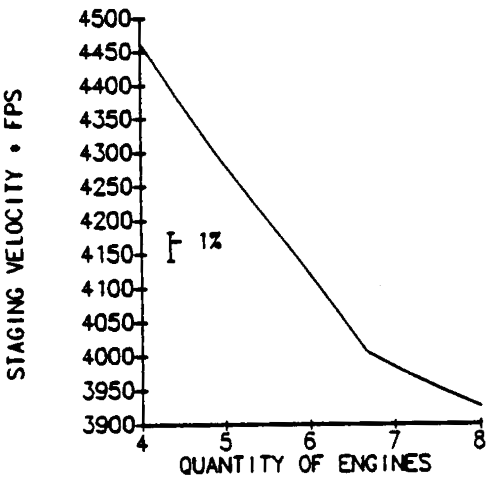
Configuration 2.J Sensitivity Studies (Continued)



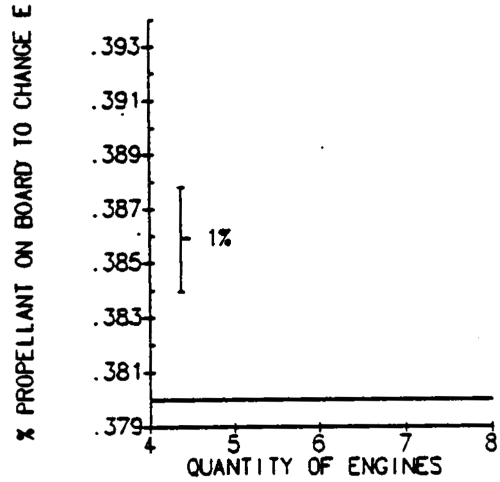
(J-73) Propellant Mixture Ratio Versus Number of Booster Engines



(J-74) Initial Booster Throttle Setting Versus Number of Booster Engines

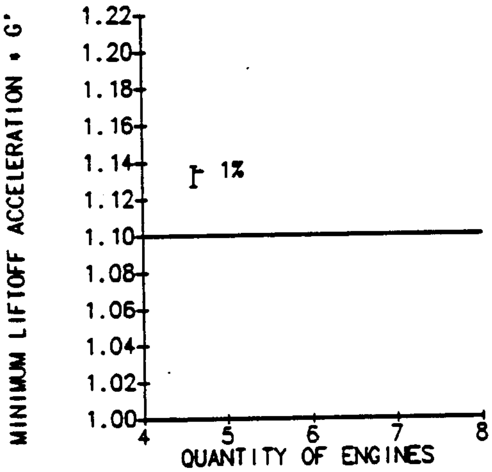


(J-75) Staging Velocity Versus Number of Booster Engines

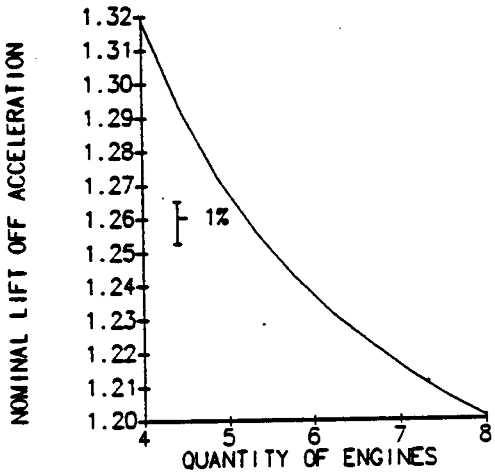


(J-76) Orbiter Propellant at Staging Versus Number of Booster Engines

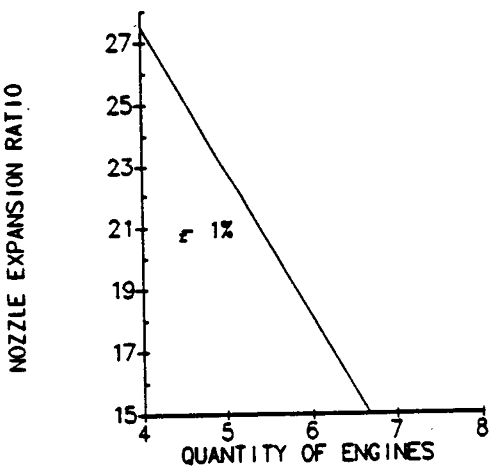
Configuration 2.J Sensitivity Studies (Continued)



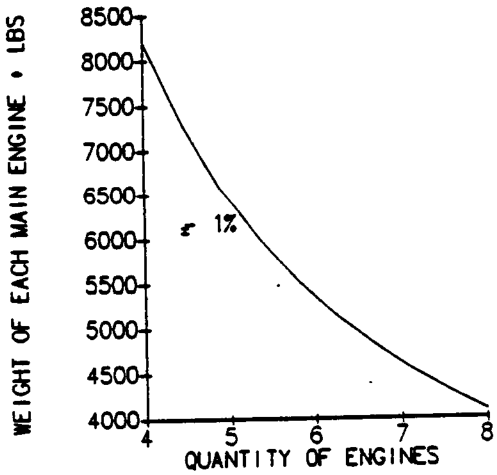
(J-77) **Engine-out Lift Off Acceleration Versus Number of Booster Engines**



(J-78) **Nominal Lift Off Acceleration Versus Number of Booster Engines**

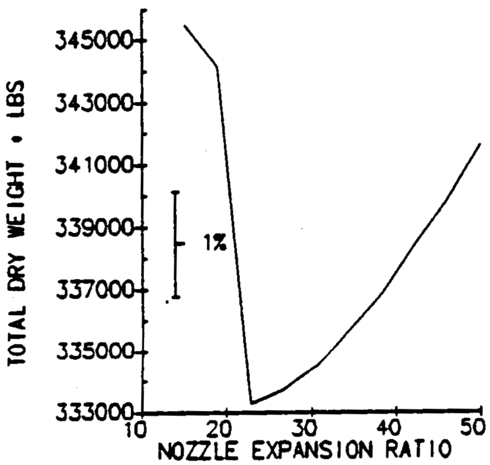


(J-79) **Nozzle Expansion Ratio Versus Number of Booster Engines**

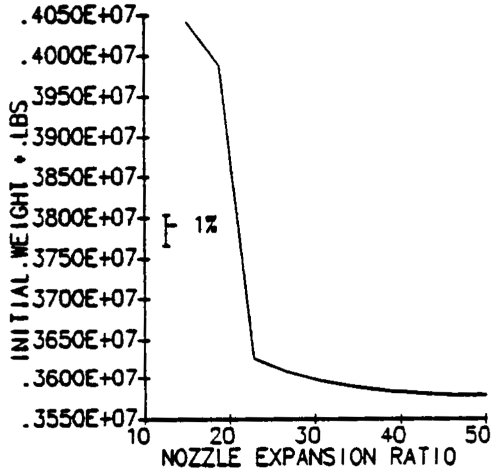


(J-80) **Booster Engine Weight Versus Number of Booster Engines**

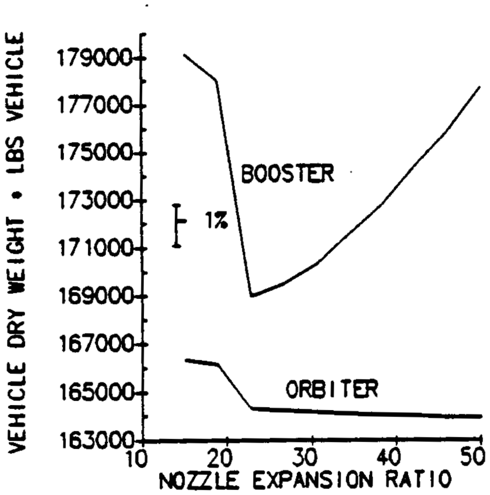
Configuration 2.J Sensitivity Studies (Continued)



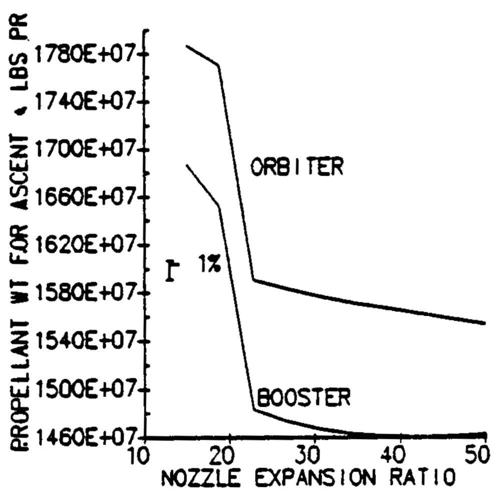
(J-81) Total Dry Weight Versus Nozzle Expansion Ratio



(J-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

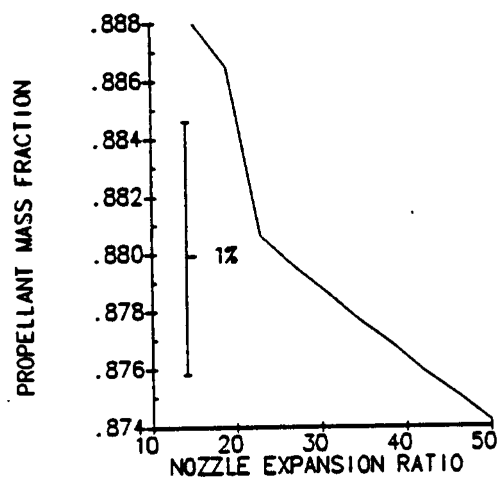


(J-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

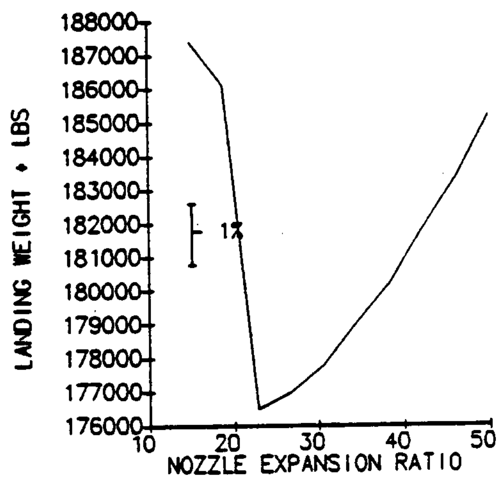


(J-84) Propellant Consumed Versus Nozzle Expansion Ratio

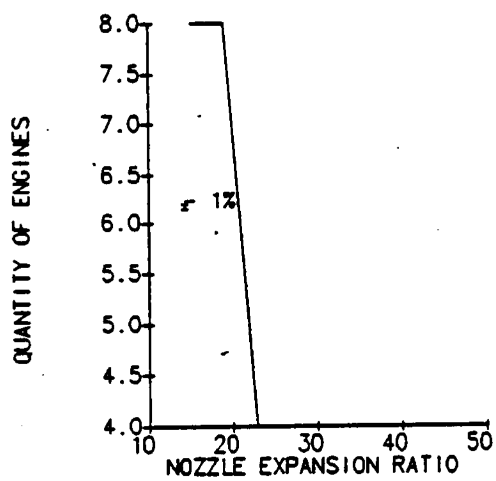
Configuration 2.J Sensitivity Studies (Continued)



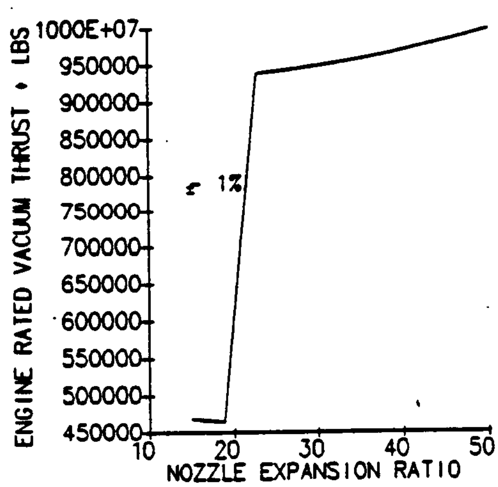
(J-85) **Propellant Mass Fraction Versus Nozzle Expansion Ratio**



(J-86) **Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio**

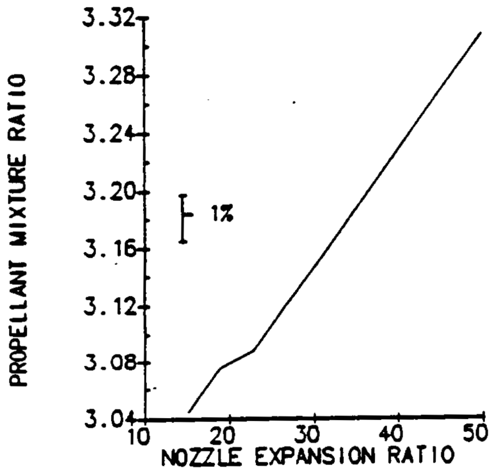


(J-87) **Number of Booster Engines Versus Nozzle Expansion Ratio**

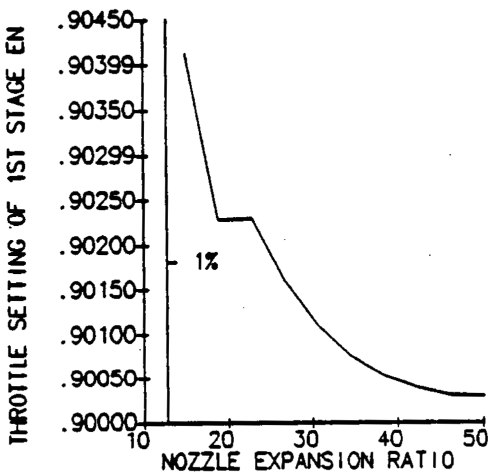


(J-88) **Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio**

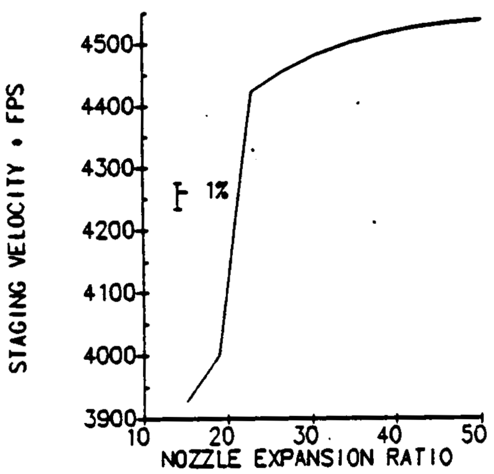
Configuration 2.J Sensitivity Studies (Continued)



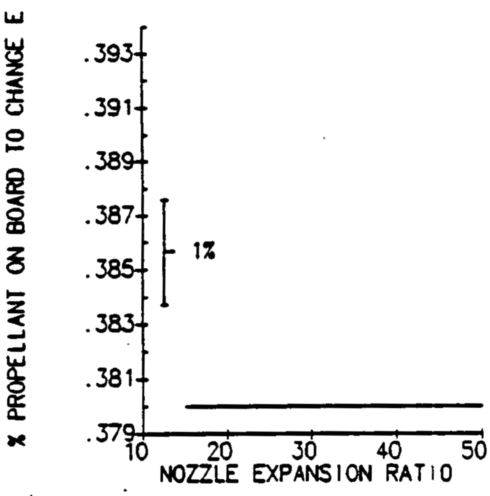
(J-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(J-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

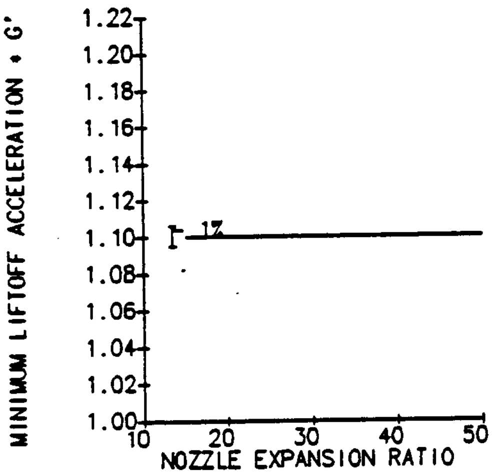


(J-91) Staging Velocity Versus Nozzle Expansion Ratio

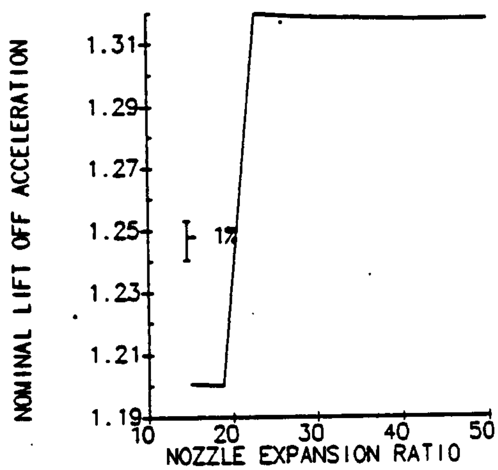


(J-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratic

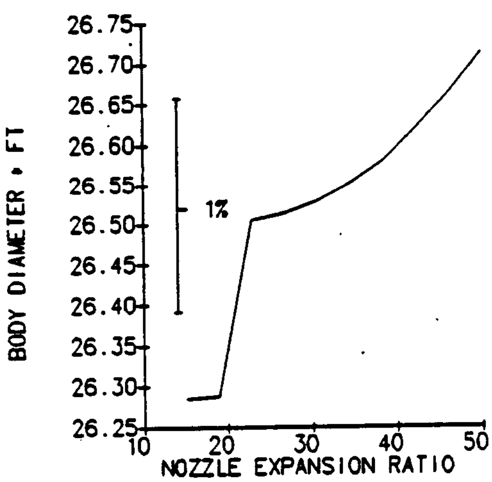
Configuration 2.J Sensitivity Studies (Continued)



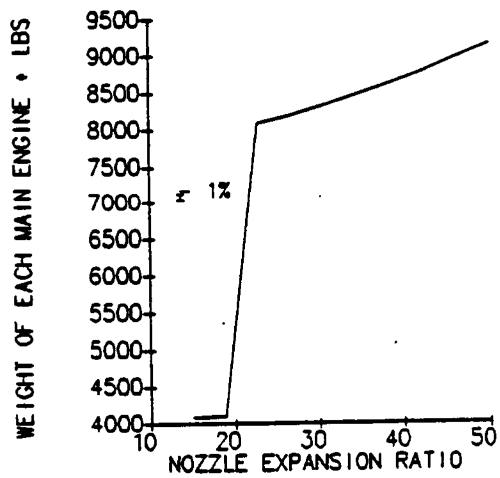
(J-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(J-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

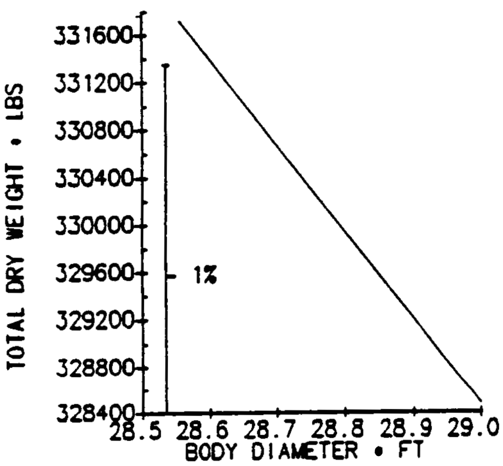


(J-95) Body Diameter Versus Nozzle Expansion Ratio

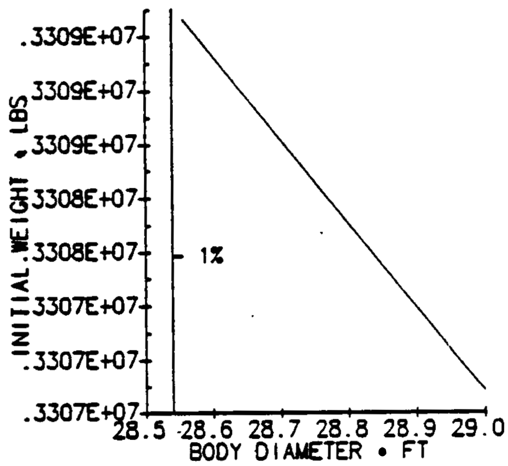


(J-96) Booster Engine Weight Versus Nozzle Expansion Ratio

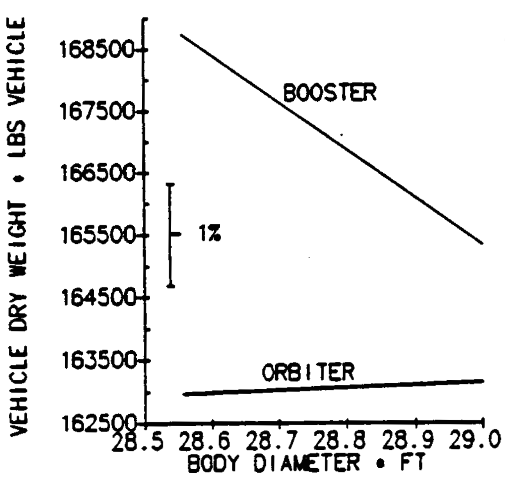
Configuration 2.J Sensitivity Studies (Continued)



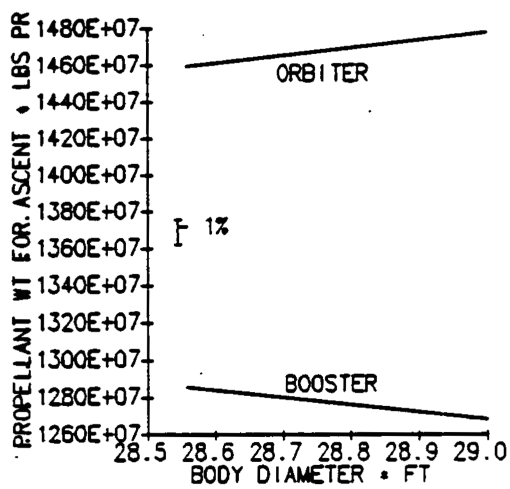
(k-1) Total Dry Weight Versus Body Diameter



(k-2) Gross Lift Off Weight Versus Body Diameter

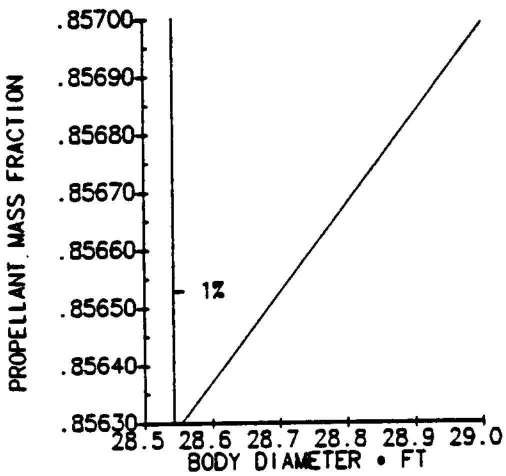


(k-3) Vehicle Dry Weight Versus Body Diameter

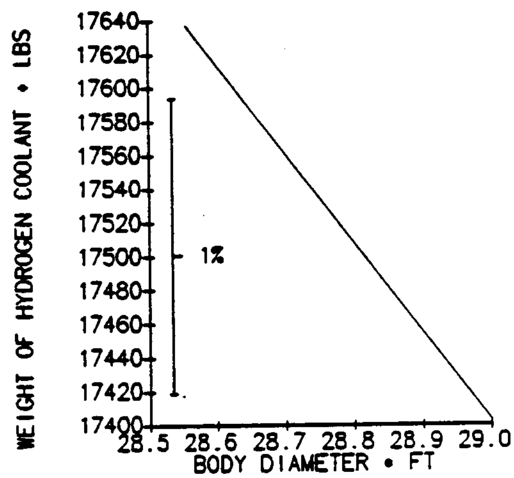


(k-4) Propellant Consumed Versus Body Diameter

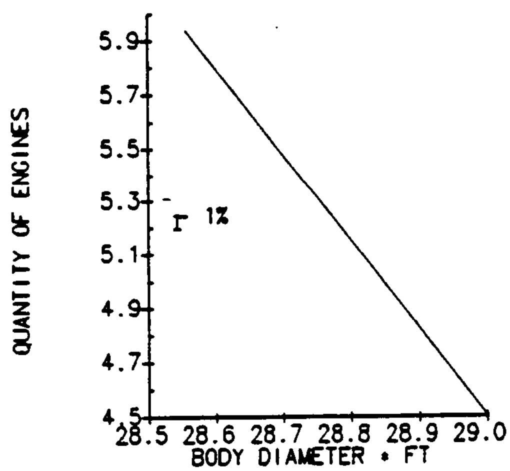
Configuration 2.K Sensitivity Studies



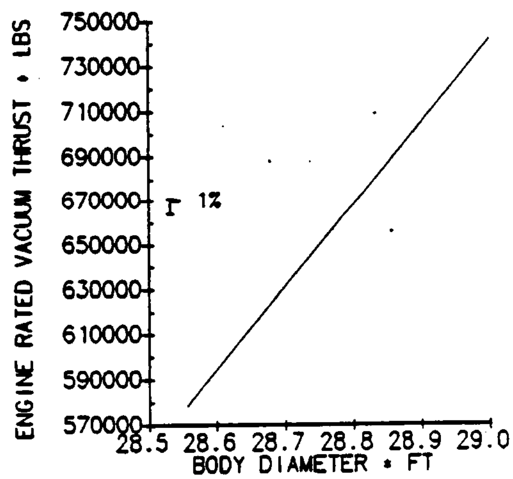
(k-5) Propellant Mass Fraction Versus Body Diameter



(k-6) Weight of Hydrogen Coolant Versus Body Diameter

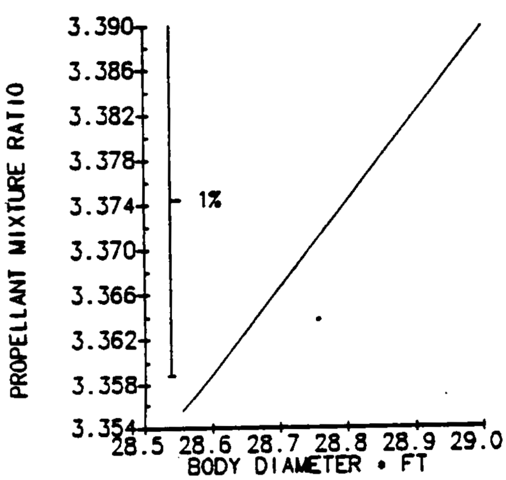


(k-7) Number of Booster Engines Versus Body Diameter

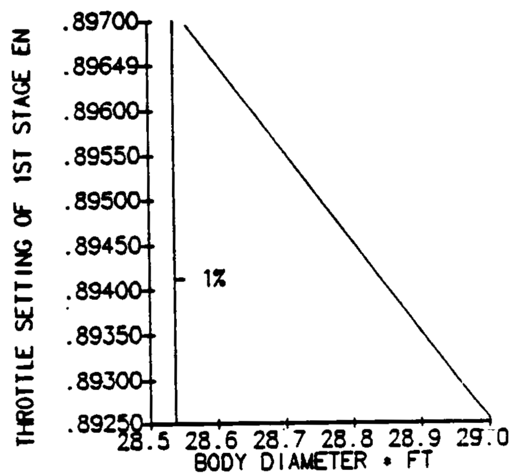


(k-8) Engine Rated Vacuum Thrust Versus Body Diameter

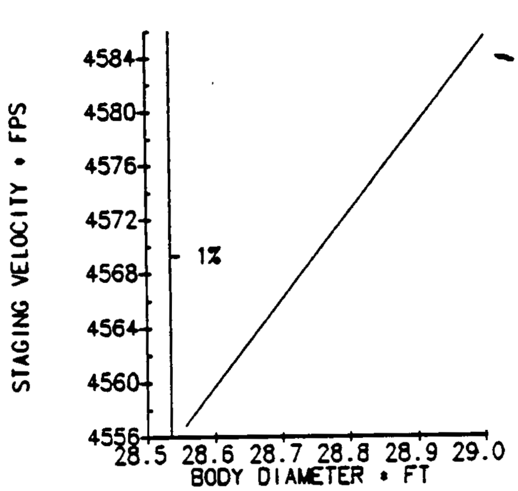
Configuration 2.K Sensitivity Studies (Continued)



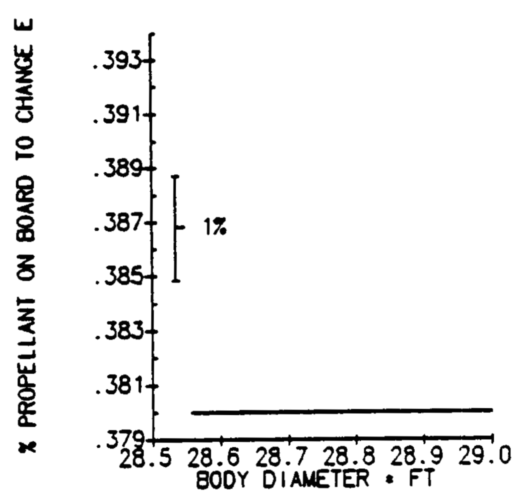
(k-9) Propellant Mixture Ratio Versus Body Diameter



(k-10) Initial Booster Throttle Setting Versus Body Diameter

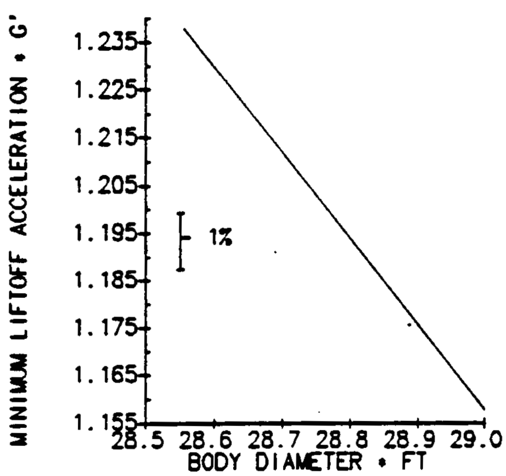


(k-11) Staging Velocity Versus Body Diameter

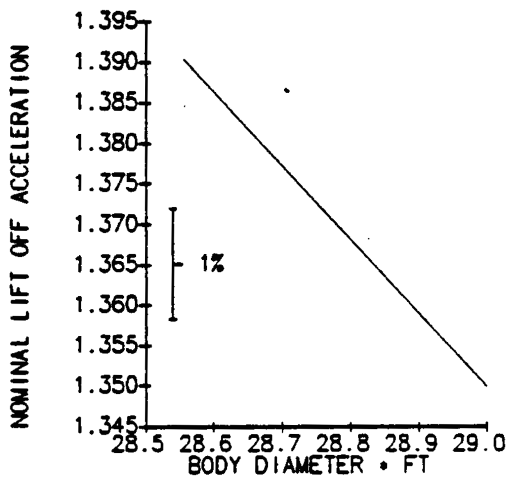


(k-12) Orbiter Propellant at Staging Versus Body Diameter

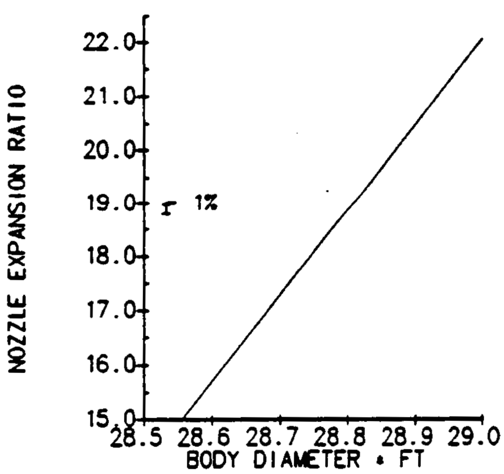
Configuration 2.K Sensitivity Studies (Continued)



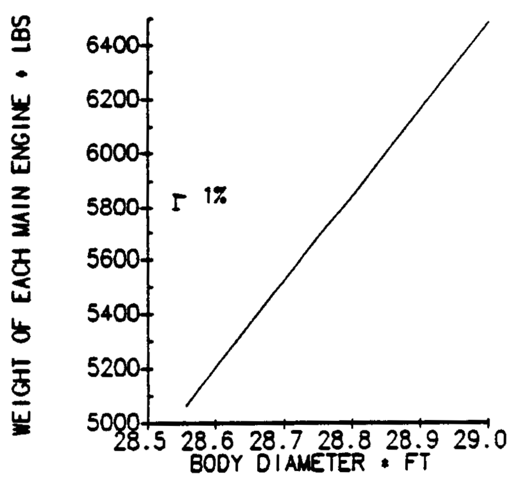
(k-13) Engine-out Lift Off Acceleration Versus Body Diameter



(k-14) Nominal Lift Off Acceleration Versus Body Diameter

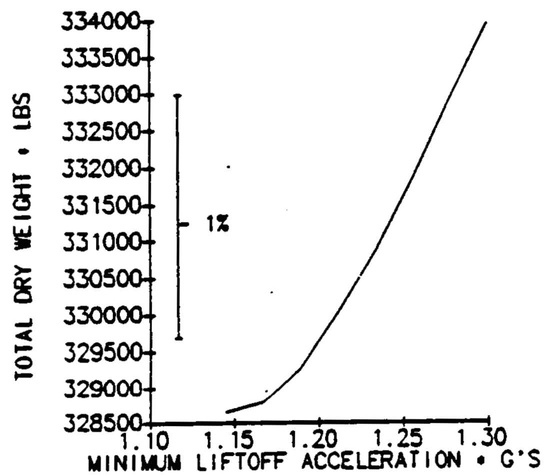


(k-15) Nozzle Expansion Ratio Versus Body Diameter

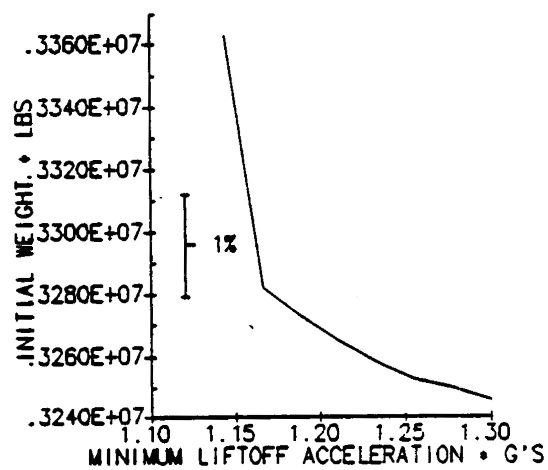


(k-16) Booster Engine Weight Versus Body Diameter

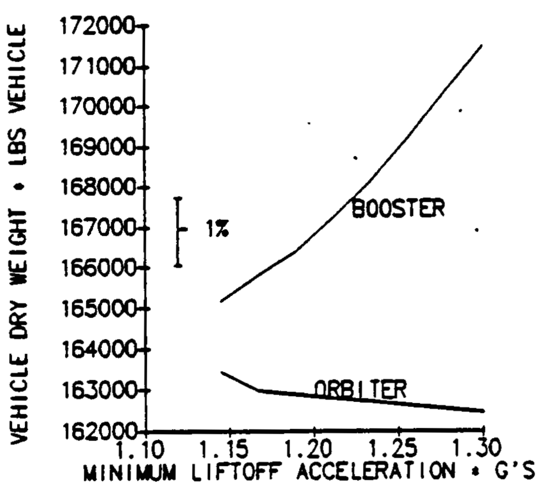
Configuration 2.K Sensitivity Studies (Continued)



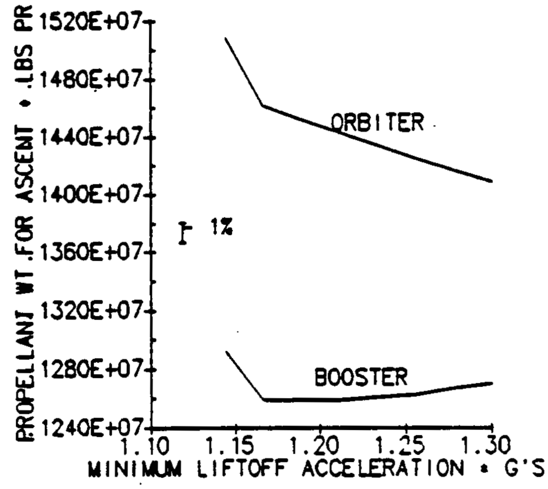
(k-17) **Total Dry Weight Versus Engine-out Lift Off Acceleration**



(k-18) **Gross Lift Off Weight Versus Engine-out Lift Off Acceleration**

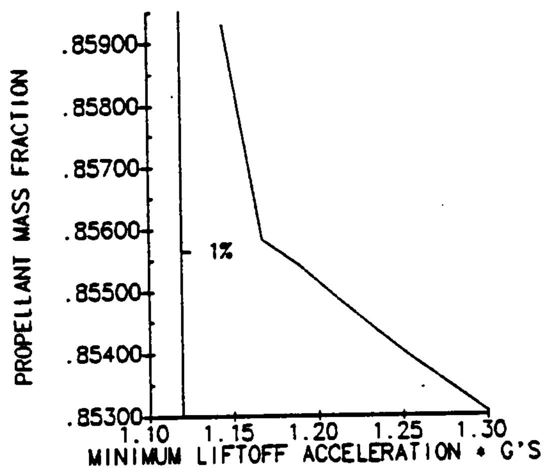


(k-19) **Vehicle Dry Weight Versus Engine-out Lift Off Acceleration**

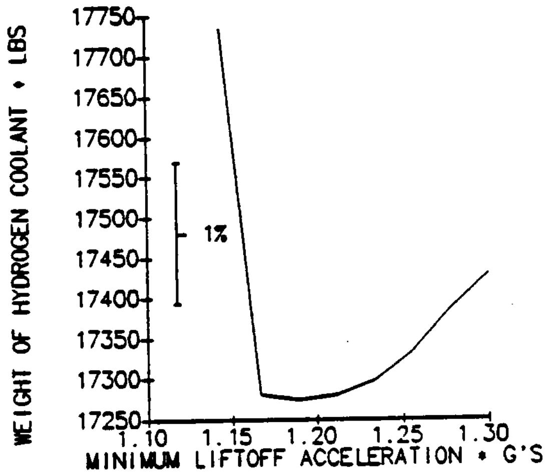


(k-20) **Propellant Consumed Versus Engine-out Lift Off Acceleration**

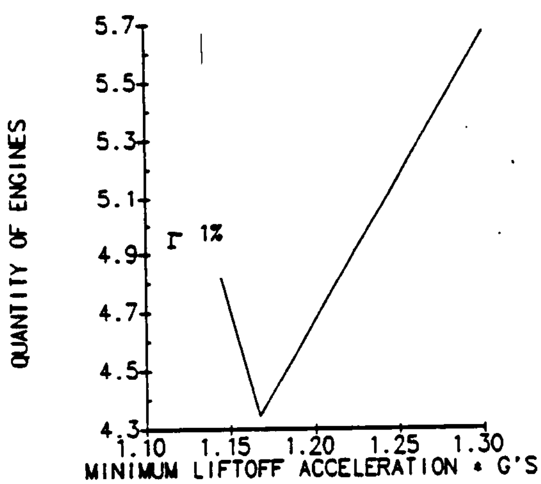
Configuration 2.K Sensitivity Studies (Continued)



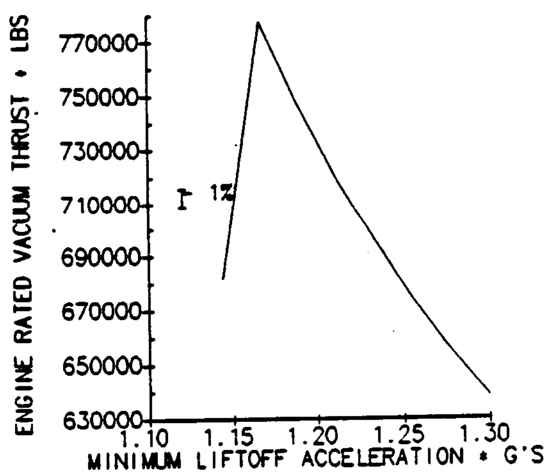
(k-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(k-22) Weight of Hydrogen Coolant Versus Engine-out Lift Off Acceleration

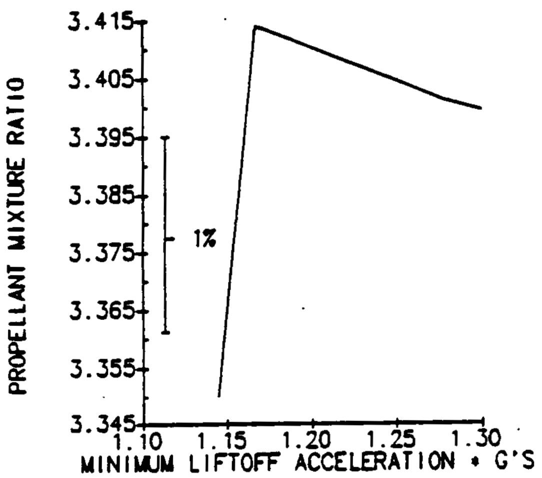


(k-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

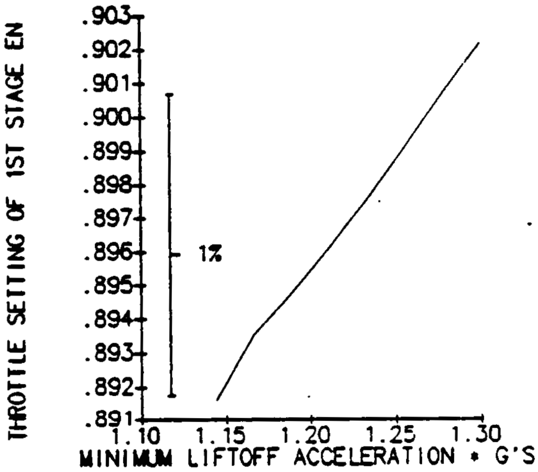


(k-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

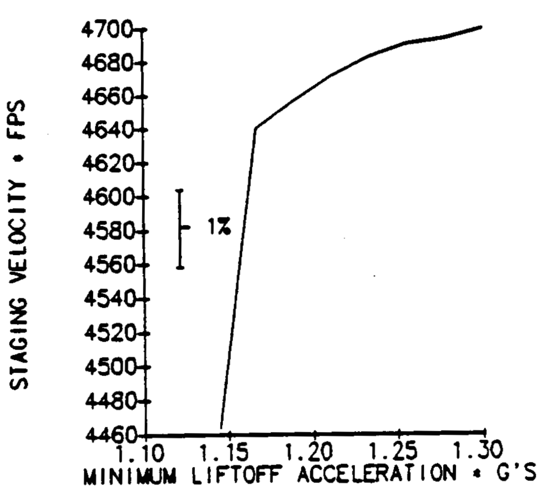
Configuration 2.K Sensitivity Studies (Continued)



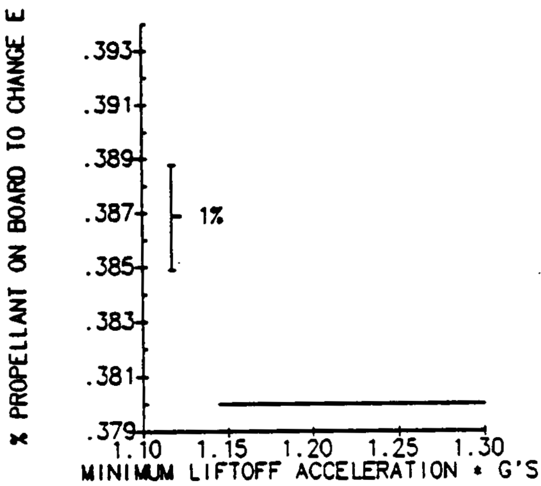
(k-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(k-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

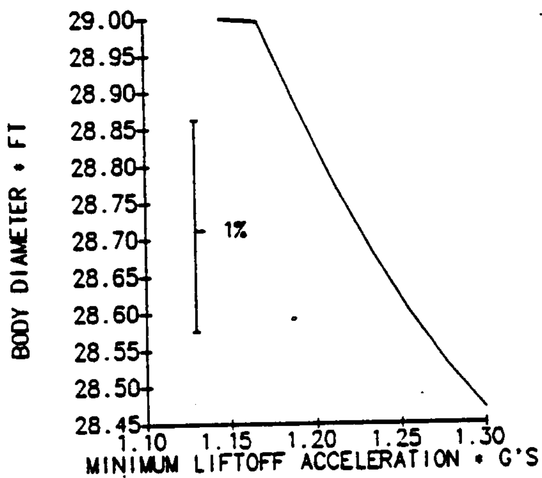


(k-27) Staging Velocity Versus Engine-out Lift Off Acceleration

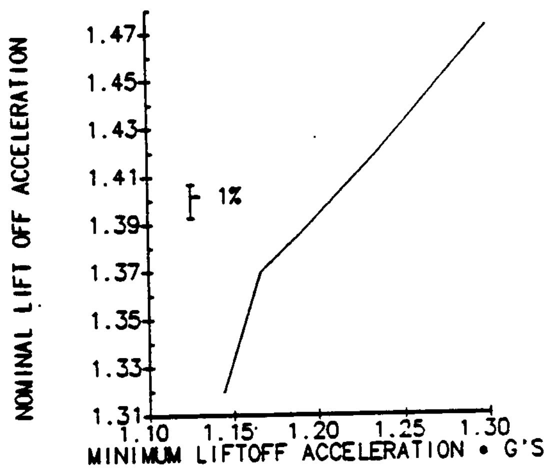


(k-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

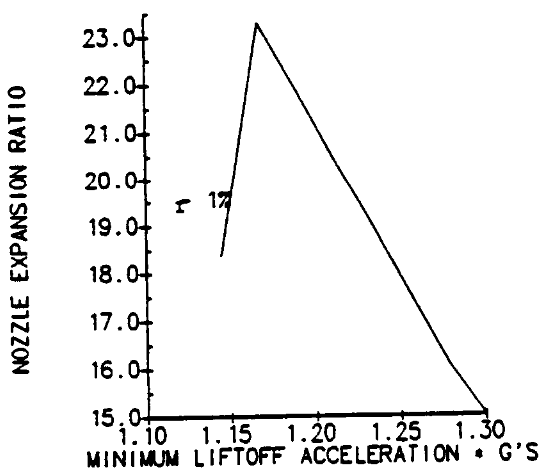
Configuration 2.K Sensitivity Studies (Continued)



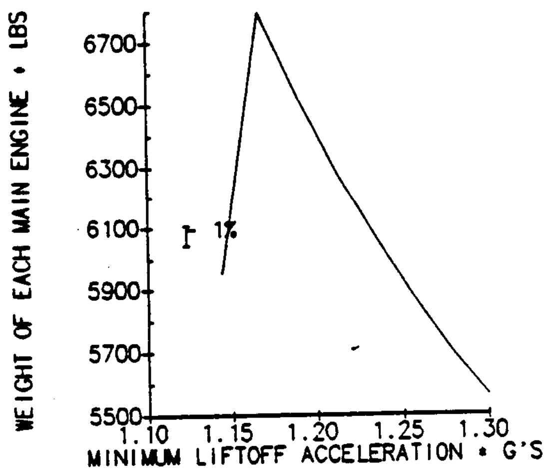
(k-29) Body Diameter Versus Engine-out Lift Off Acceleration



(k-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

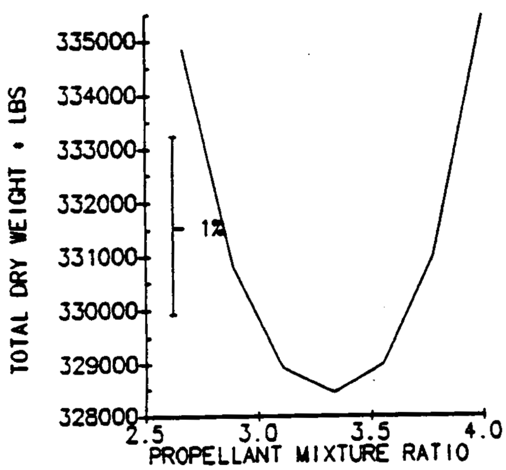


(k-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

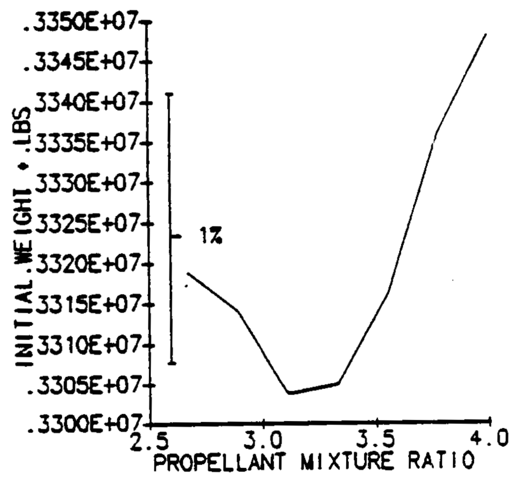


(k-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

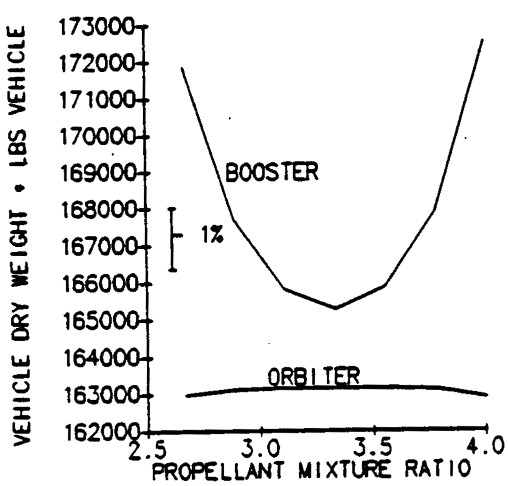
Configuration 2.K Sensitivity Studies (Continued)



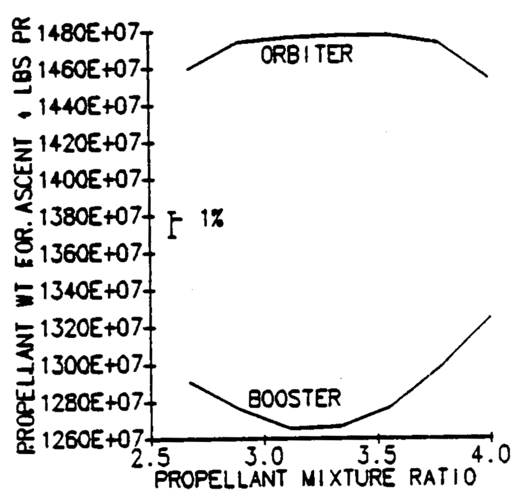
(k-33) Total Dry Weight Versus Propellant Mixture Ratio



(k-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

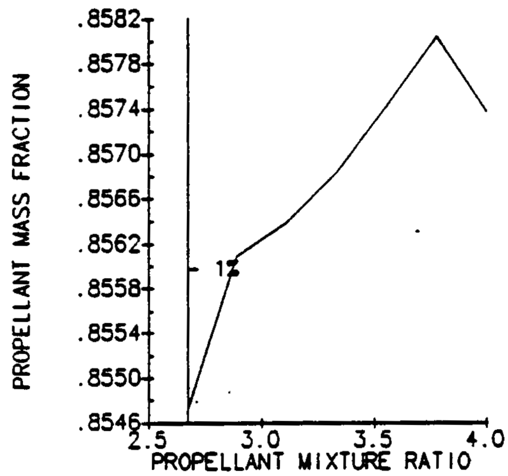


(k-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

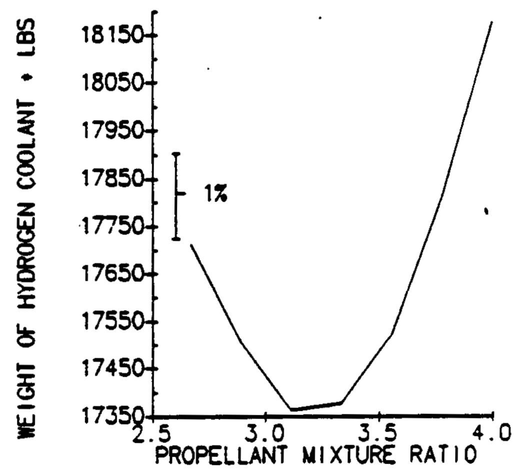


(k-36) Propellant Consumed Versus Propellant Mixture Ratio

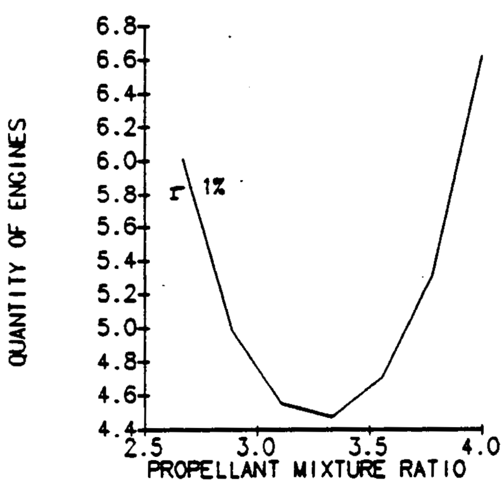
Configuration 2.K Sensitivity Studies (Continued)



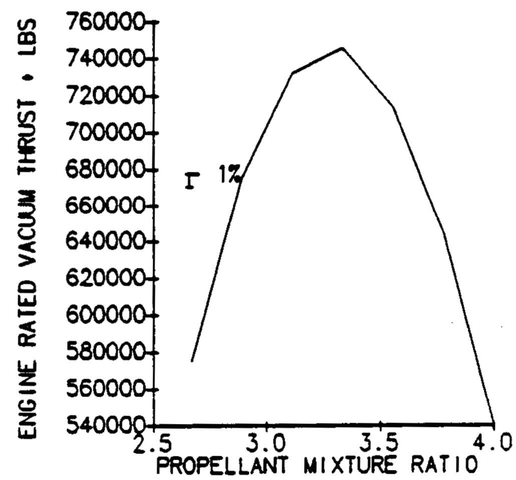
(k-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(k-38) Weight of Hydrogen Coolant Versus Propellant Mixture Ratio

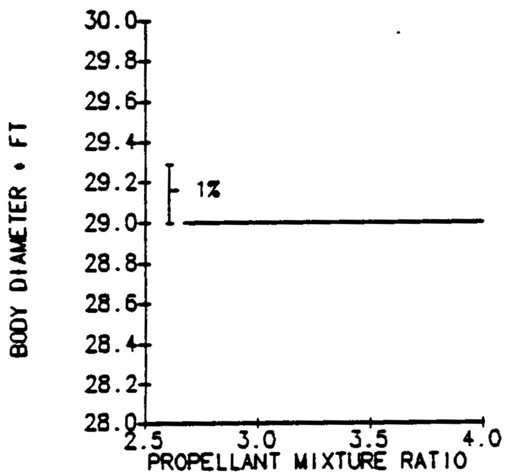


(k-39) Number of Booster Engines Versus Propellant Mixture Ratio

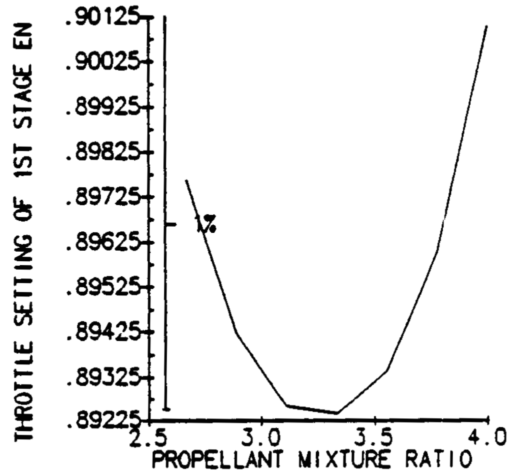


(k-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

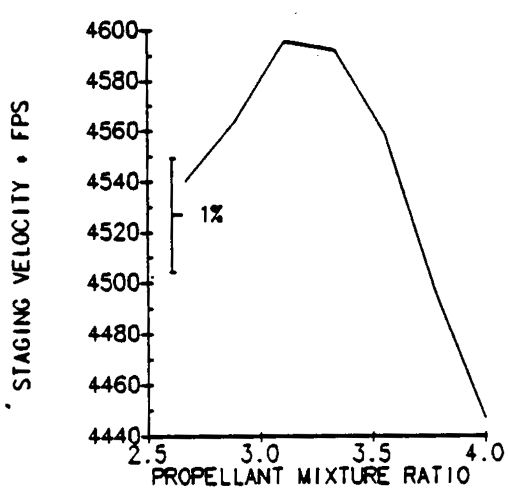
Configuration 2.K Sensitivity Studies (Continued)



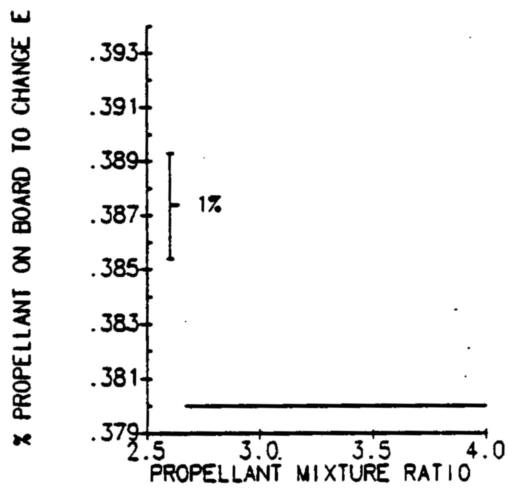
(k-41) Body Diameter Versus Propellant Mixture Ratio



(k-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

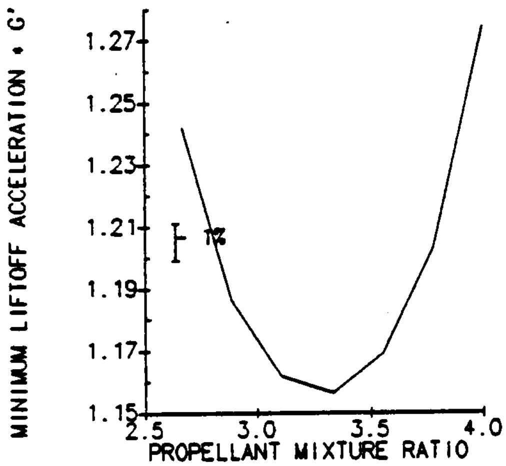


(k-43) Staging Velocity Versus Propellant Mixture Ratio

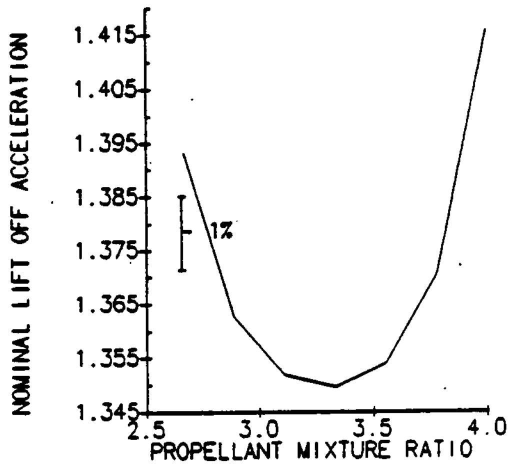


(k-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

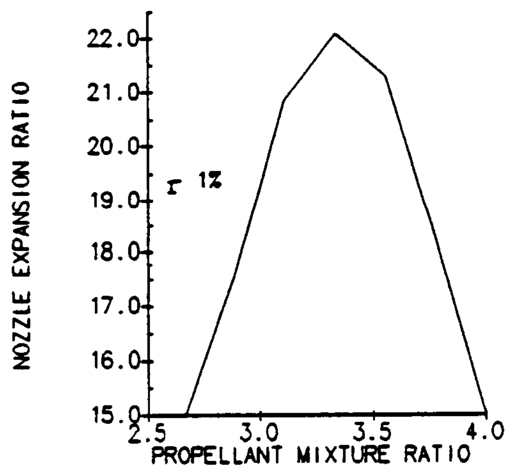
Configuration 2.K Sensitivity Studies (Continued)



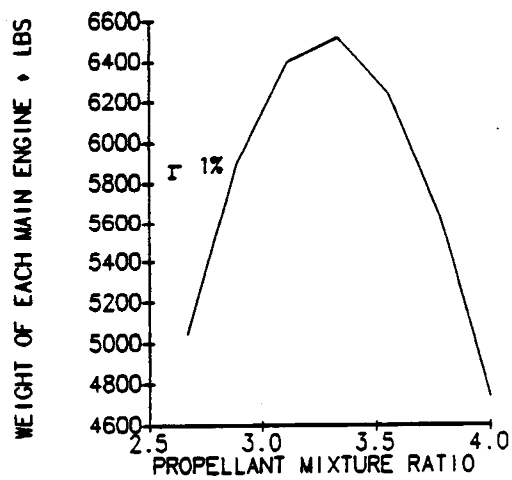
(k-45) **Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio**



(k-46) **Nominal Lift Off Acceleration Versus Propellant Mixture Ratio**

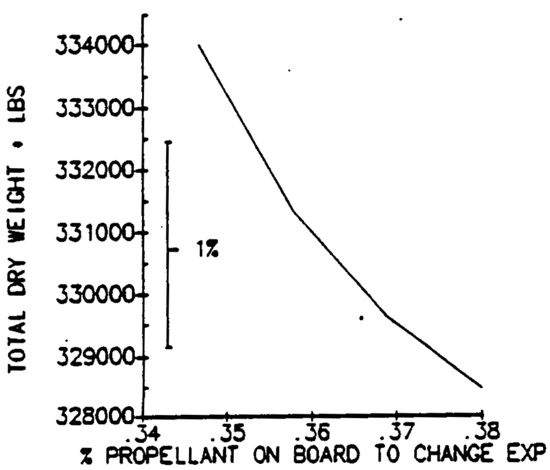


(k-47) **Nozzle Expansion Ratio Versus Propellant Mixture Ratio**

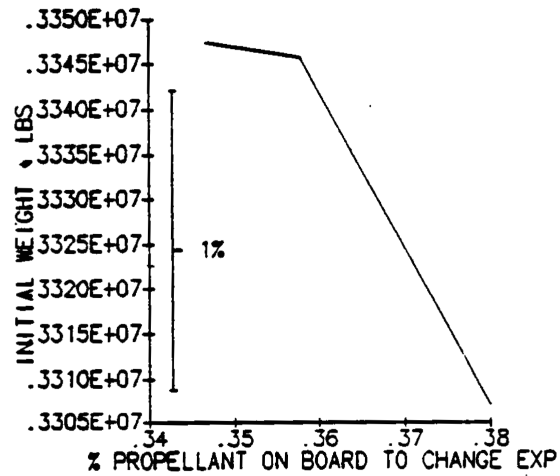


(k-48) **Booster Engine Weight Versus Propellant Mixture Ratio**

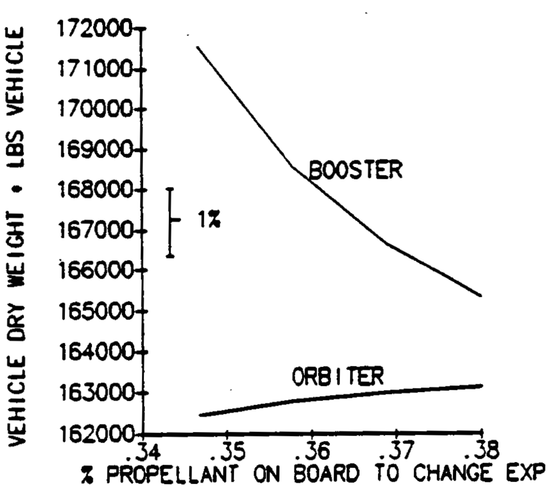
Configuration 2.K Sensitivity Studies (Continued)



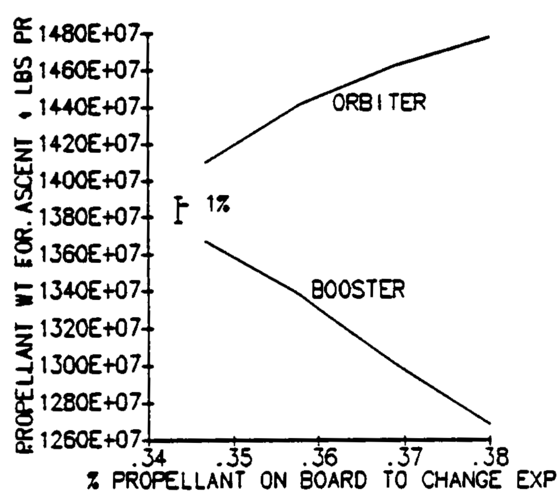
(k-49) **Total Dry Weight Versus Orbiter Propellant at Staging**



(k-50) **Gross Lift Off Weight Versus Orbiter Propellant at Staging**

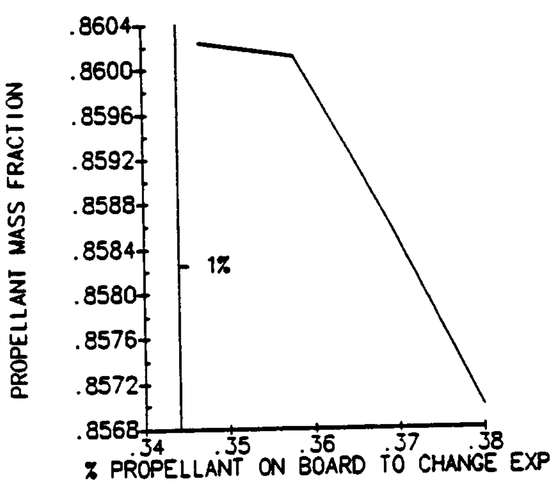


(k-51) **Vehicle Dry Weight Versus Orbiter Propellant at Staging**

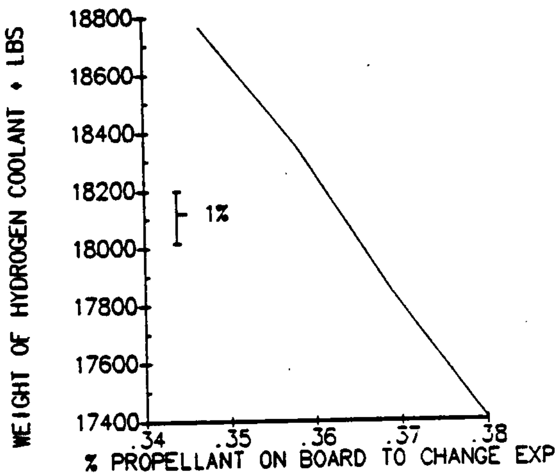


(k-52) **Propellant Consumed Versus Orbiter Propellant at Staging**

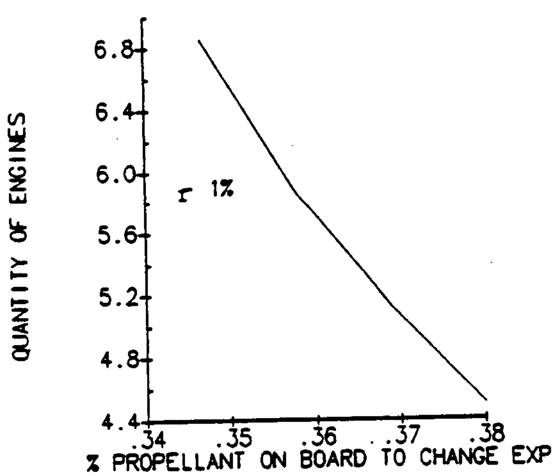
Configuration 2.K Sensitivity Studies (Continued)



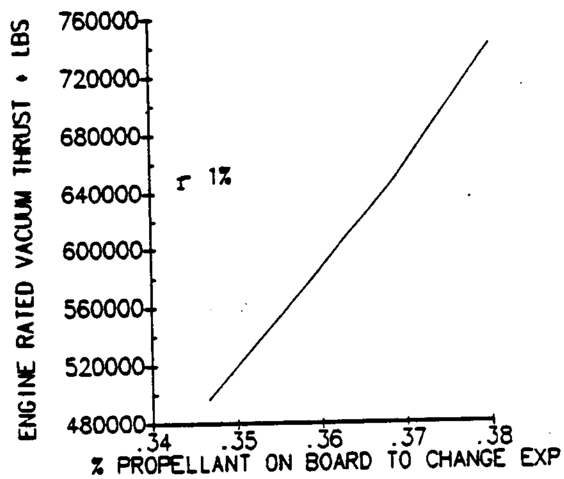
(k-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(k-54) Weight of Hydrogen Coolant Versus Orbiter Propellant at Staging

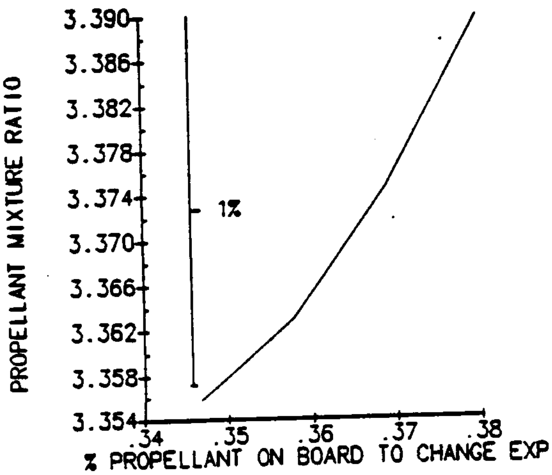


(k-55) Number of Booster Engines Versus Orbiter Propellant at Staging

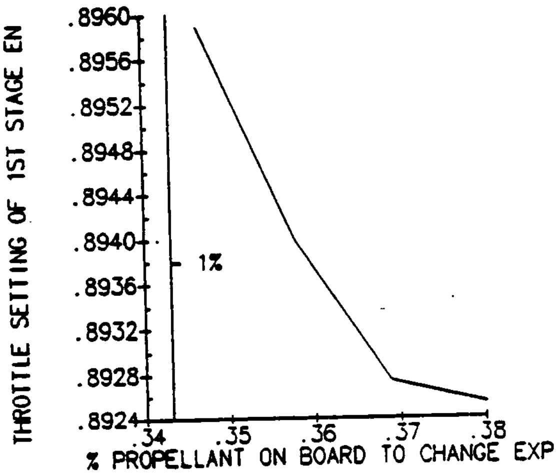


(k-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

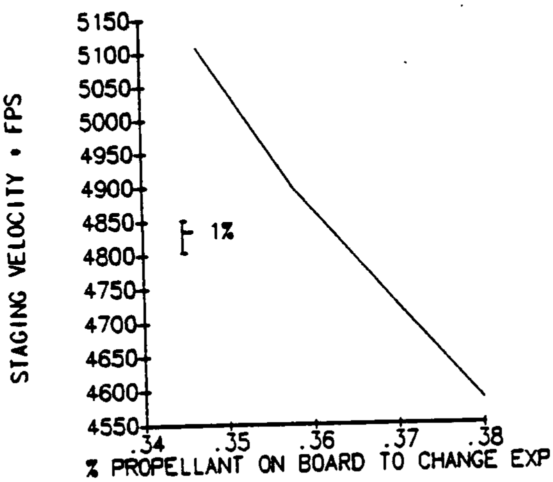
Configuration 2.K Sensitivity Studies (Continued)



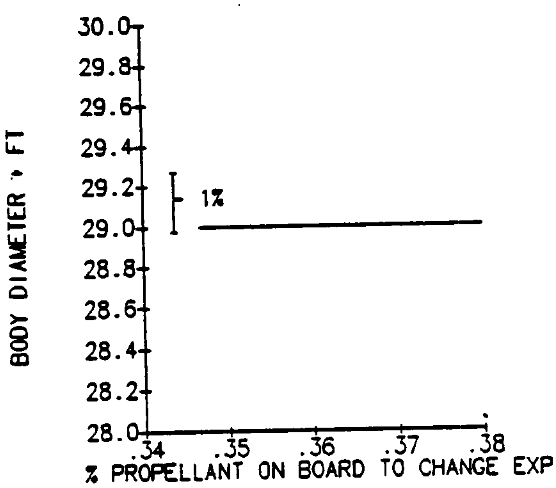
(k-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(k-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

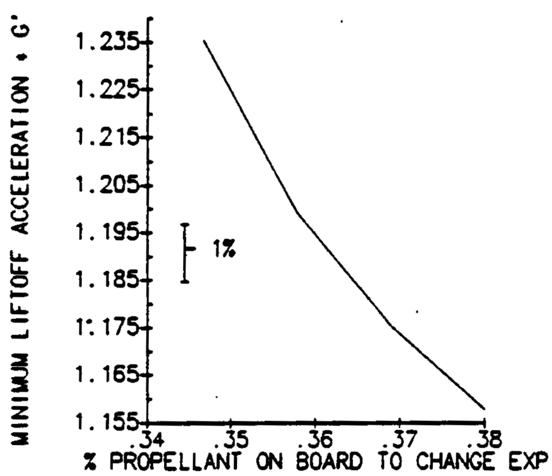


(k-59) Staging Velocity Versus Orbiter Propellant at Staging

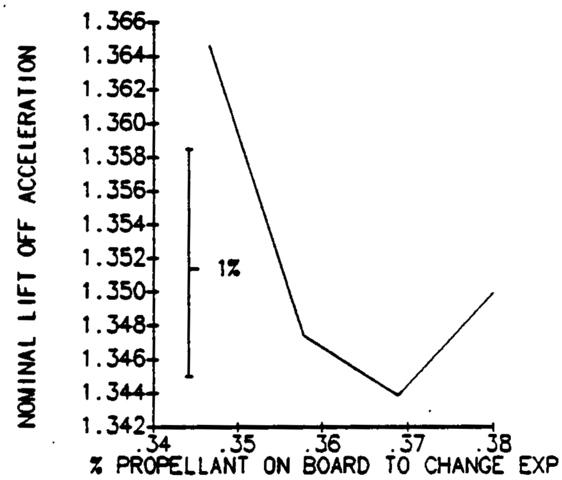


(k-60) Body Diameter Versus Orbiter Propellant at Staging

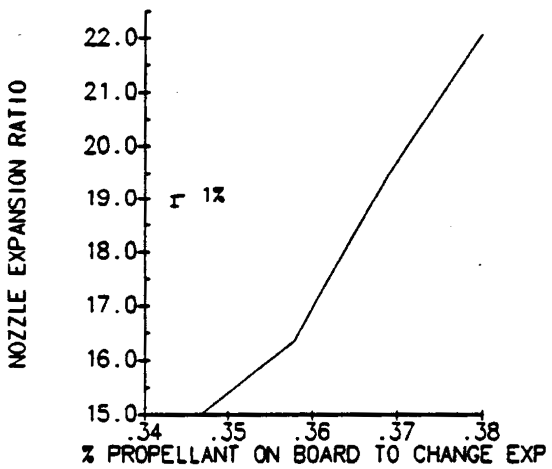
Configuration 2.K Sensitivity Studies (Continued)



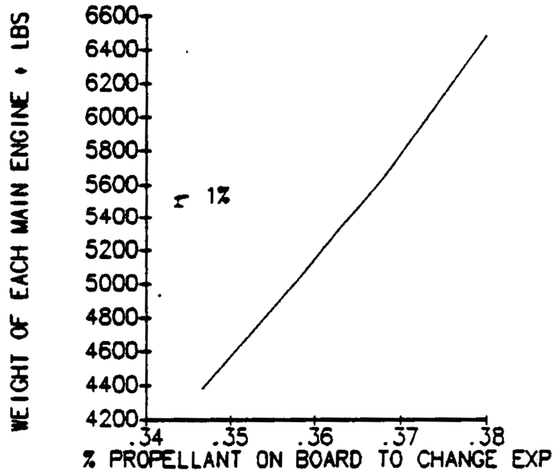
(k-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(k-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

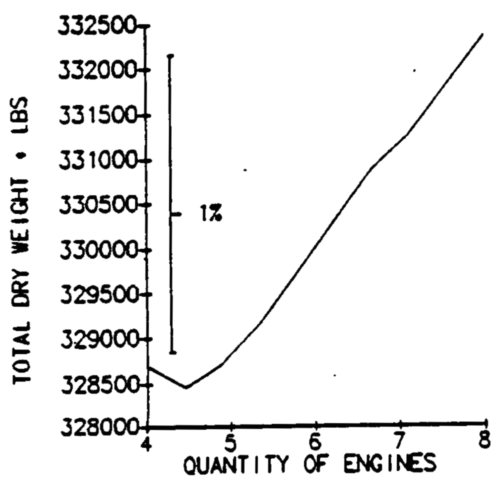


(k-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

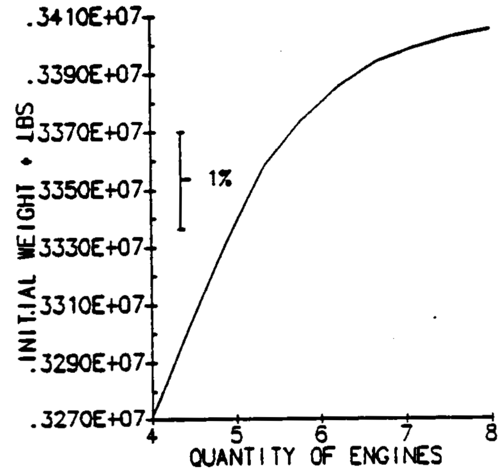


(k-64) Booster Engine Weight Versus Orbiter Propellant at Staging

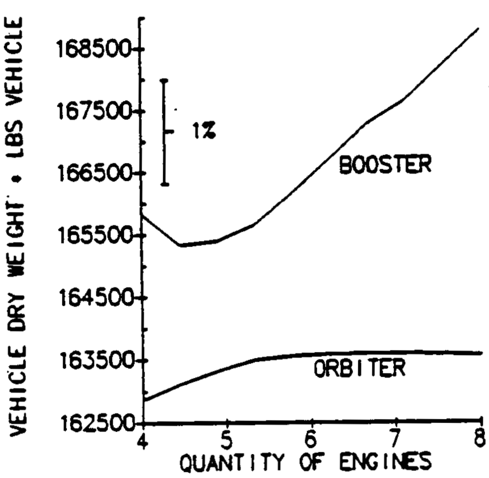
Configuration 2.K Sensitivity Studies (Continued)



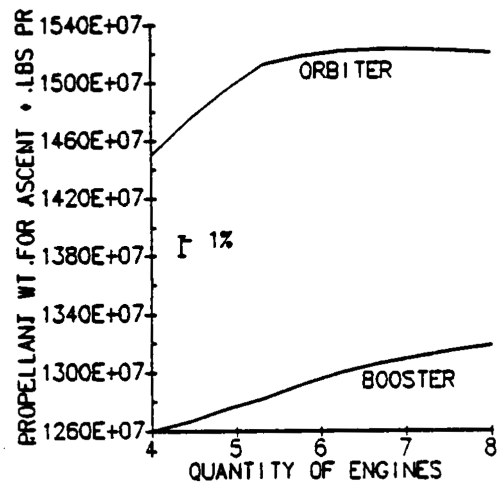
(k-65) Total Dry Weight Versus Number of Booster Engines



(k-66) Gross Lift Off Weight Versus Number of Booster Engines

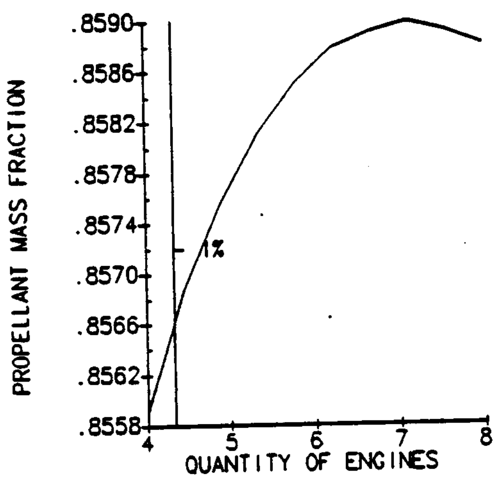


(k-67) Vehicle Dry Weight Versus Number of-Booster Engines

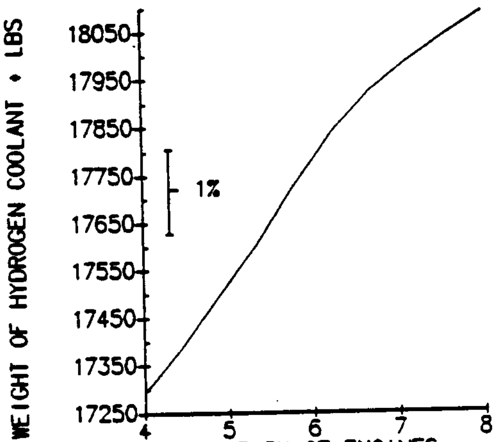


(k-68) Propellant Consumed Versus Number of Booster Engines

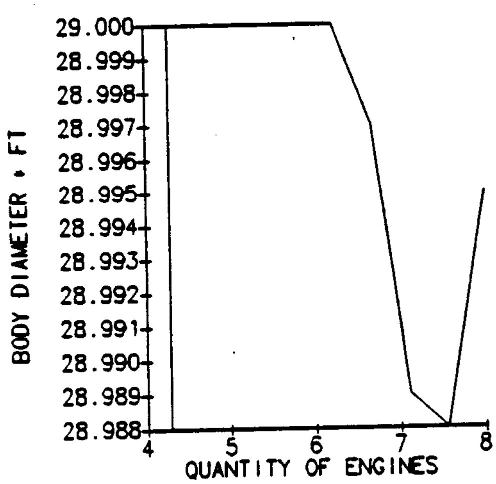
Configuration 2.K Sensitivity Studies (Continued)



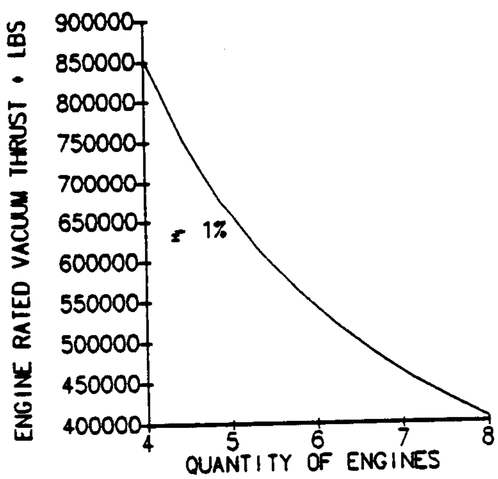
(k-69) Propellant Mass Fraction Versus Number of Booster Engines



(k-70) Weight of Hydrogen Coolant Versus Number of Booster Engines

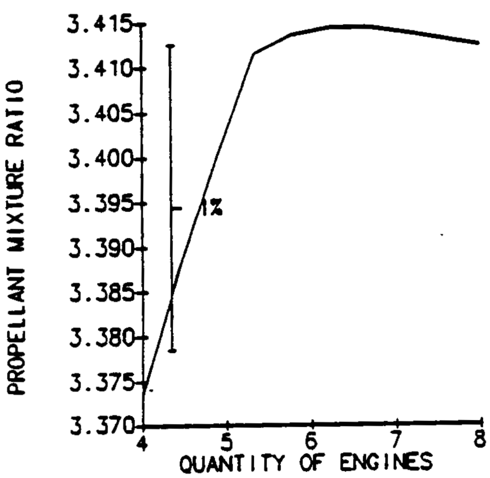


(k-71) Body Diameter Versus Number of Booster Engines

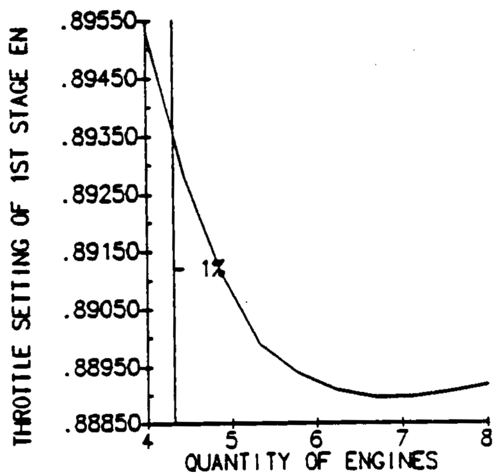


(k-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

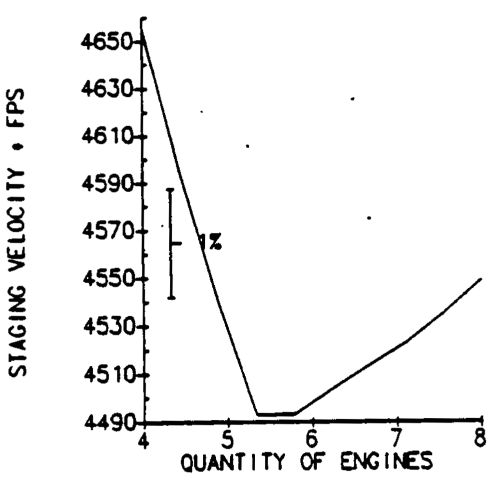
Configuration 2.K Sensitivity Studies (Continued)



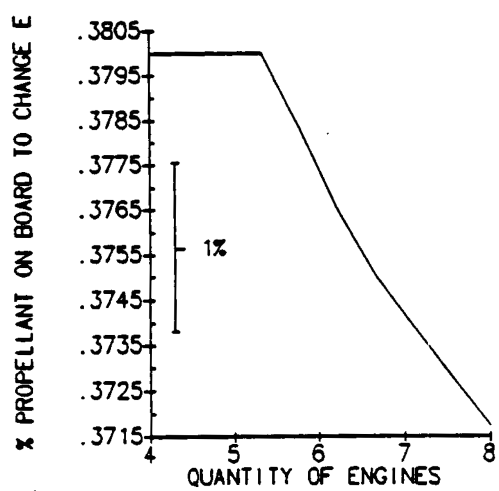
(k-73) Propellant Mixture Ratio Versus Number of Booster Engines



(k-74) Initial Booster Throttle Setting Versus Number of Booster Engines

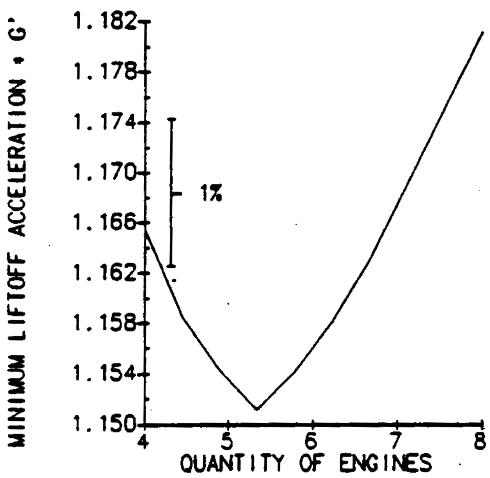


(k-75) Staging Velocity Versus Number of Booster Engines

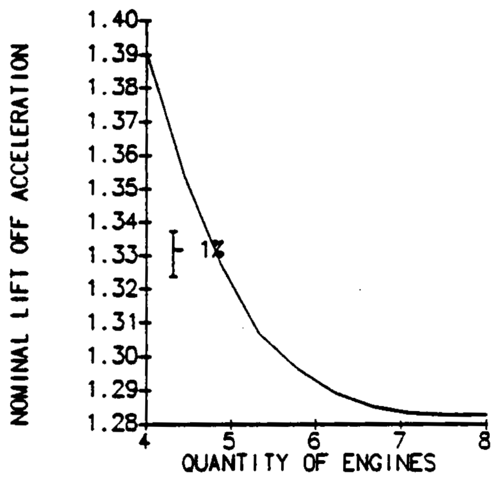


(k-76) Orbiter Propellant at Staging Versus Number of Booster Engines

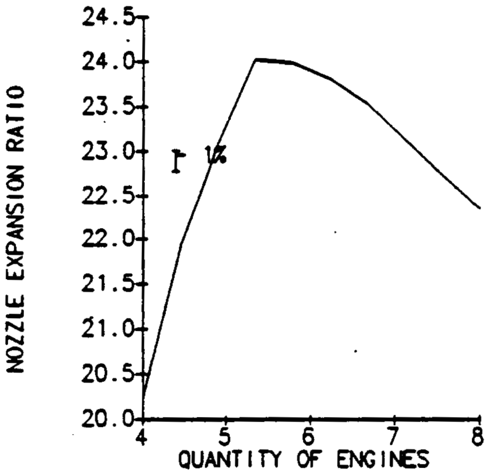
Configuration 2.K Sensitivity Studies (Continued)



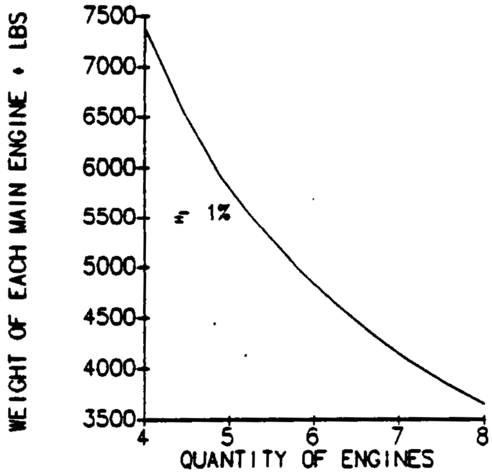
(k-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(k-78) Nominal Lift Off Acceleration Versus Number of Booster Engines



(k-79) Nozzle Expansion Ratio Versus Number of Booster Engines



(k-80) Booster Engine Weight Versus Number of Booster Engines

Configuration 2.K Sensitivity Studies (Continued)

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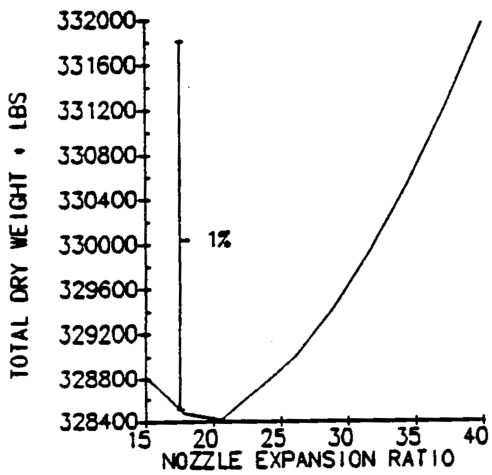
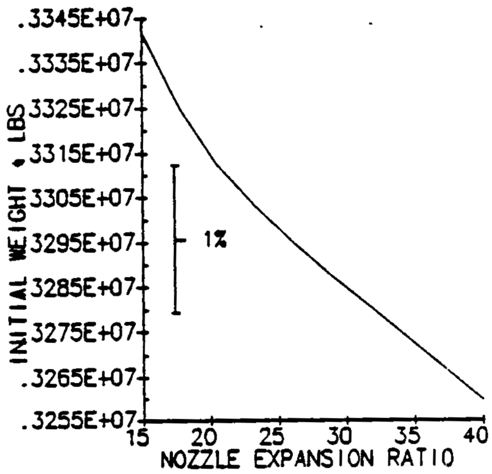
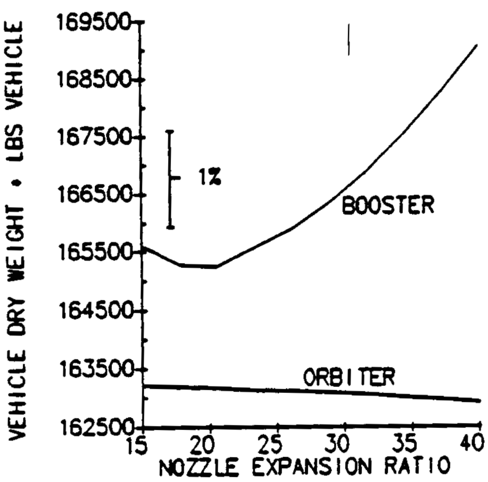


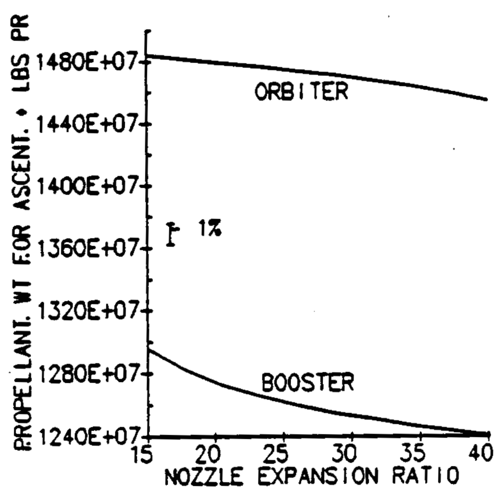
(k-81) Total Dry Weight Versus Nozzle Expansion Ratio



(k-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio



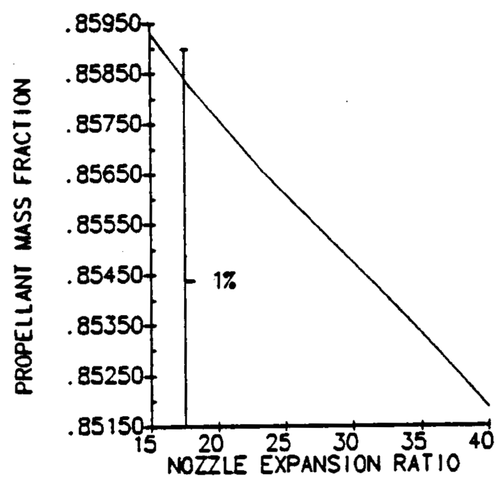
(k-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio



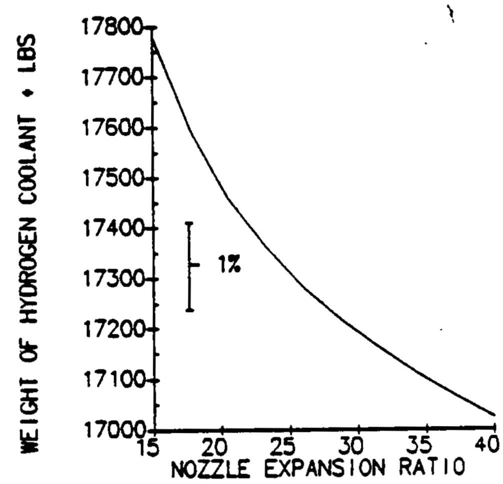
(k-84) Propellant Consumed Versus Nozzle Expansion Ratio

Configuration 2.K Sensitivity Studies (Continued)

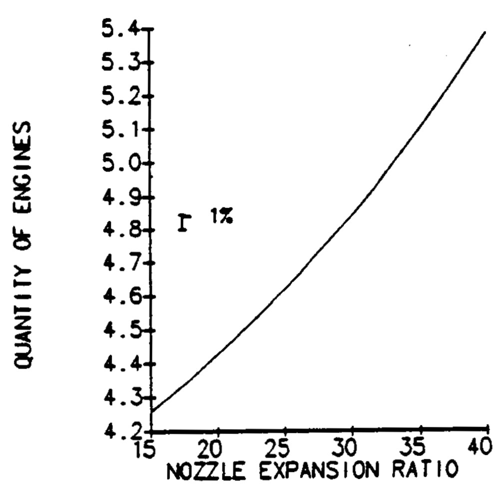
C-6



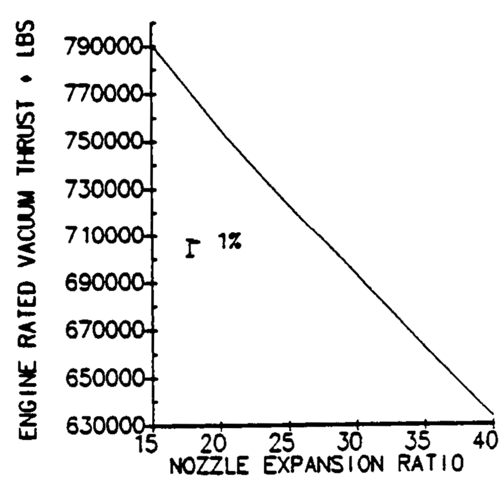
(k-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(k-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

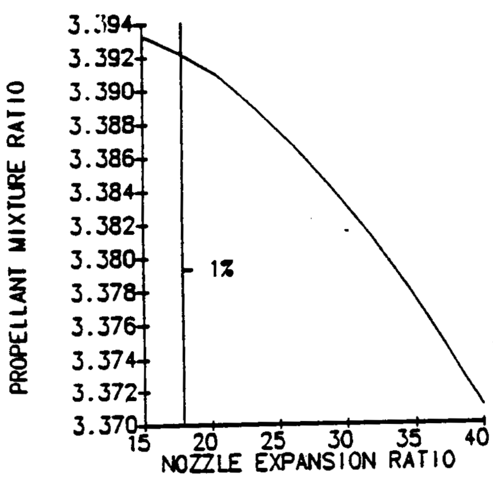


(k-87) Number of Booster Engines Versus Nozzle Expansion Ratio

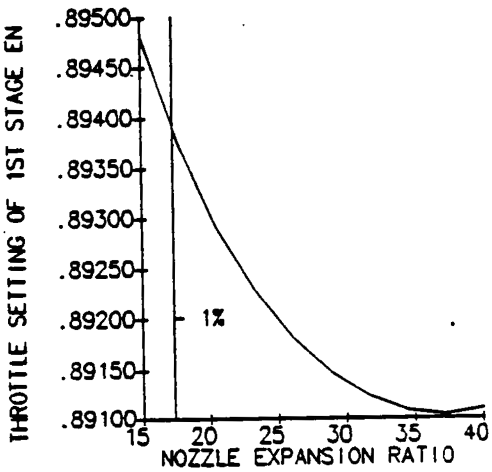


(k-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

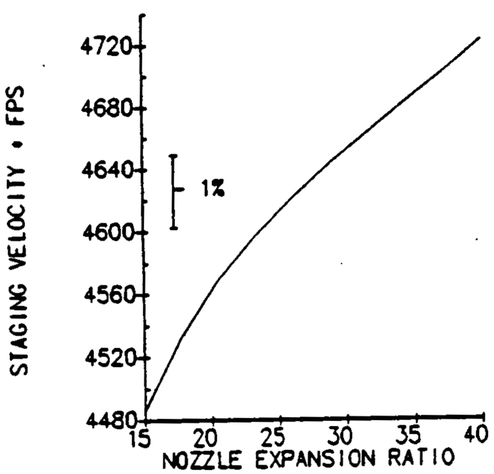
Configuration 2.K Sensitivity Studies (Continued)



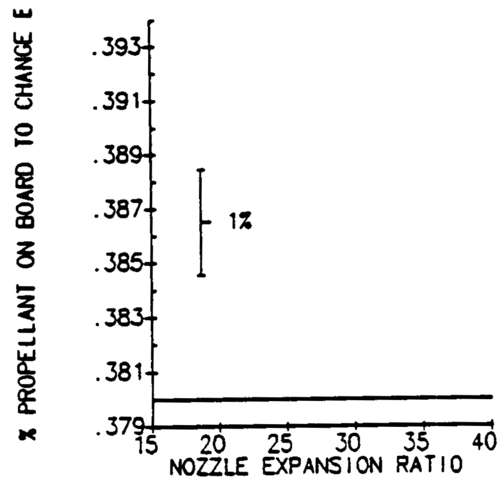
(k-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(k-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

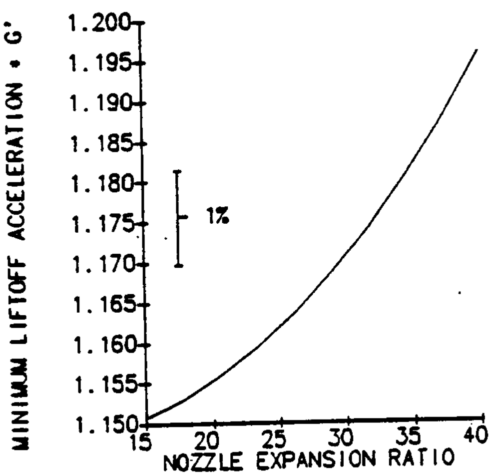


(k-91) Staging Velocity Versus Nozzle Expansion Ratio

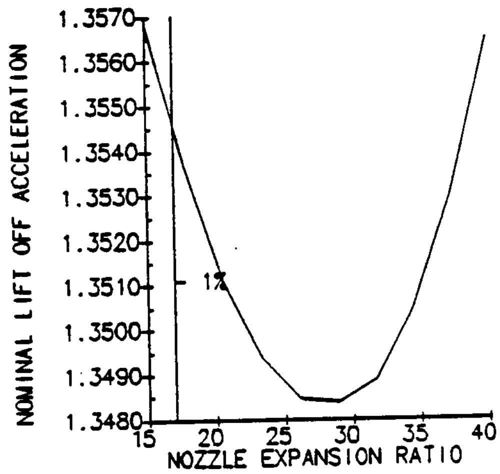


(k-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

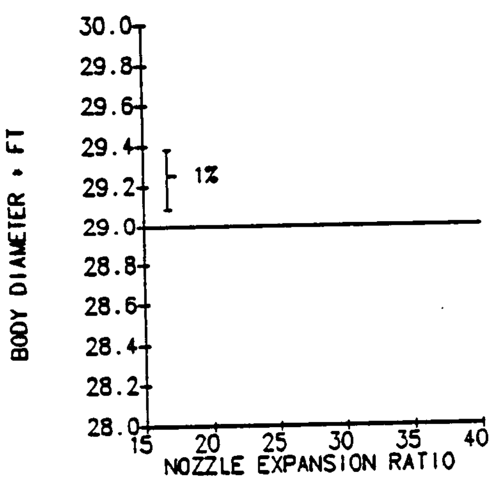
Configuration 2.K Sensitivity Studies (Continued)



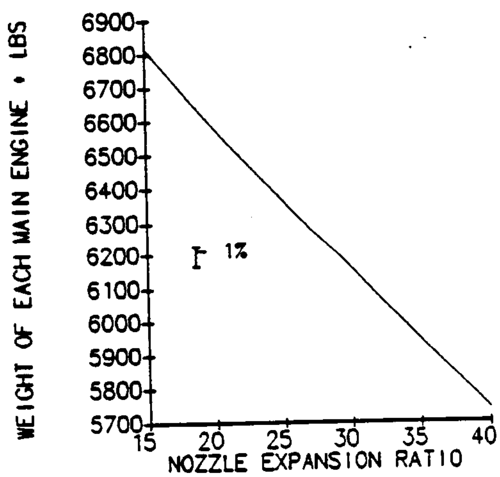
(k-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(k-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

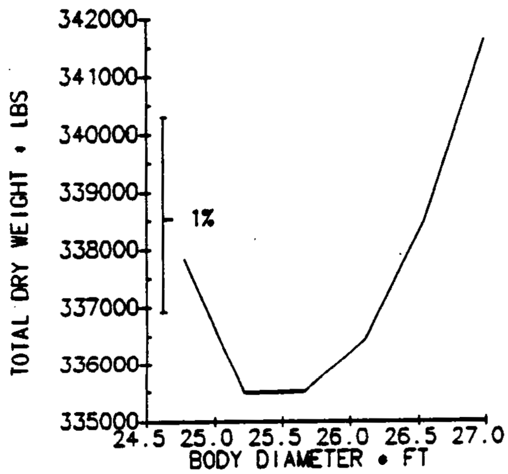


(k-95) Body Diameter Versus Nozzle Expansion Ratio

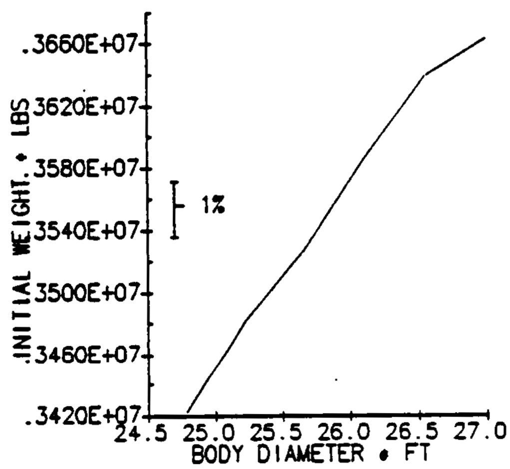


(k-96) Booster Engine Weight Versus Nozzle Expansion Ratio

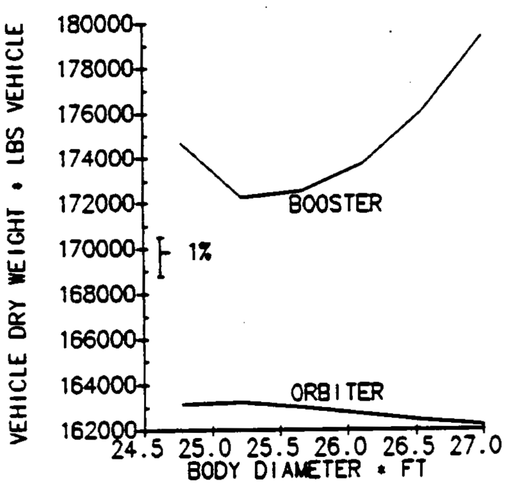
Configuration 2.K Sensitivity Studies (Continued)



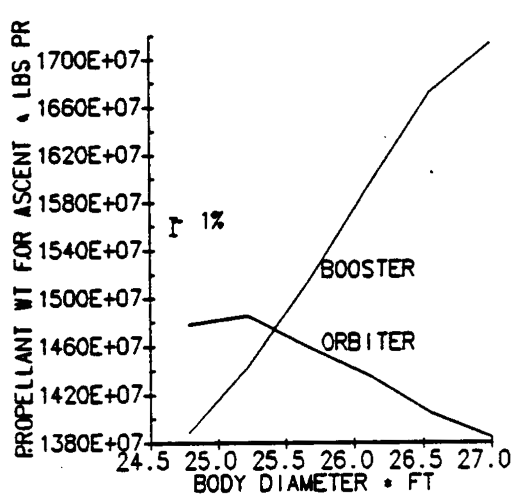
(I-1) Total Dry Weight Versus Body Diameter



(I-2) Gross Lift Off Weight Versus Body Diameter

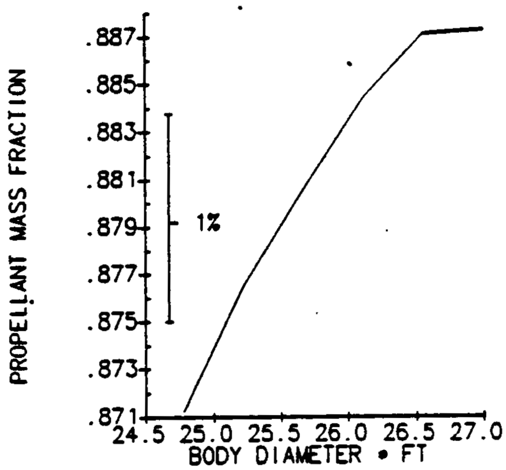


(I-3) Vehicle Dry Weight Versus Body Diameter

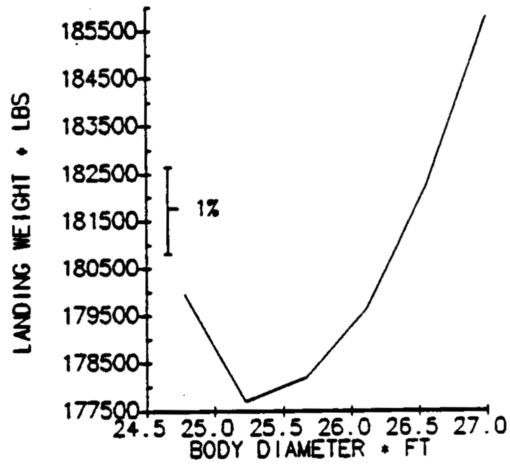


(I-4) Propellant Consumed Versus Body Diameter

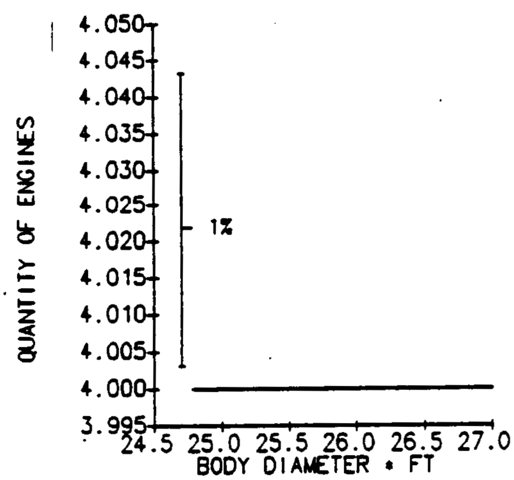
Configuration 2.L Sensitivity Studies



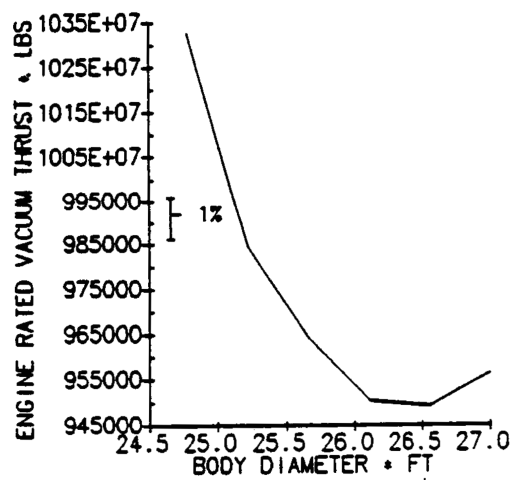
(I-5) Propellant Mass Fraction Versus Body Diameter



(I-6) Landing Weight Versus Body Diameter

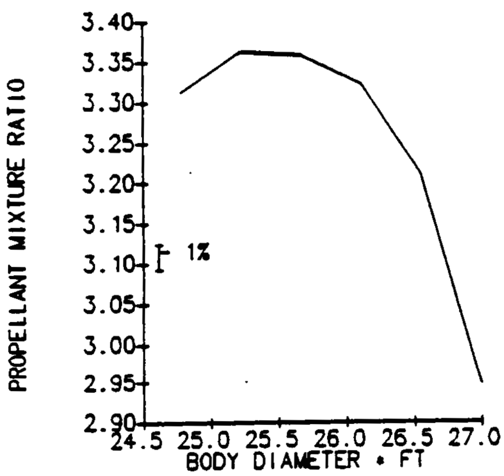


(I-7) Number of Booster Engines Versus Body Diameter

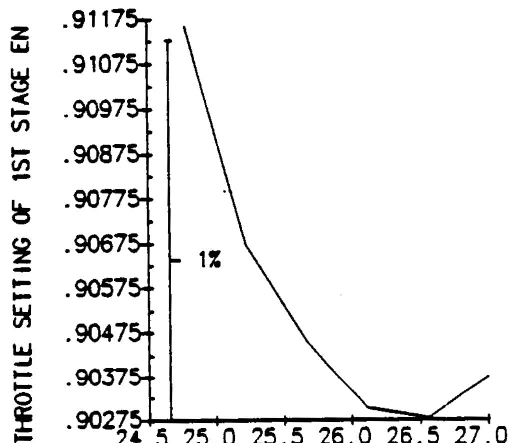


(I-8) Engine Rated Vacuum Thrust Versus Body Diameter

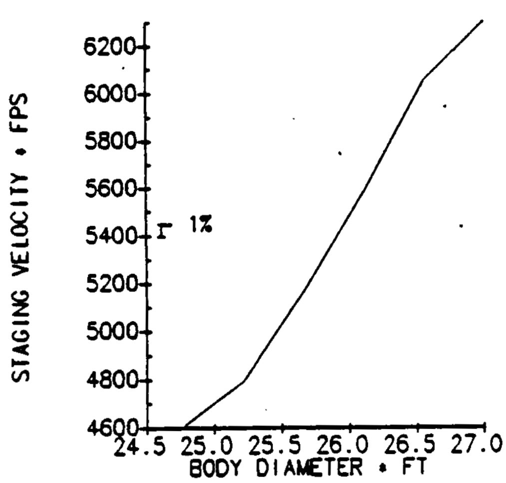
Configuration 2.L Sensitivity Studies (Continued)



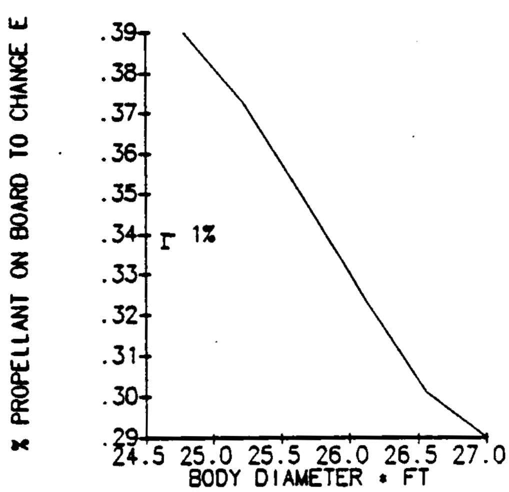
(I-9) Propellant Mixture Ratio Versus Body Diameter



(I-10) Initial Booster Throttle Setting Versus Body Diameter

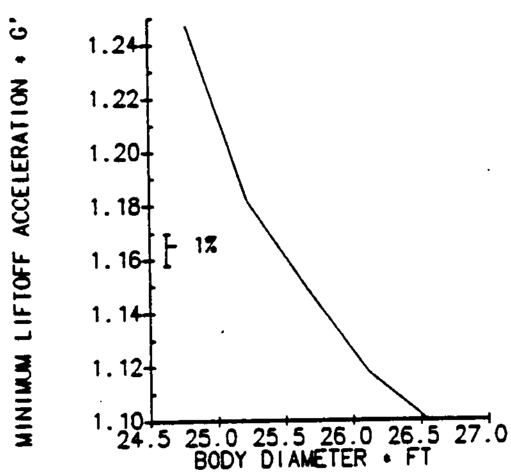


(I-11) Staging Velocity Versus Body Diameter

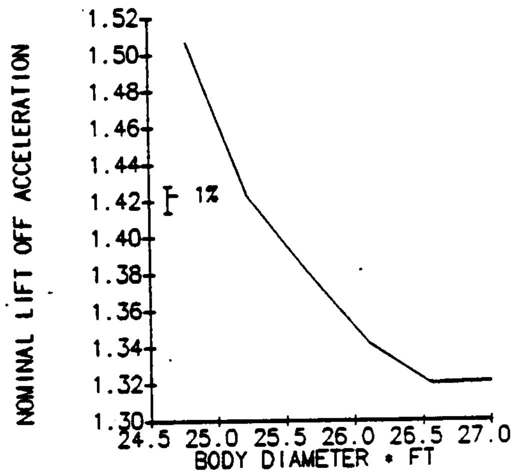


(I-12) Orbiter Propellant at Staging Versus Body Diameter

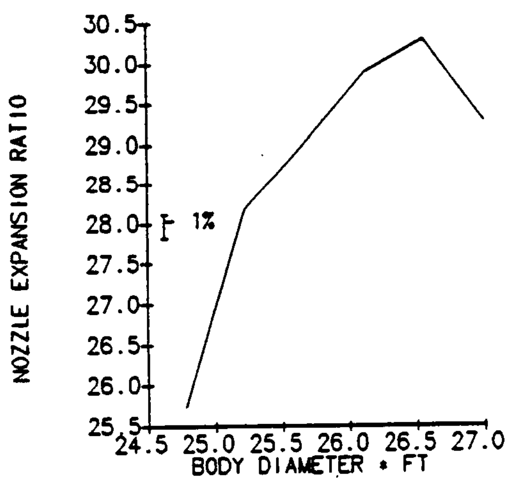
Configuration 2.L Sensitivity Studies (Continued)



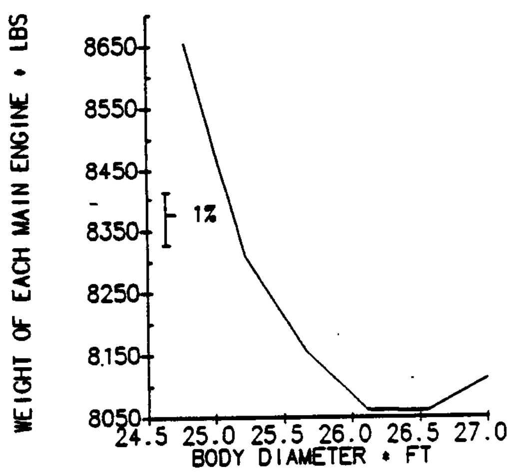
(I-13) Engine-out Lift Off Acceleration Versus Body Diameter



(I-14) Nominal Lift Off Acceleration Versus Body Diameter

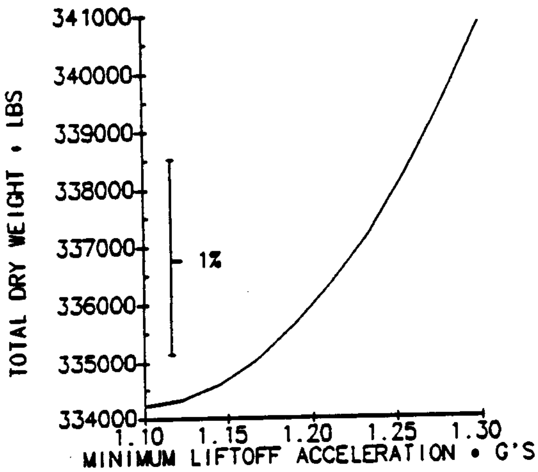


(I-15) Nozzle Expansion Ratio Versus Body Diameter

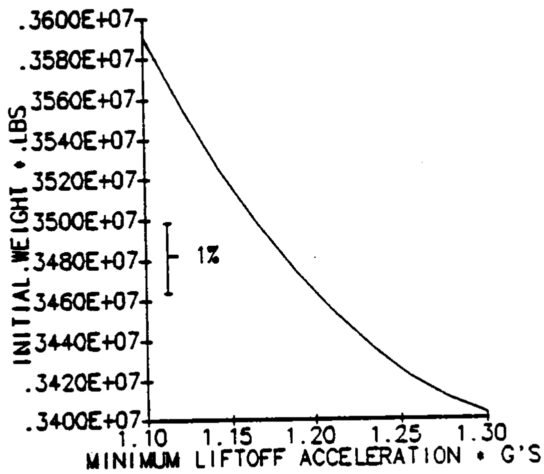


(I-16) Booster Engine Weight Versus Body Diameter

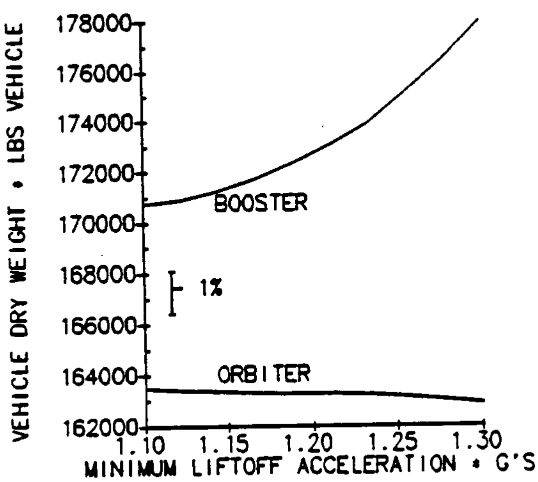
Configuration 2.L Sensitivity Studies (Continued)



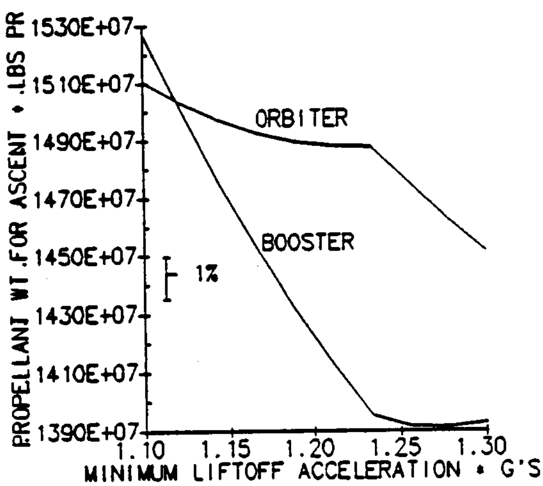
(I-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(I-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

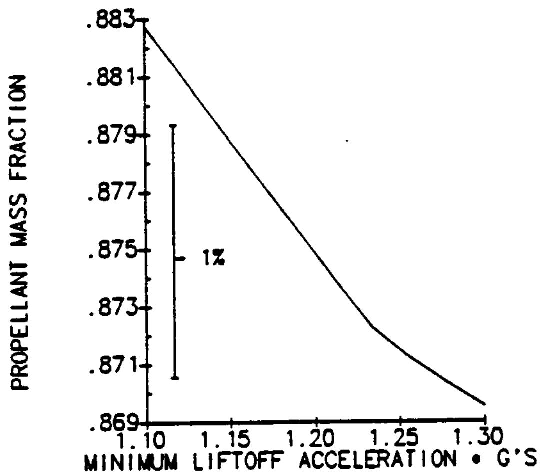


(I-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

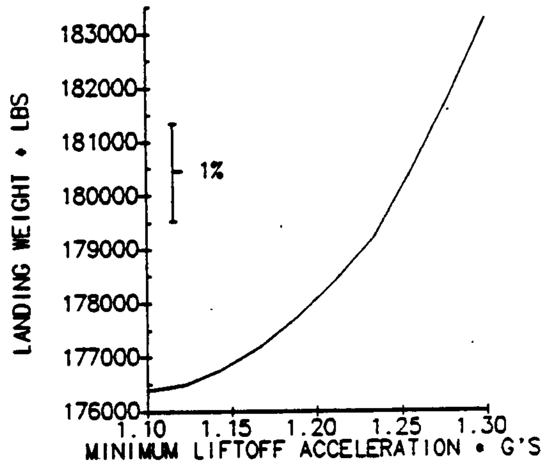


(I-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

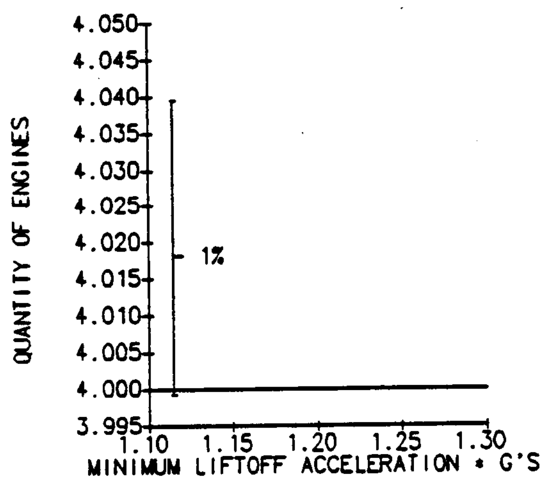
Configuration 2.L Sensitivity Studies (Continued)



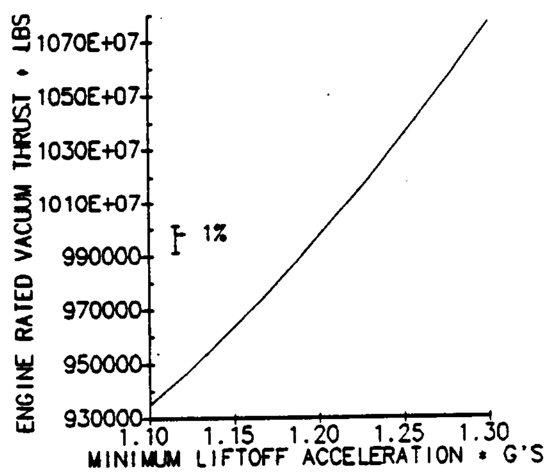
(I-21) Propellant Mass Fraction Versus Engine-out Lift Off Acceleration



(I-22) Landing Weight Versus Engine-out Lift Off Acceleration

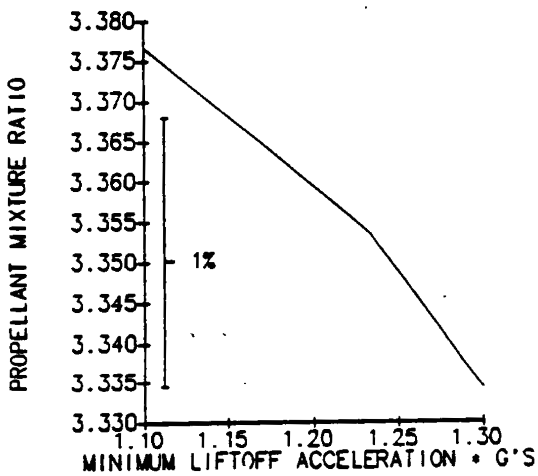


(I-23) Number of Booster Engines Versus Engine-out Lift Off Acceleration

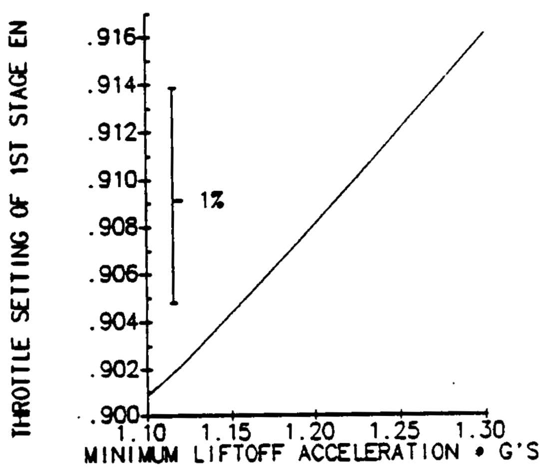


(I-24) Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration

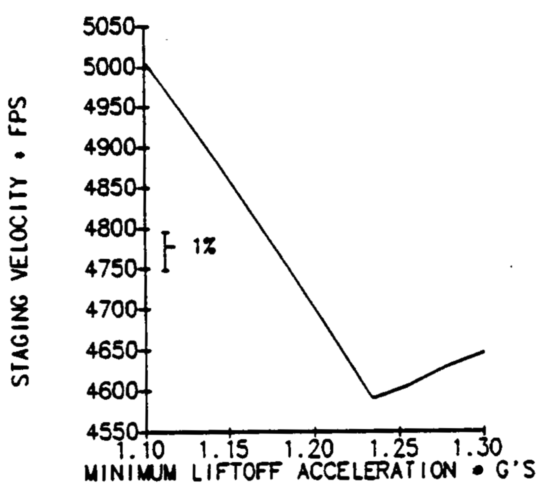
Configuration 2.L Sensitivity Studies (Continued)



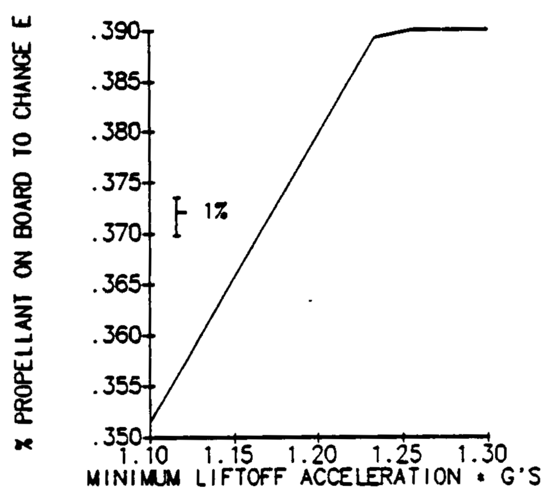
(I-25) Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration



(I-26) Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration

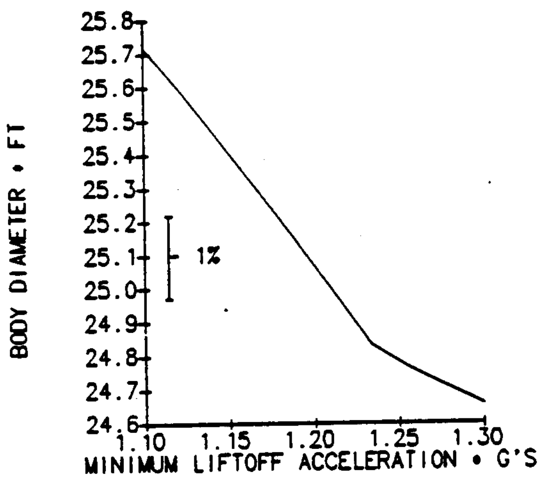


(I-27) Staging Velocity Versus Engine-out Lift Off Acceleration

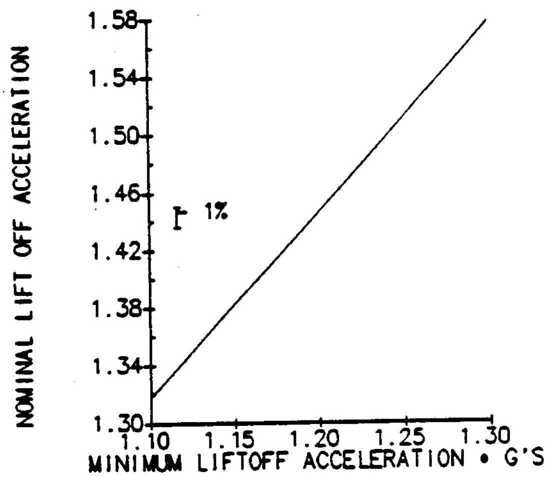


(I-28) Orbiter Propellant at Staging Versus Engine-out Lift Off Acceleration

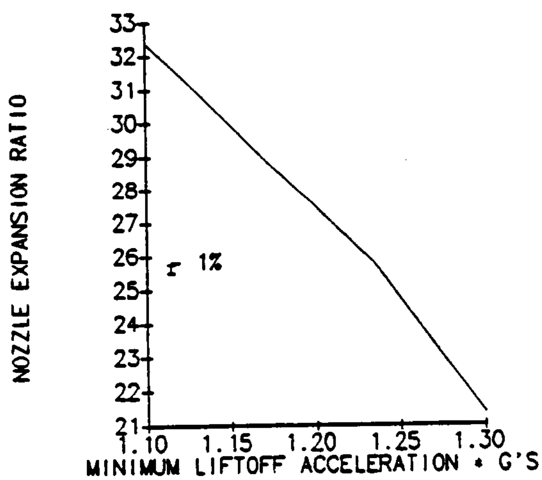
Configuration 2.L Sensitivity Studies (Continued)



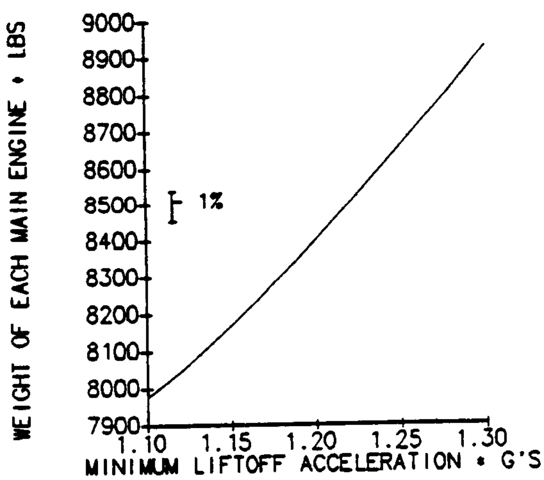
(I-29) Body Diameter Versus Engine-out Lift Off Acceleration



(I-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

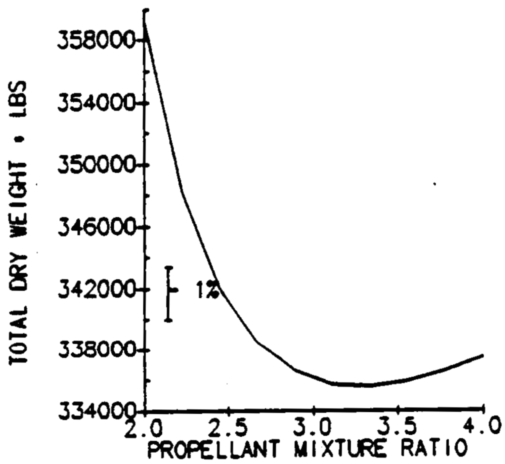


(I-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

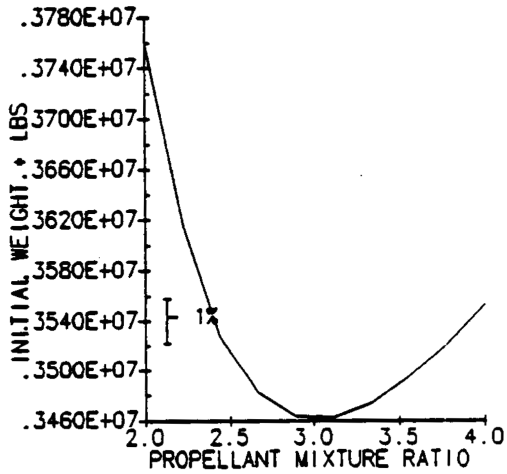


(I-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

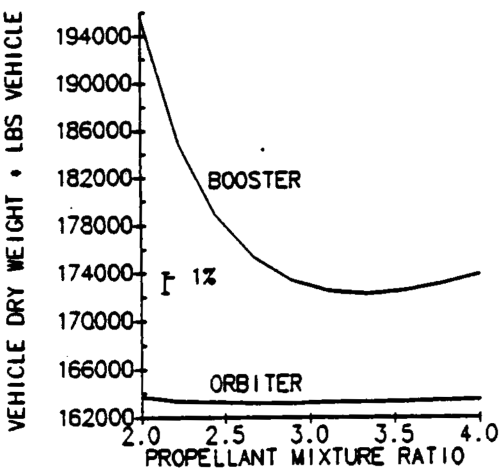
Configuration 2.L Sensitivity Studies (Continued)



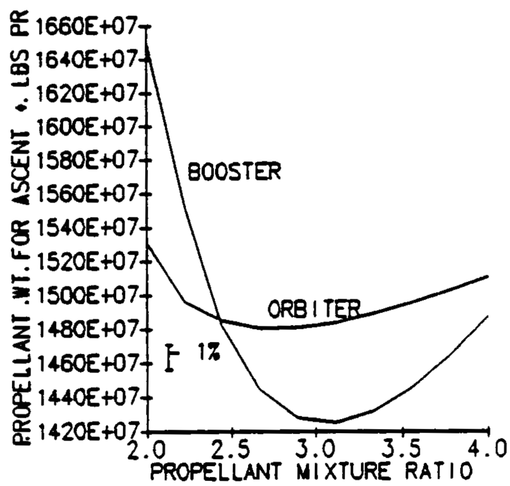
(I-33) Total Dry Weight Versus Propellant Mixture Ratio



(I-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

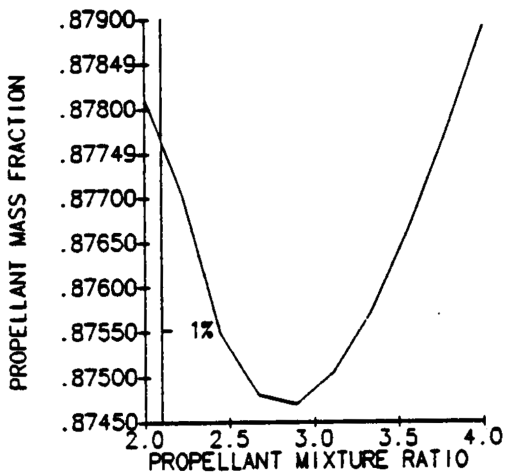


(I-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

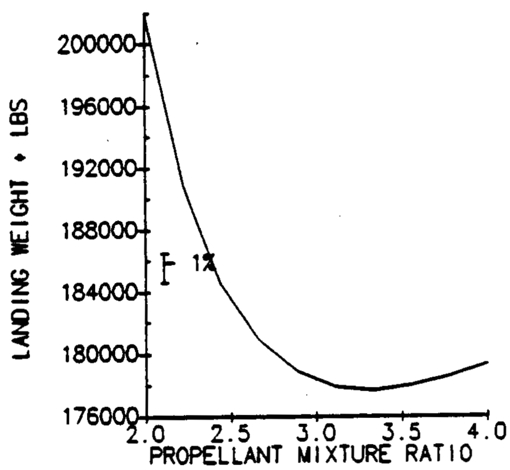


(I-36) Propellant Consumed Versus Propellant Mixture Ratio

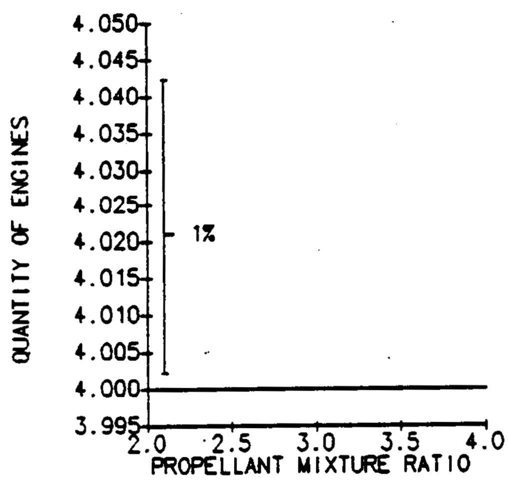
Configuration 2.L Sensitivity Studies (Continued)



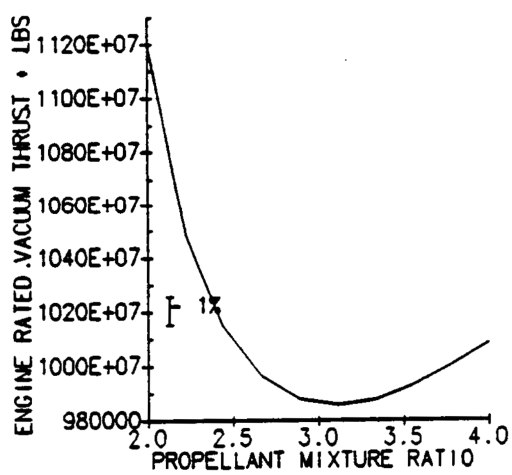
(I-37) Propellant Mass Fraction Versus Propellant Mixture Ratio



(I-38) Landing Weight Versus Propellant Mixture Ratio

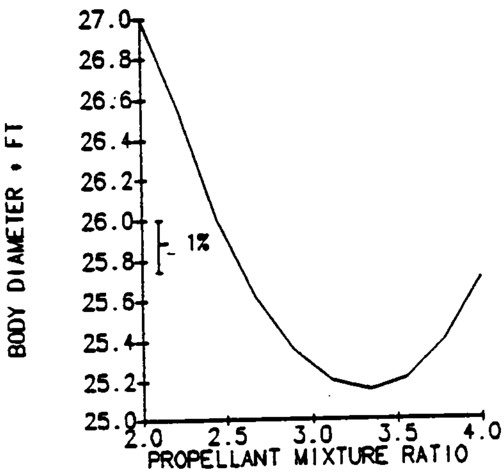


(I-39) Number of Booster Engines Versus Propellant Mixture Ratio

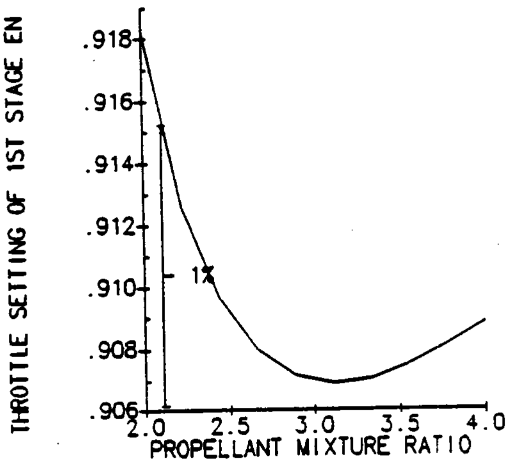


(I-40) Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio

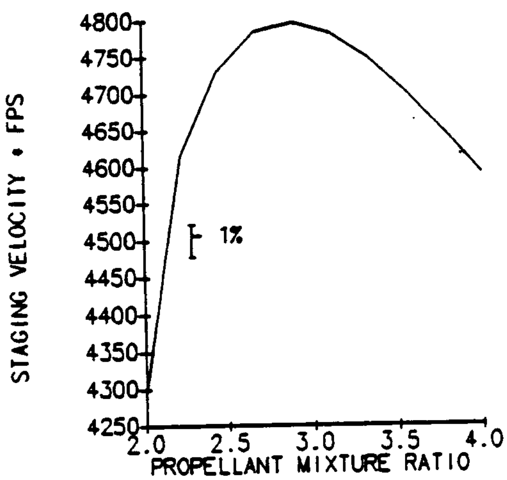
Configuration 2.L Sensitivity Studies (Continued)



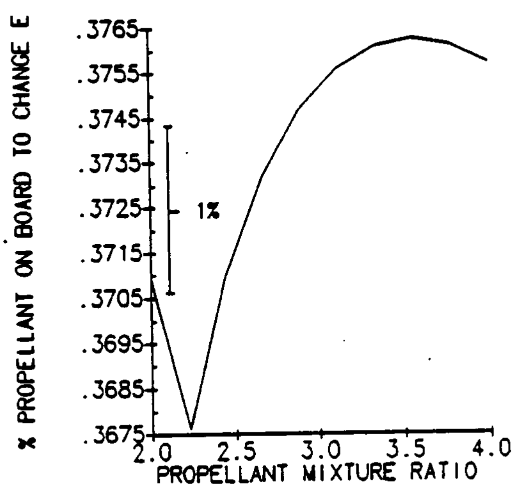
(I-41) Body Diameter Versus Propellant Mixture Ratio



(I-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

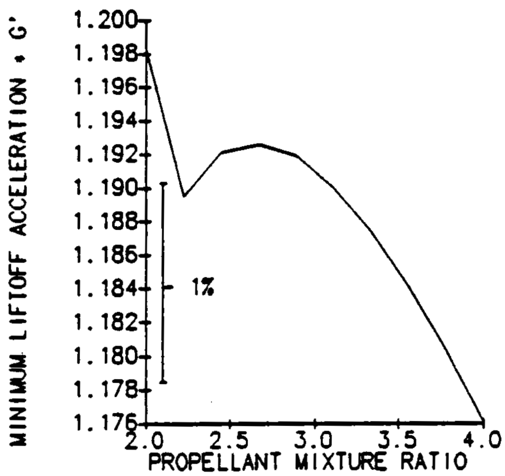


(I-43) Staging Velocity Versus Propellant Mixture Ratio

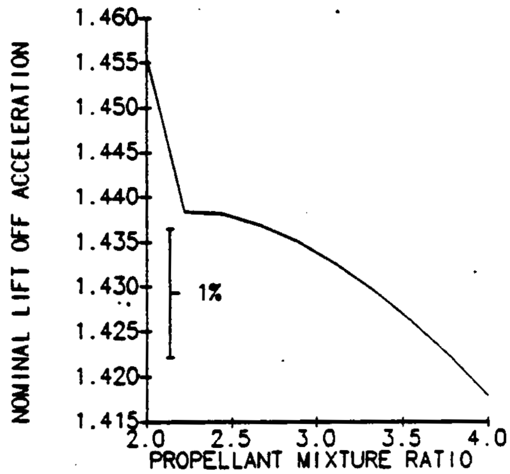


(I-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

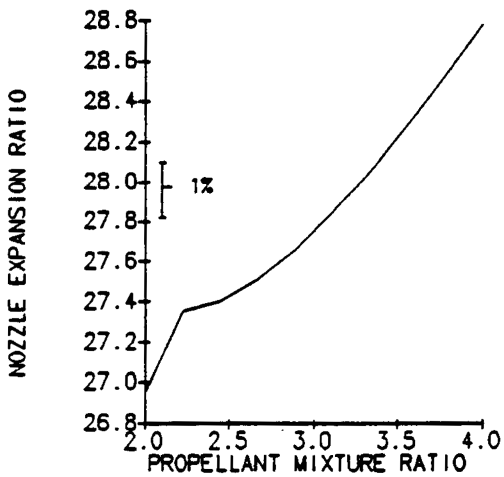
Configuration 2.L Sensitivity Studies (Continued)



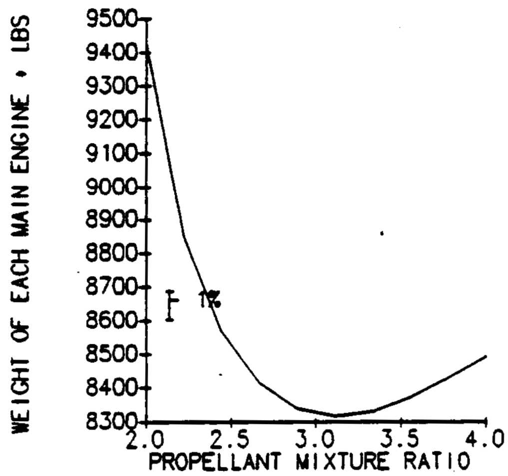
(I-45) Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio



(I-46) Nominal Lift Off Acceleration Versus Propellant Mixture Ratio

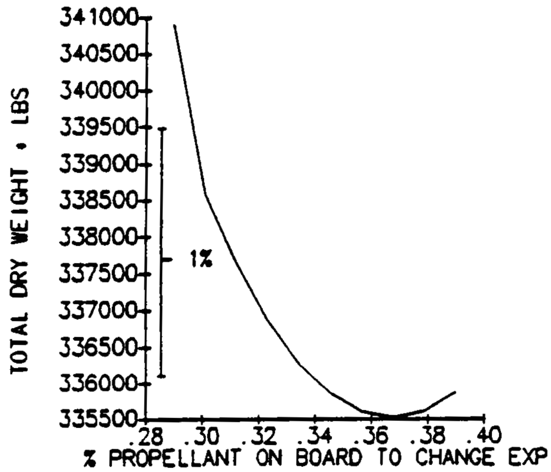


(I-47) Nozzle Expansion Ratio Versus Propellant Mixture Ratio

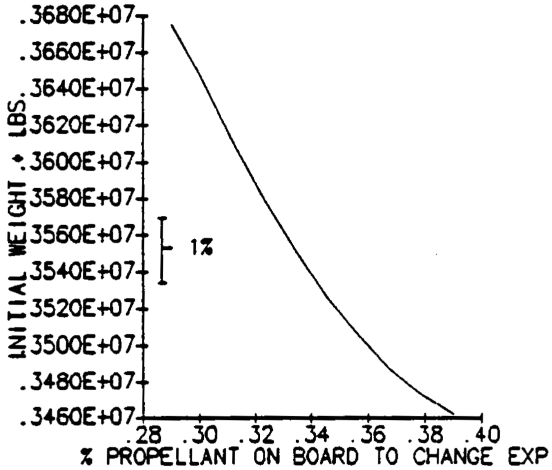


(I-48) Booster Engine Weight Versus Propellant Mixture Ratio

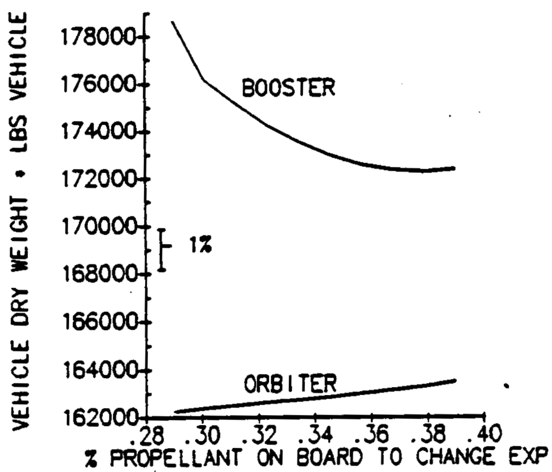
Configuration 2.L Sensitivity Studies (Continued)



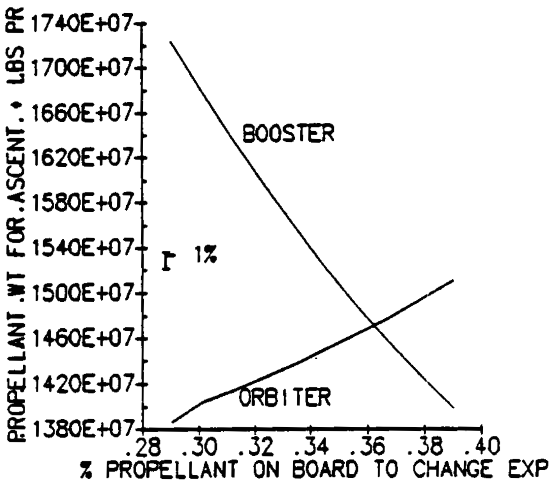
(I-49) Total Dry Weight Versus Orbiter Propellant at Staging



(I-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

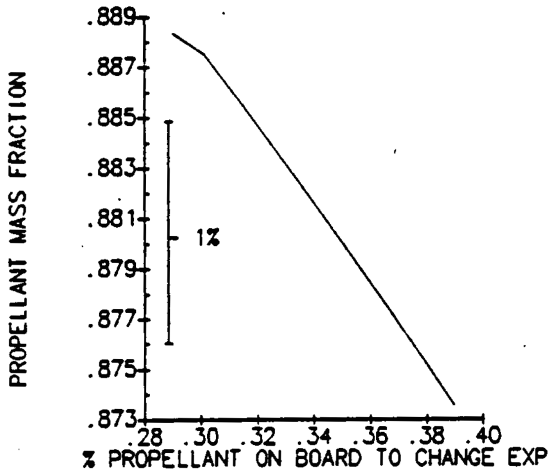


(I-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

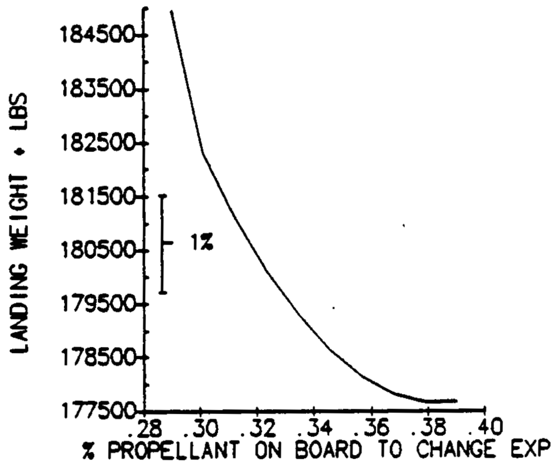


(I-52) Propellant Consumed Versus Orbiter Propellant at Staging

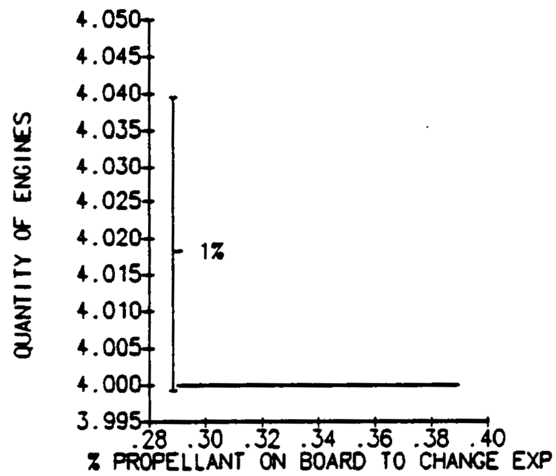
Configuration 2.L Sensitivity Studies (Continued)



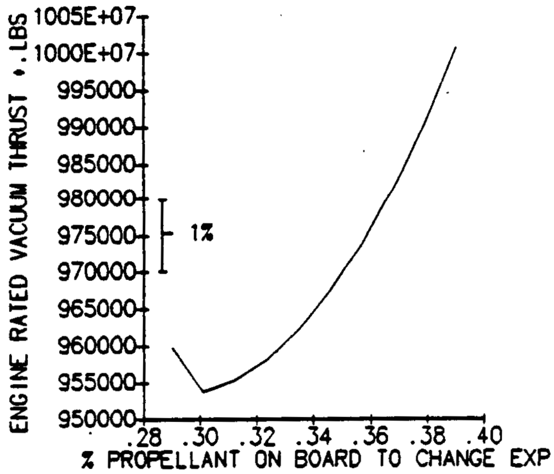
(I-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(I-54) Landing Weight Versus Orbiter Propellant at Staging

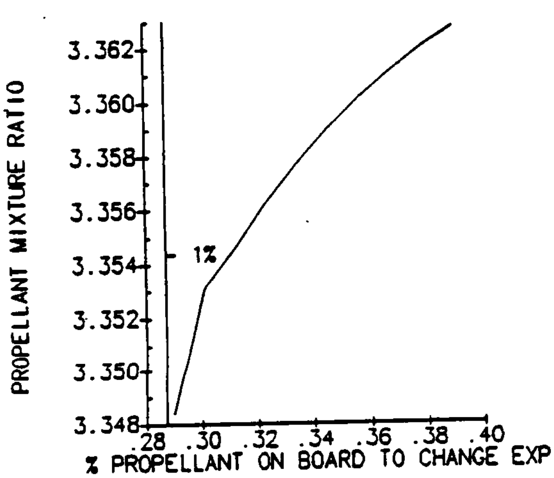


(I-55) Number of Booster Engines Versus Orbiter Propellant at Staging

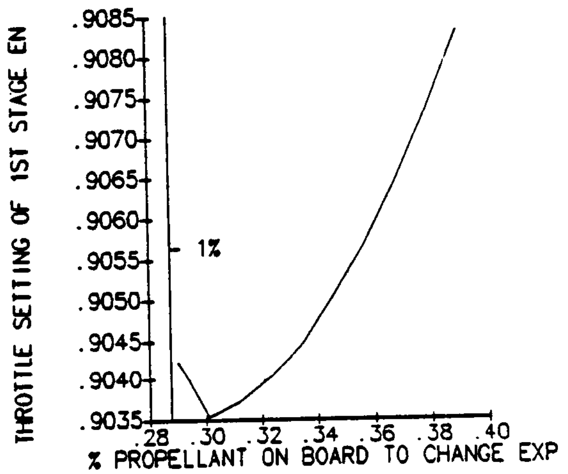


(I-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

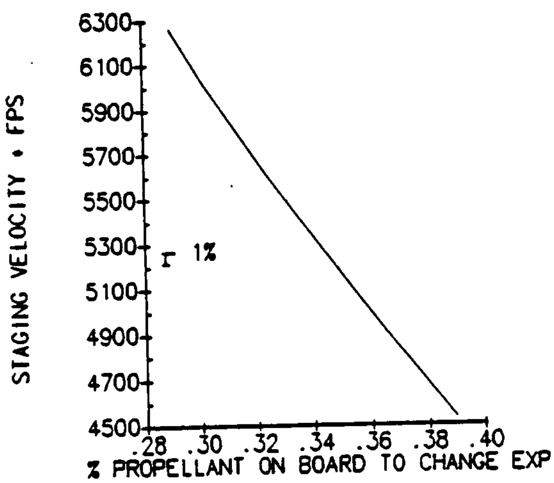
Configuration 2.L Sensitivity Studies (Continued)



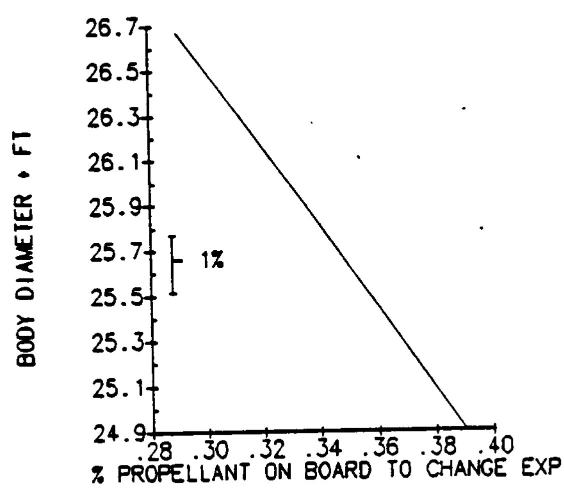
(I-57) Propellant Mixture Ratio Versus Orbiter Propellant at Staging



(I-58) Initial Booster Throttle Setting Versus Orbiter Propellant at Staging

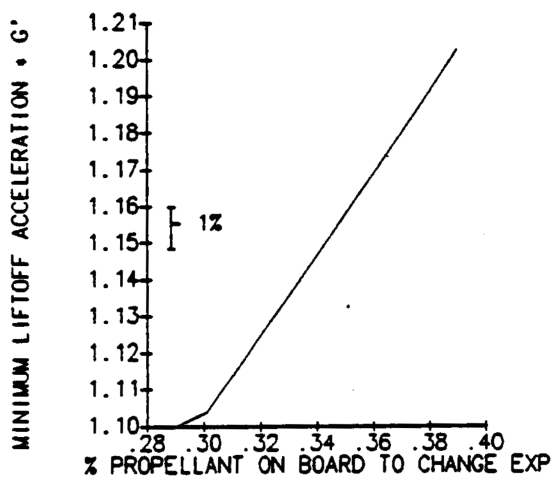


(I-59) Staging Velocity Versus Orbiter Propellant at Staging

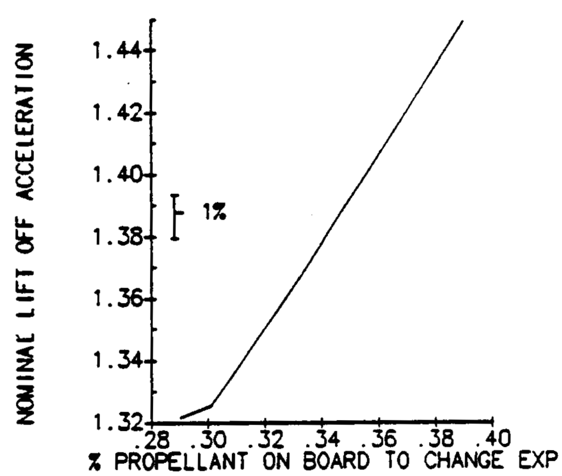


(I-60) Body Diameter Versus Orbiter Propellant at Staging

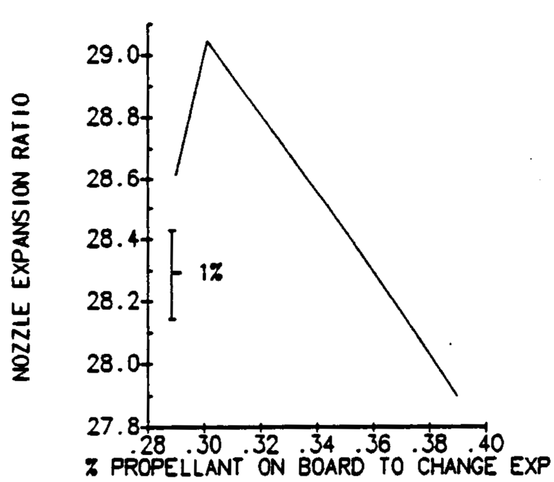
Configuration 2.L Sensitivity Studies (Continued)



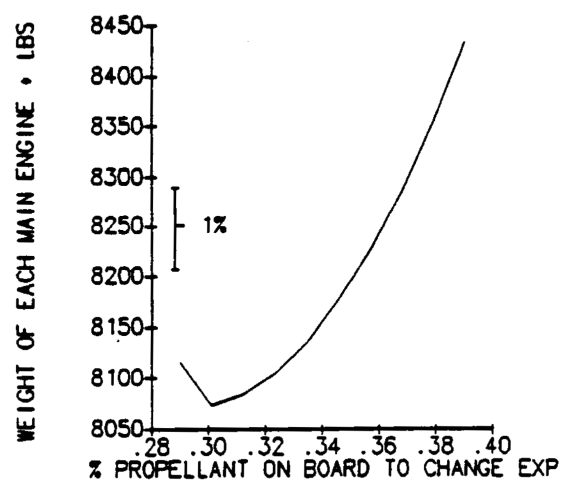
(I-61) Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging



(I-62) Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging

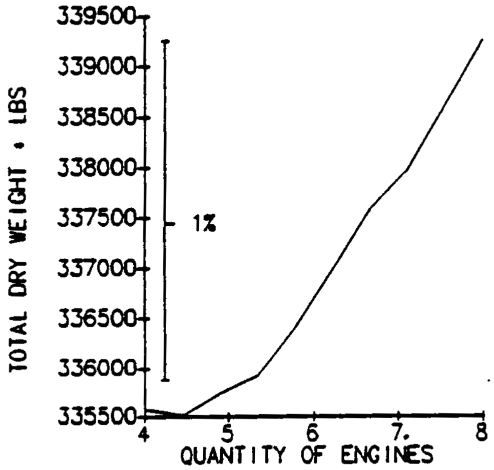


(I-63) Nozzle Expansion Ratio Versus Orbiter Propellant at Staging

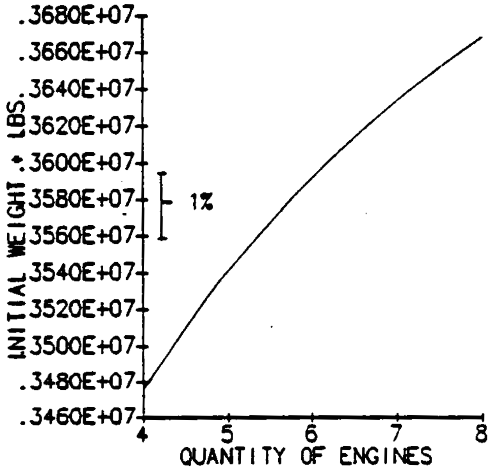


(I-64) Booster Engine Weight Versus Orbiter Propellant at Staging

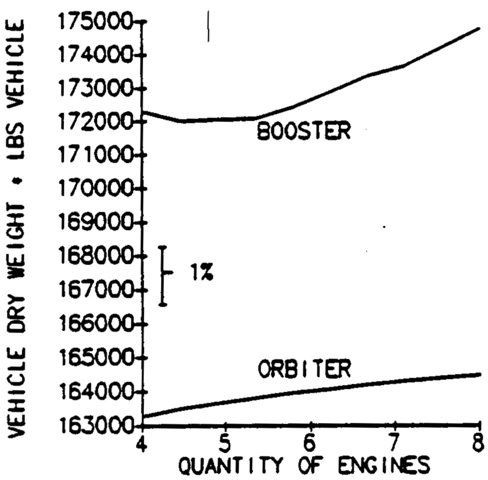
Configuration 2.L Sensitivity Studies (Continued)



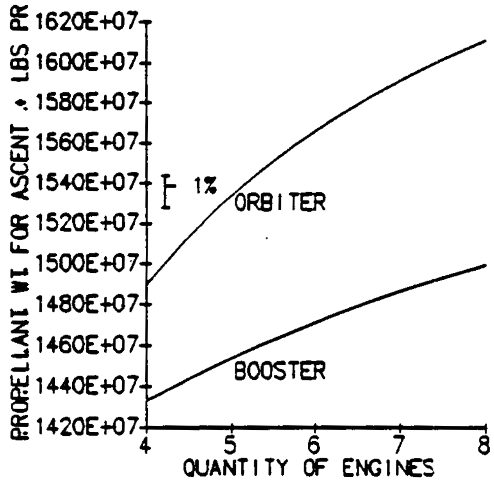
(I-65) Total Dry Weight Versus Number of Booster Engines



(I-66) Gross Lift Off Weight Versus Number of Booster Engines

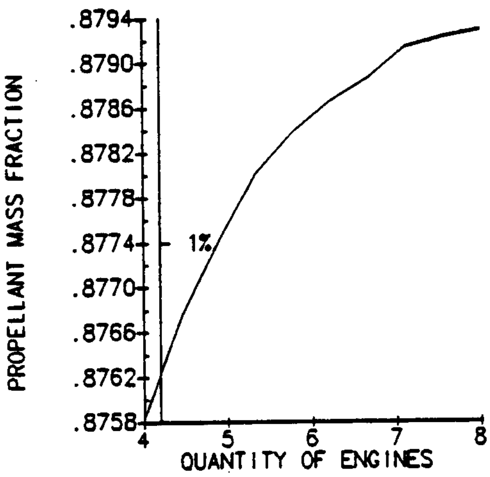


(I-67) Vehicle Dry Weight Versus Number of Booster Engines

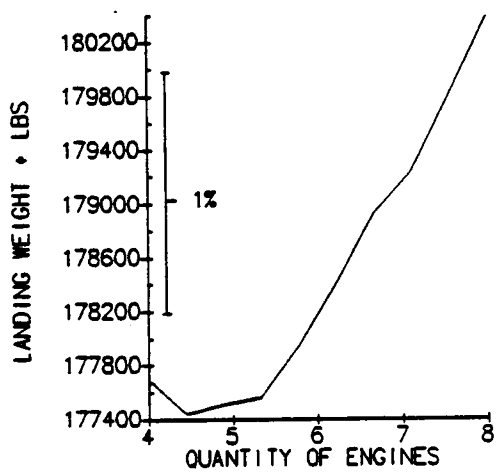


(I-68) Propellant Consumed Versus Number of Booster Engines

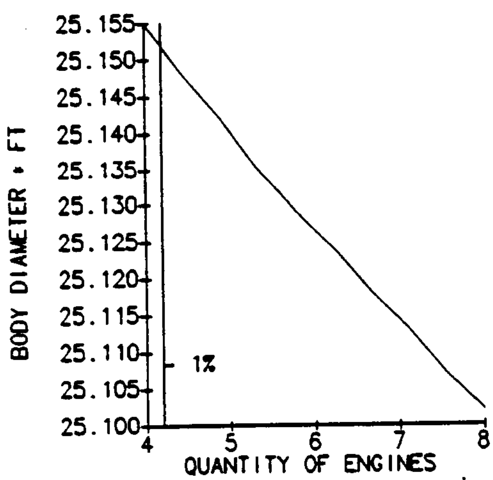
Configuration 2.L Sensitivity Studies (Continued)



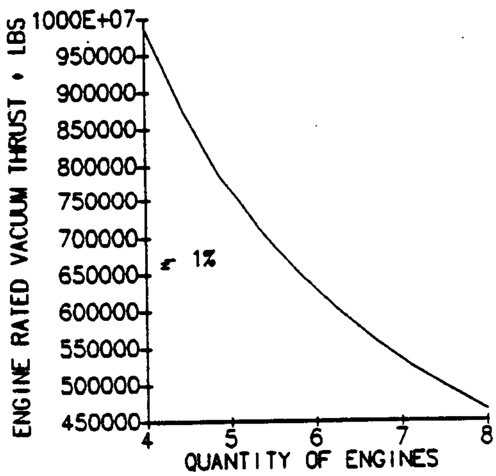
(I-69) Propellant Mass Fraction Versus Number of Booster Engines



(I-70) Landing Weight Versus Number of Booster Engines

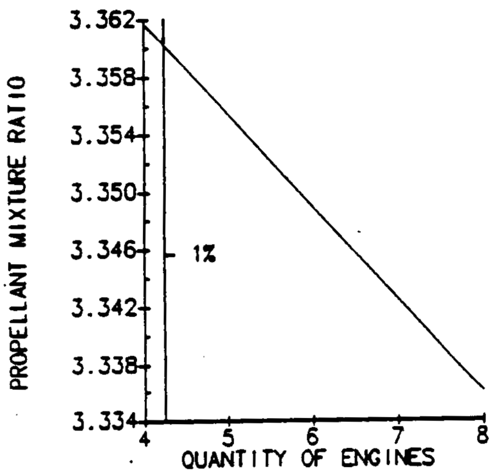


(I-71) Body Diameter Versus Number of Booster Engines

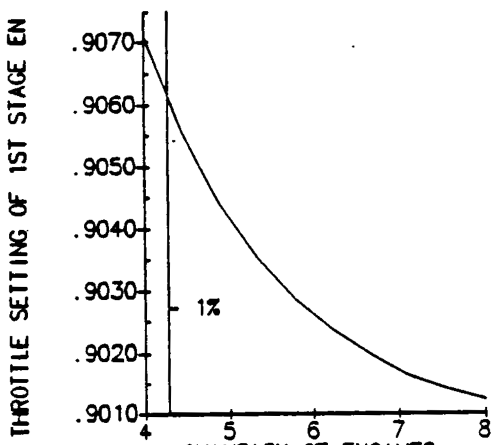


(I-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

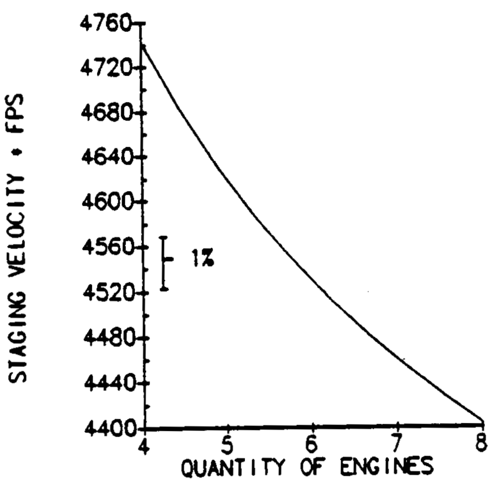
Configuration 2.L Sensitivity Studies (Continued)



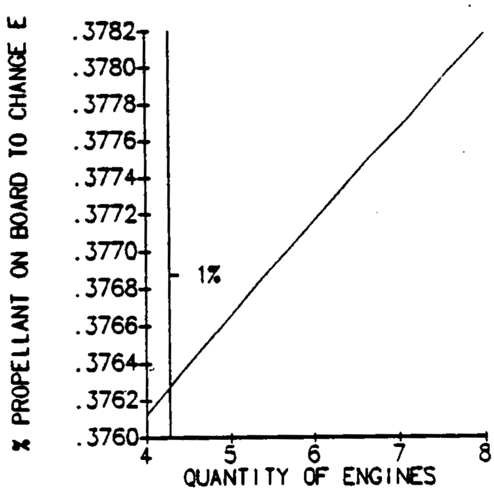
(I-73) Propellant Mixture Ratio Versus Number of Booster Engines



(I-74) Initial Booster Throttle Setting Versus Number of Booster Engines

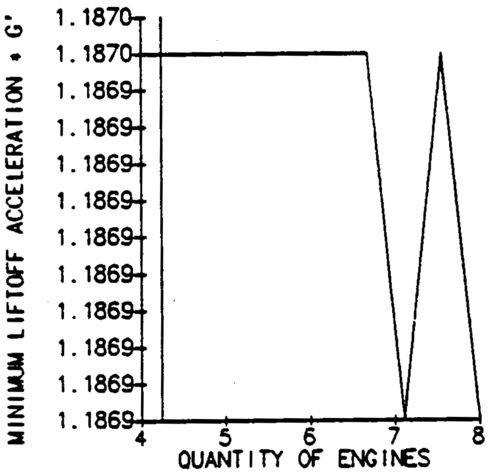


(I-75) Staging Velocity Versus Number of Booster Engines

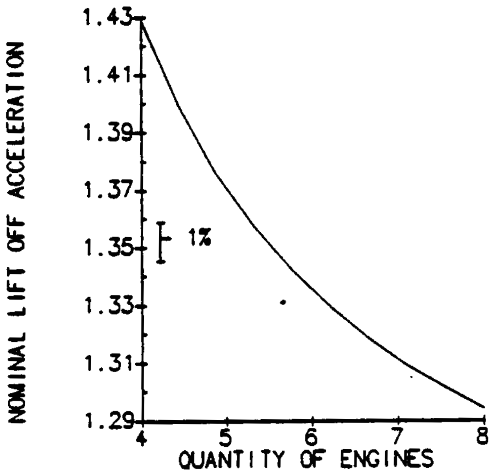


(I-76) Orbiter Propellant at Staging Versus Number of Booster Engines

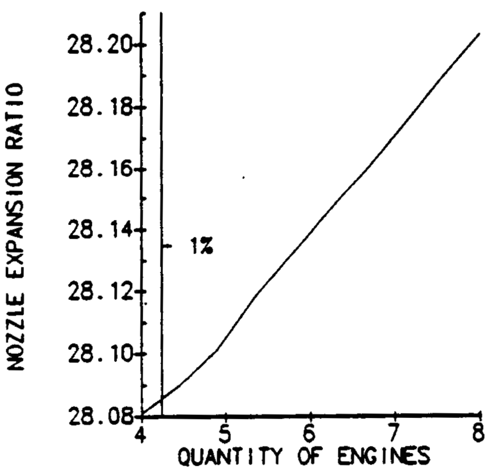
Configuration 2.L Sensitivity Studies (Continued)



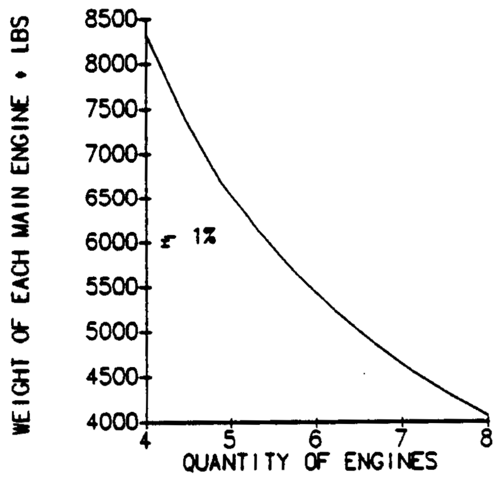
(1-77) **Engine-out Lift Off Acceleration Versus Number of Booster Engines**



(1-78) **Nominal Lift Off Acceleration Versus Number of Booster Engines**

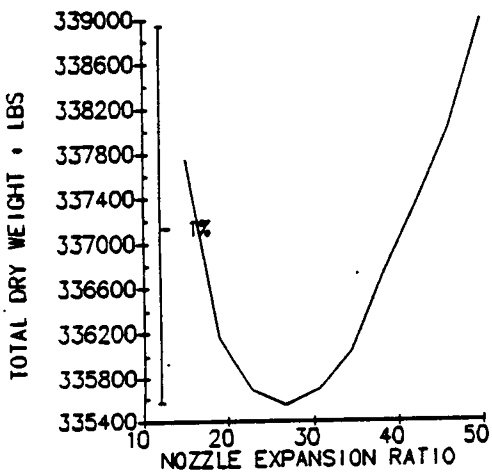


(1-79) **Nozzle Expansion Ratio Versus Number of Booster Engines**

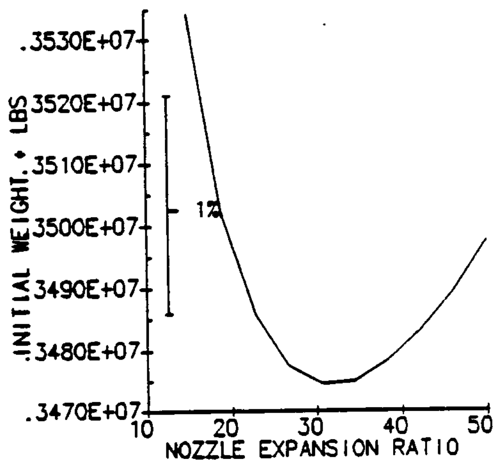


(1-80) **Booster Engine Weight Versus Number of Booster Engines**

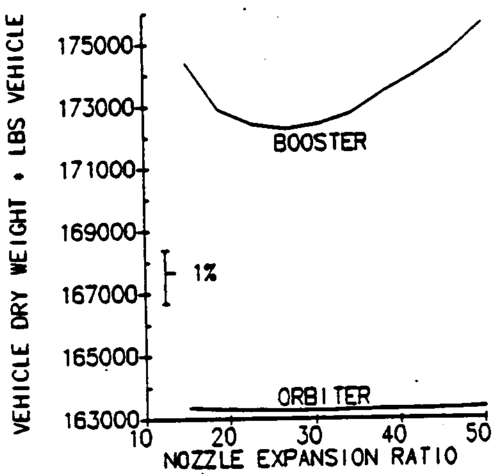
Configuration 2.L Sensitivity Studies (Continued)



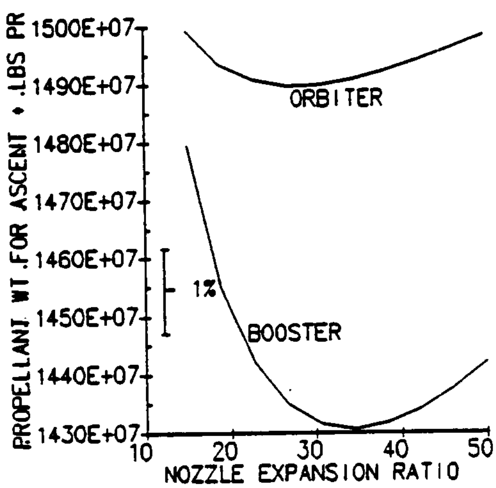
(I-81) Total Dry Weight Versus Nozzle Expansion Ratio



(I-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

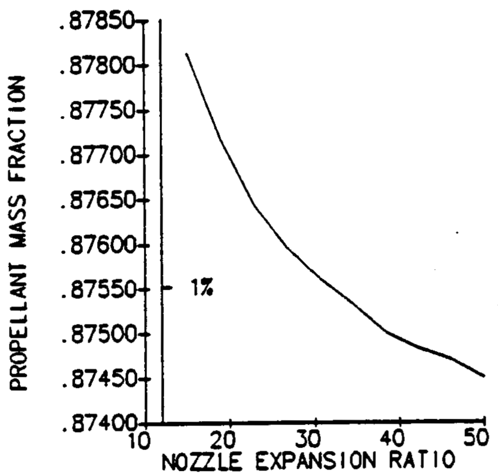


(I-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

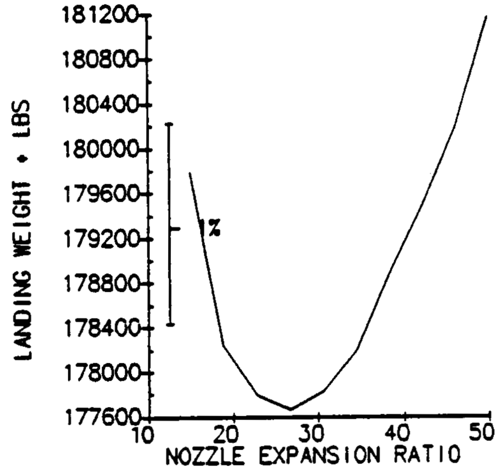


(I-84) Propellant Consumed Versus Nozzle Expansion Ratio

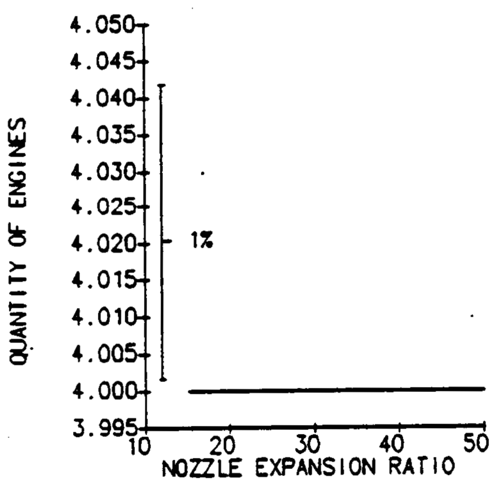
Configuration 2.L Sensitivity Studies (Continued)



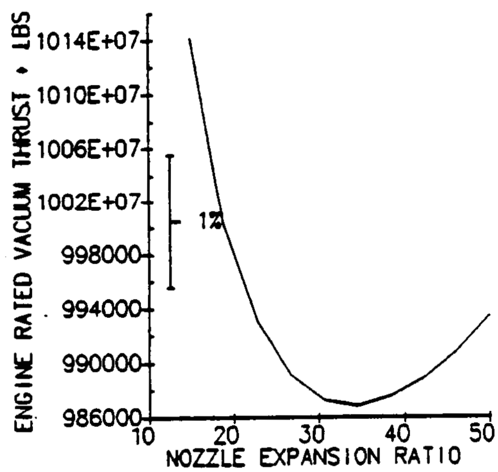
(I-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(I-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

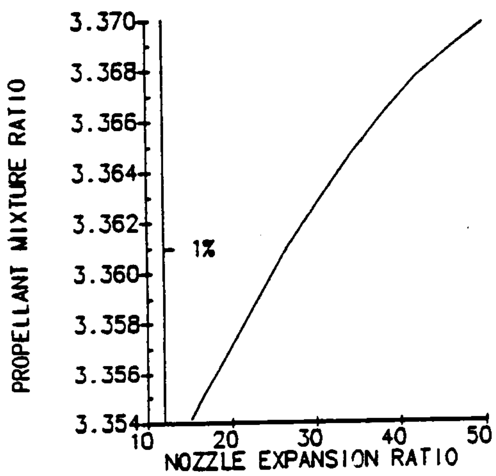


(I-87) Number of Booster Engines Versus Nozzle Expansion Ratio

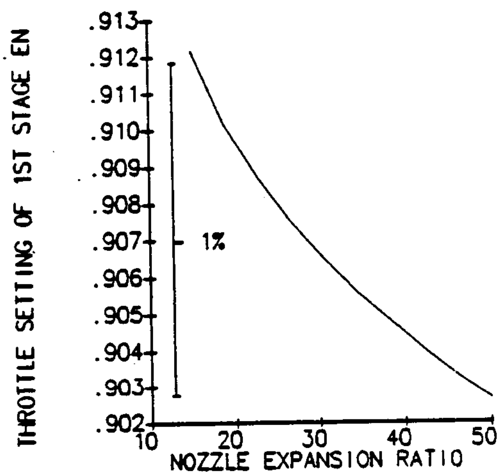


(I-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

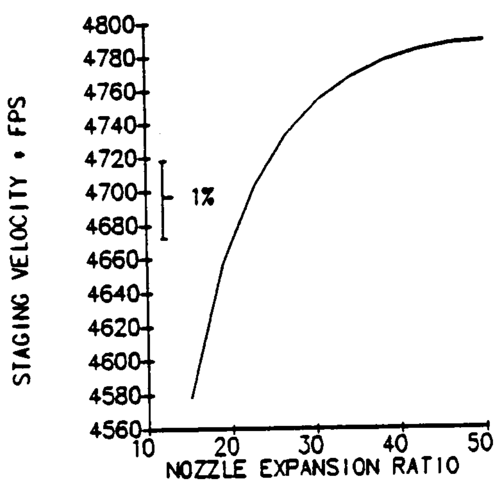
Configuration 2.L Sensitivity Studies (Continued)



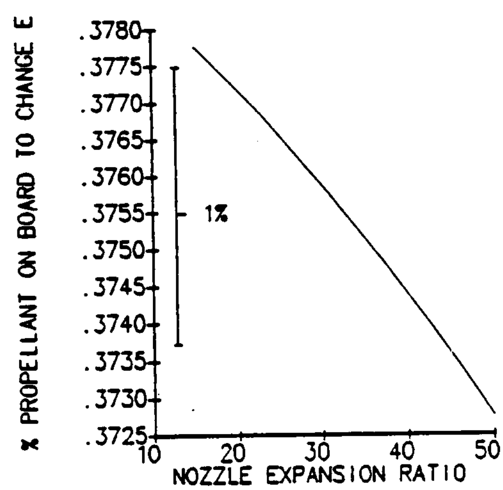
(I-89) Propellant Mixture Ratio Versus Nozzle Expansion Ratio



(I-90) Initial Booster Throttle Setting Versus Nozzle Expansion Ratio

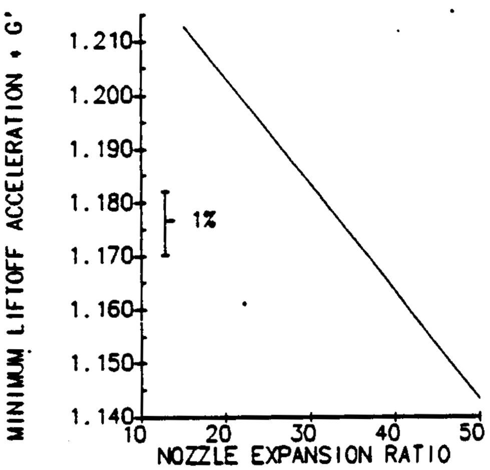


(I-91) Staging Velocity Versus Nozzle Expansion Ratio

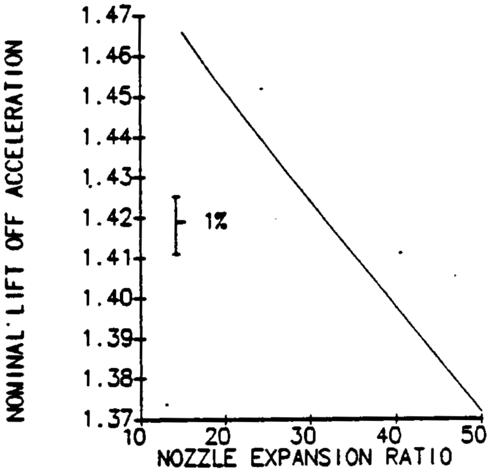


(I-92) Orbiter Propellant at Staging Versus Nozzle Expansion Ratio

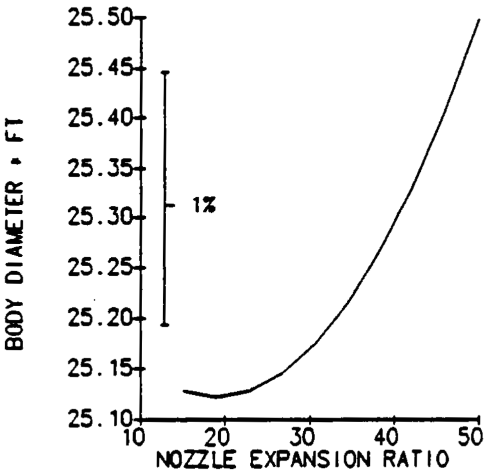
Configuration 2.L Sensitivity Studies (Continued)



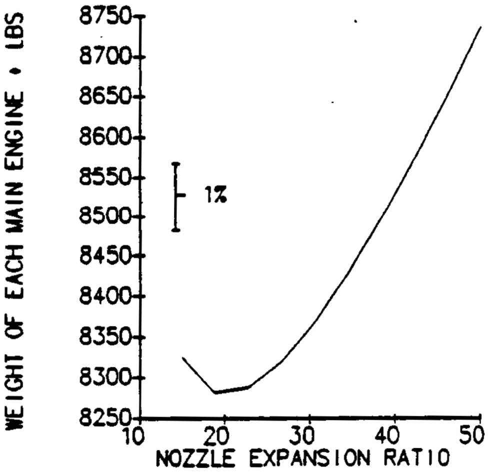
(I-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(I-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

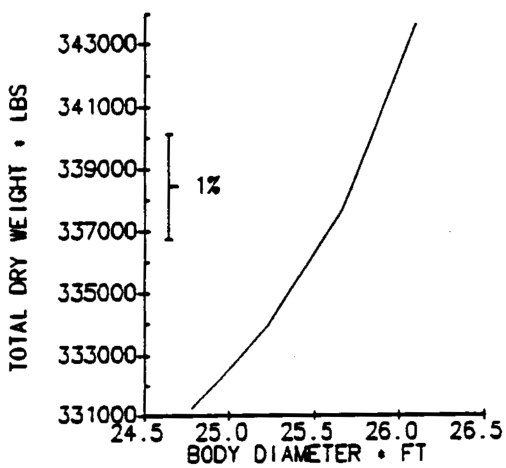


(I-95) Body Diameter Versus Nozzle Expansion Ratio

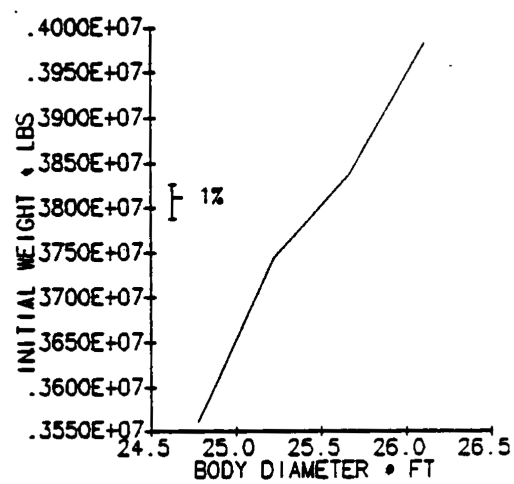


(I-96) Booster Engine Weight Versus Nozzle Expansion Ratio

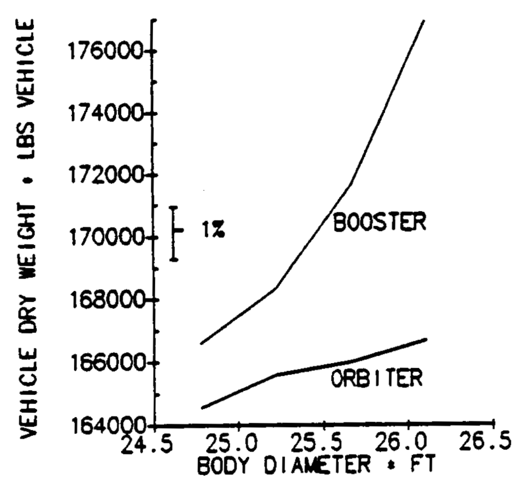
Configuration 2.L Sensitivity Studies (Continued)



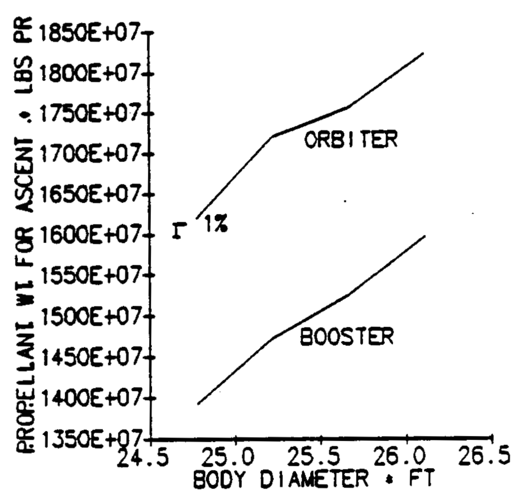
(m-1) Total Dry Weight Versus Body Diameter



(m-2) Gross Lift Off Weight Versus Body Diameter

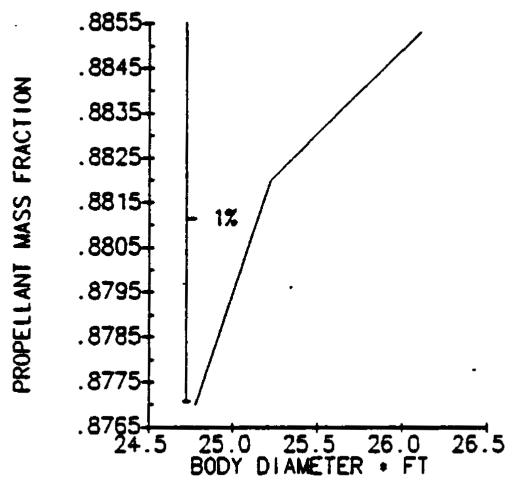


(m-3) Vehicle Dry Weight Versus Body Diameter

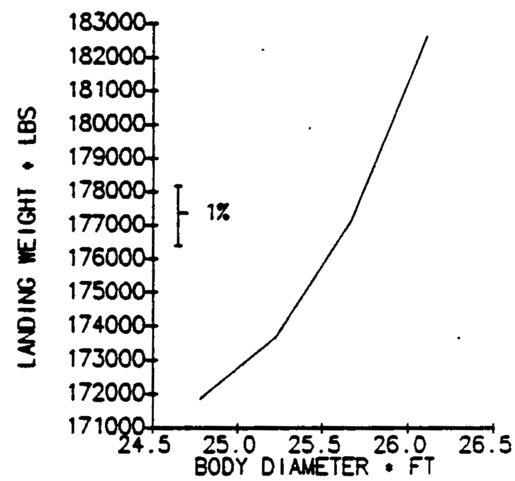


(m-4) Propella..t Consumed Versus Body Diameter

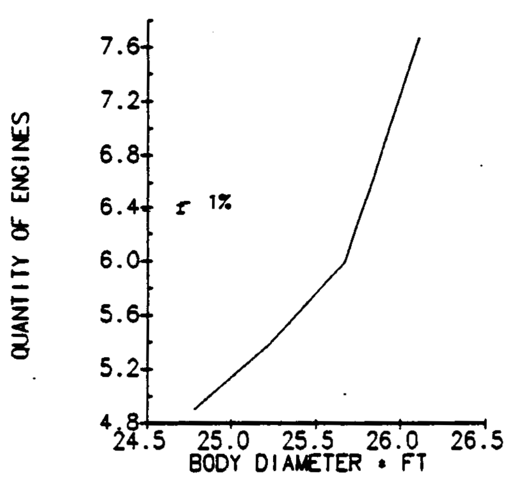
Configuration 2.M Sensitivity Studies (Continued)



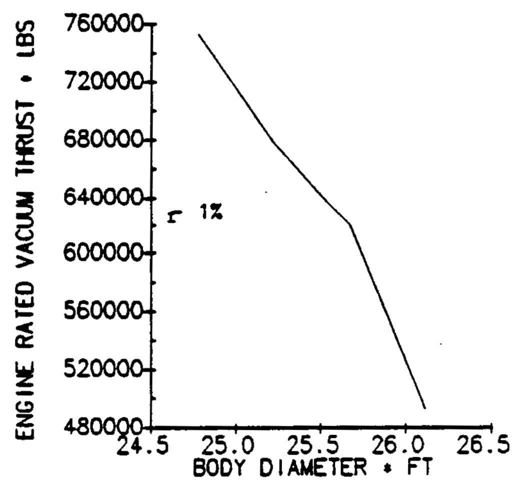
(m-5) **Propellant Mass Fraction Versus Body Diameter**



(m-6) **Landing Weight Versus Body Diameter**

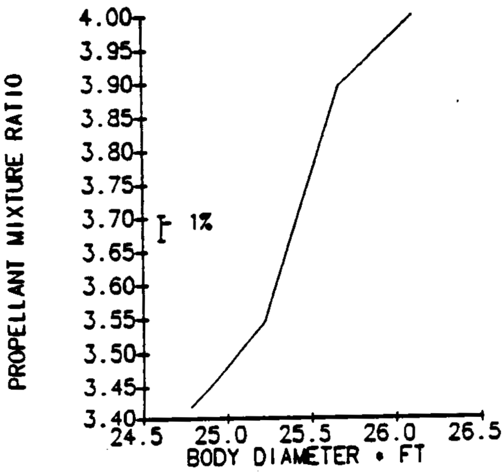


(m-7) **Number of Booster Engines Versus Body Diameter**

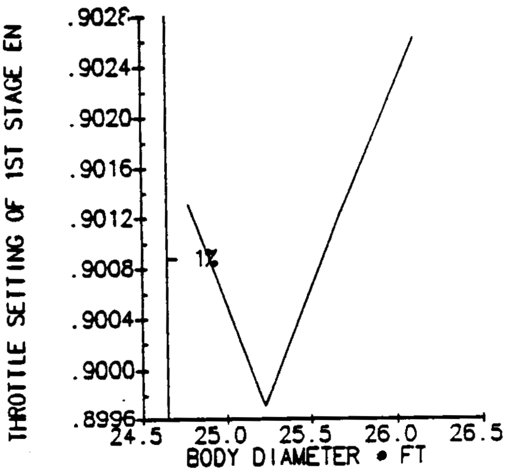


(m-8) **Engine Rated Vacuum Thrust Versus Body Diameter**

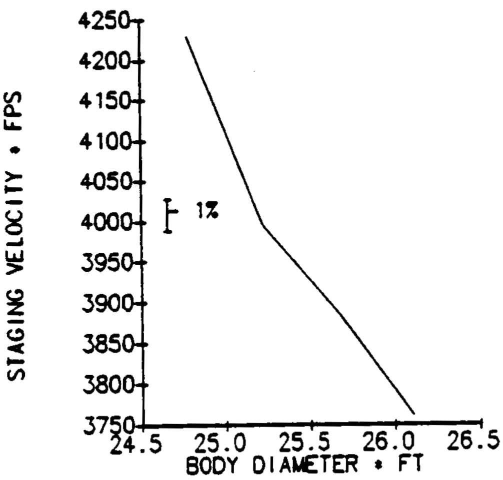
Configuration 2.M Sensitivity Studies (Continued)



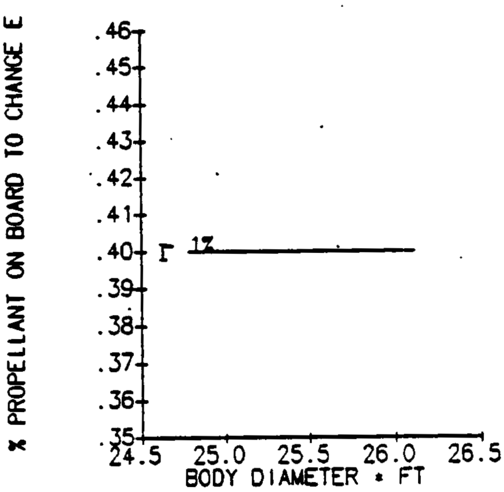
(m-9) Propellant Mixture Ratio Versus Body Diameter



(m-10) Initial Booster Throttle Setting Versus Body Diameter

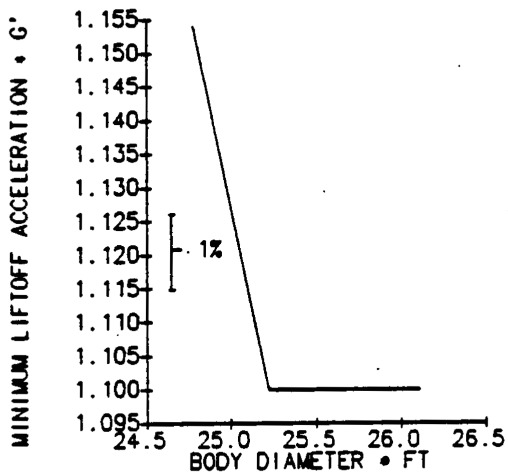


(m-11) Staging Velocity Versus Body Diameter

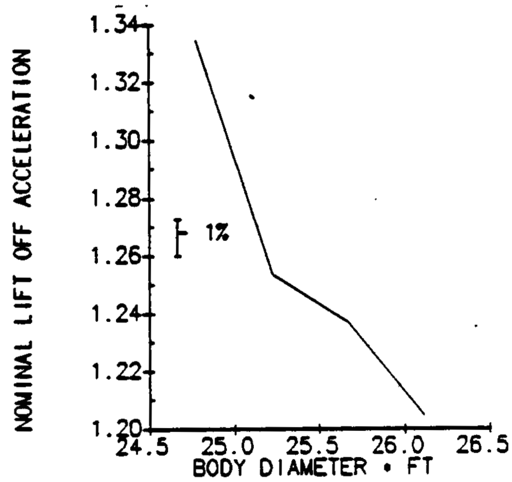


(m-12) Orbiter Propellant at Staging Versus Body Diameter

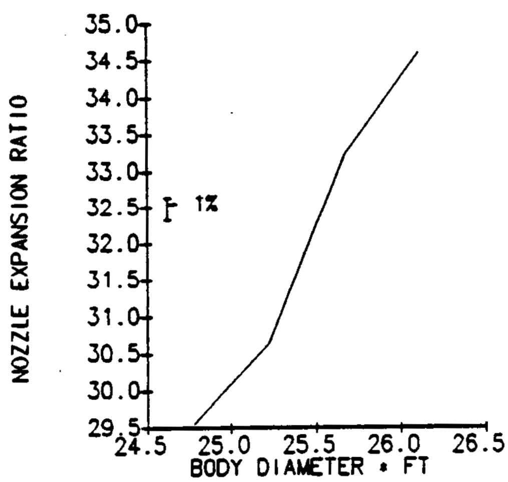
Configuration 2.M Sensitivity Studies (Continued)



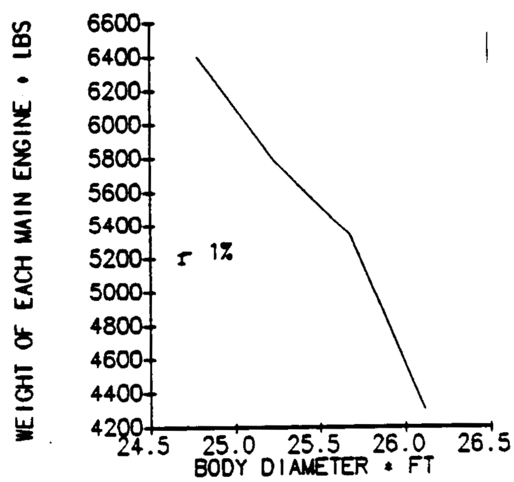
(m-13) Engine-out Lift Off Acceleration Versus Body Diameter



(m-14) Nominal Lift Off Acceleration Versus Body Diameter

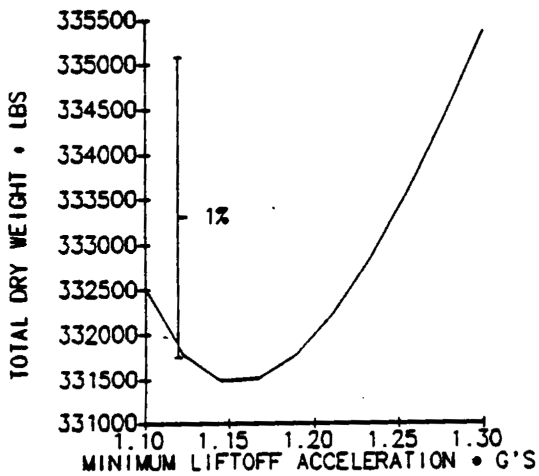


(m-15) Nozzle Expansion Ratio Versus Body Diameter

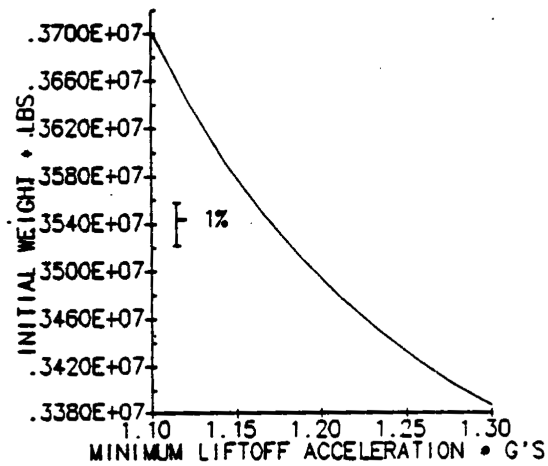


(m-16) Booster Engine Weight Versus Body Diameter

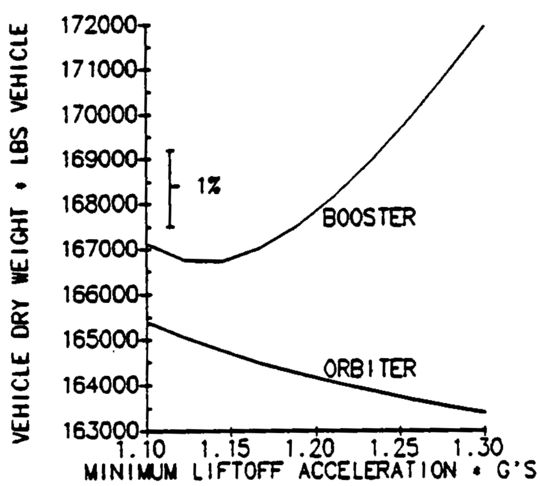
Configuration 2.M Sensitivity Studies (Continued)



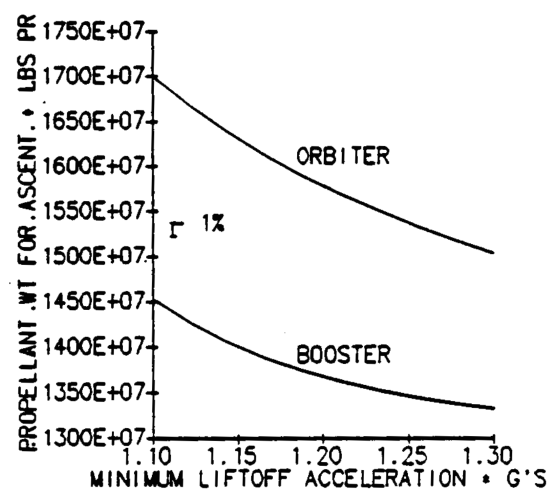
(m-17) Total Dry Weight Versus Engine-out Lift Off Acceleration



(m-18) Gross Lift Off Weight Versus Engine-out Lift Off Acceleration

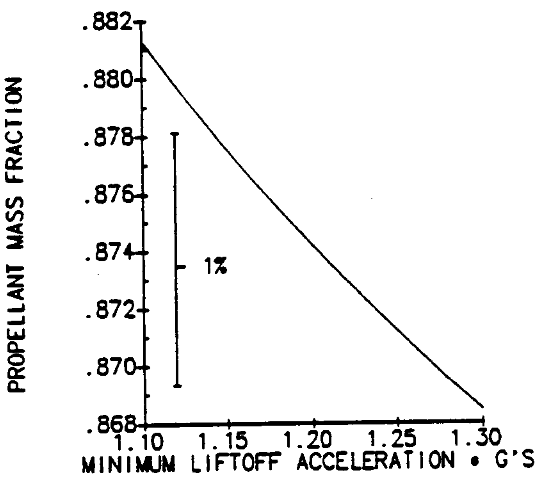


(m-19) Vehicle Dry Weight Versus Engine-out Lift Off Acceleration

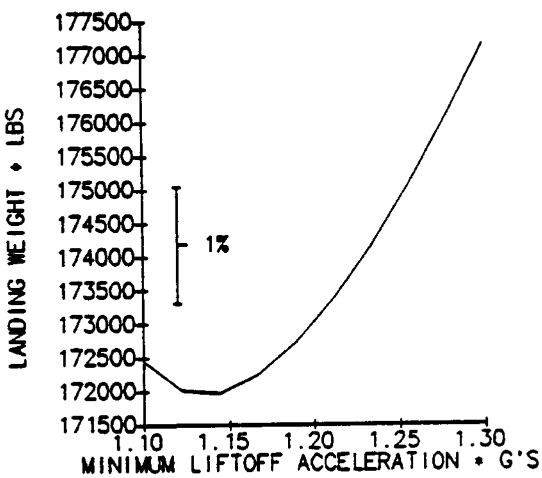


(m-20) Propellant Consumed Versus Engine-out Lift Off Acceleration

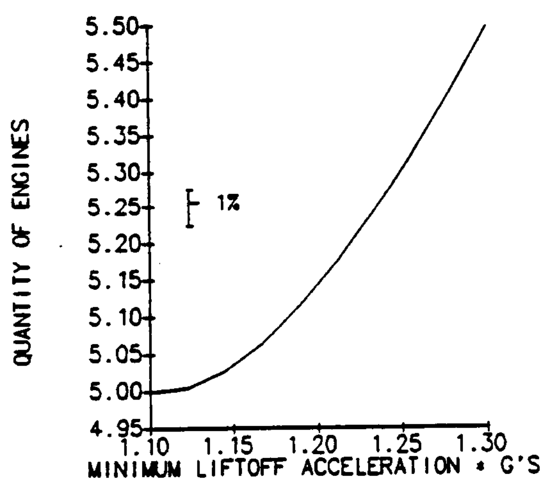
Configuration 2.M Sensitivity Studies (Continued)



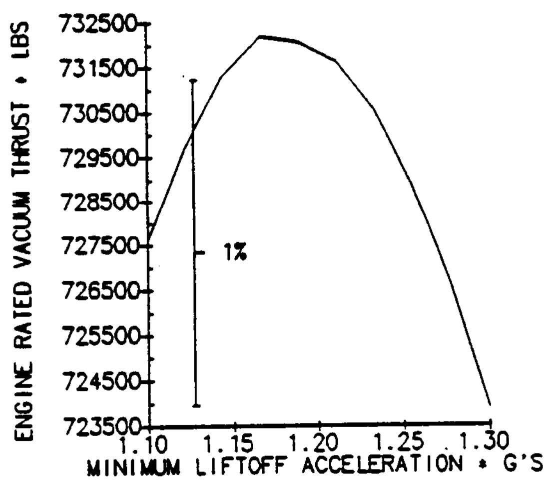
(m-21) **Propellant Mass Fraction Versus Engine-out Lift Off Acceleration**



(m-22) **Landing Weight Versus Engine-out Lift Off Acceleration**

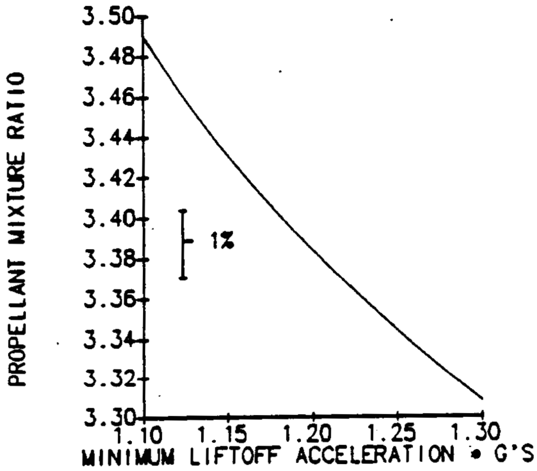


(m-23) **Number of Booster Engines Versus Engine-out Lift Off Acceleration**

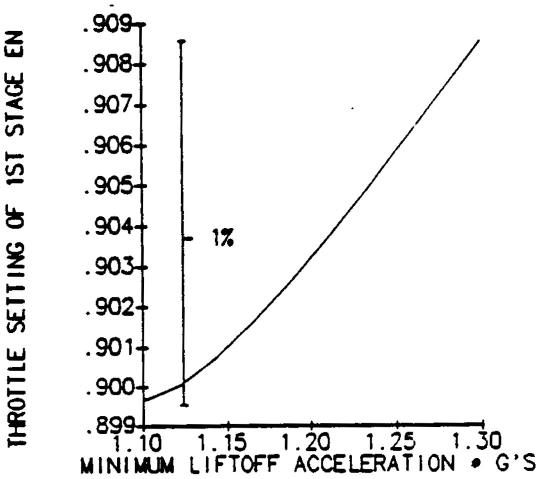


(m-24) **Engine Rated Vacuum Thrust Versus Engine-out Lift Off Acceleration**

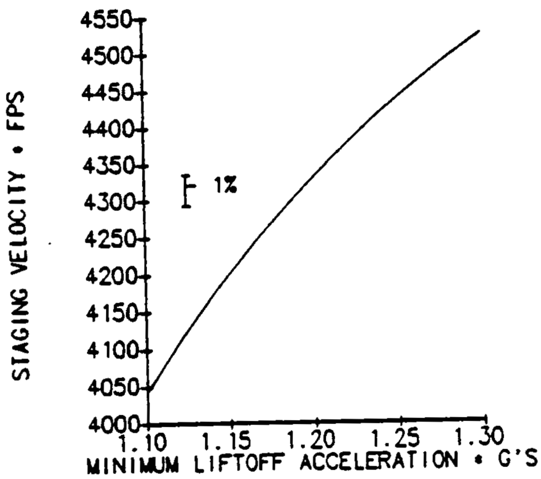
Configuration 2.M Sensitivity Studies (Continued)



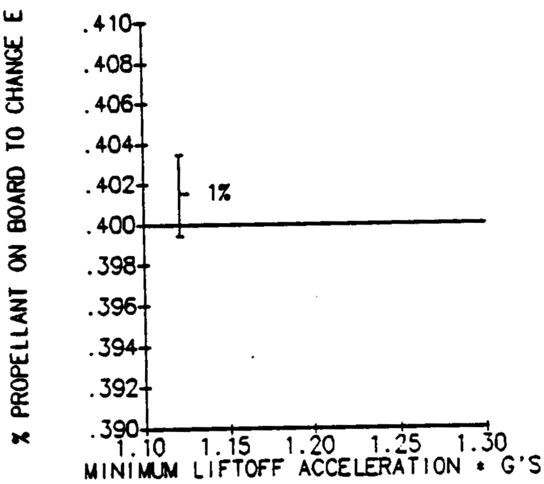
(m-25) **Propellant Mixture Ratio Versus Engine-out Lift Off Acceleration**



(m-26) **Initial Booster Throttle Setting Versus Engine-out Lift Off Acceleration**

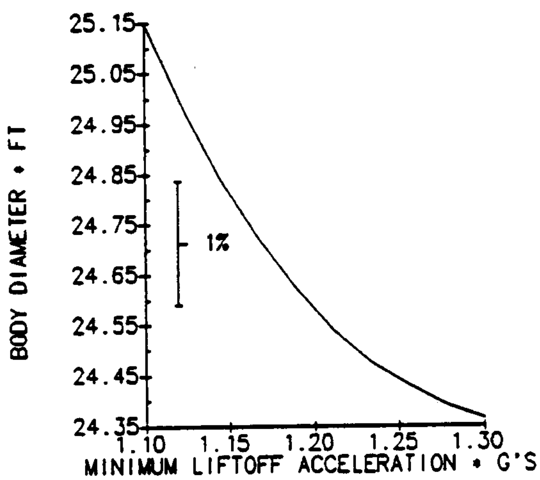


(m-27) **Staging Velocity Versus Engine-out Lift Off Acceleration**

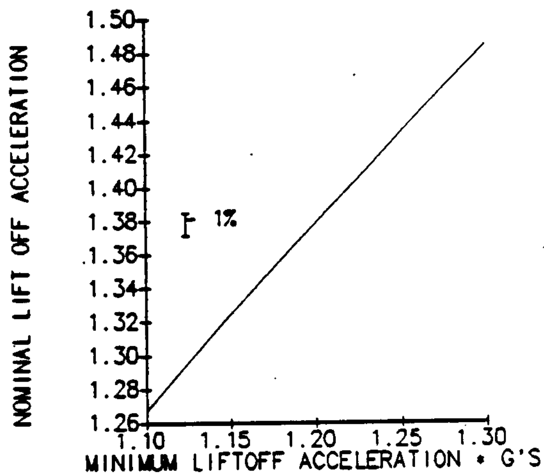


(m-28) **Orbiter F.opellant at Staging Versus Engine-out Lift Off Acceleration**

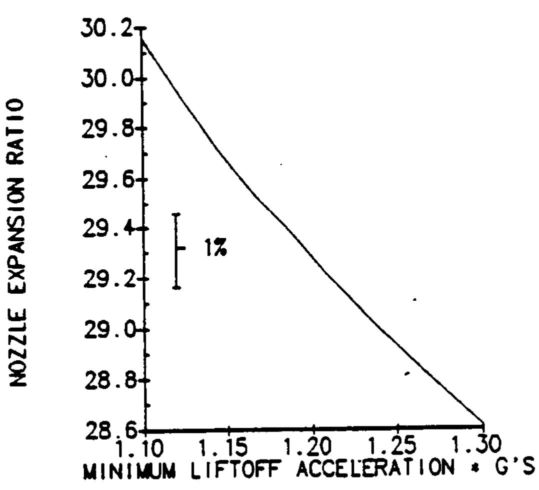
Configuration 2.M Sensitivity Studies (Continued)



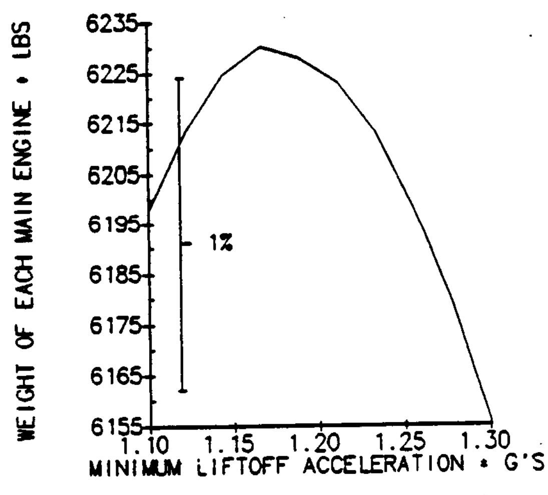
(m-29) Body Diameter Versus Engine-out Lift Off Acceleration



(m-30) Nominal Lift Off Acceleration Versus Engine-out Lift Off Acceleration

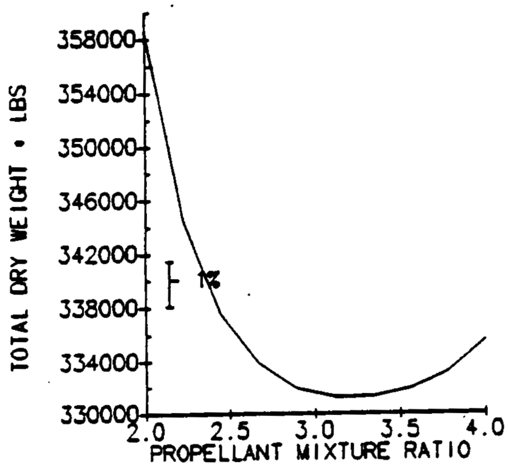


(m-31) Nozzle Expansion Ratio Versus Engine-out Lift Off Acceleration

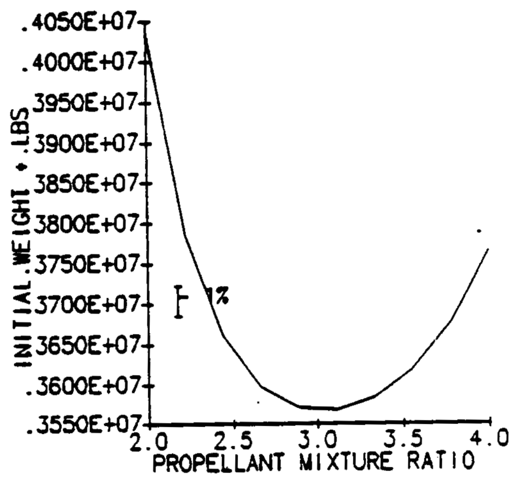


(m-32) Booster Engine Weight Versus Engine-out Lift Off Acceleration

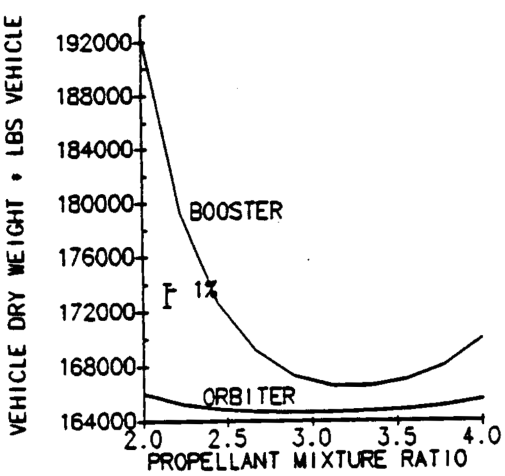
Configuration 2.M Sensitivity Studies (Continued)



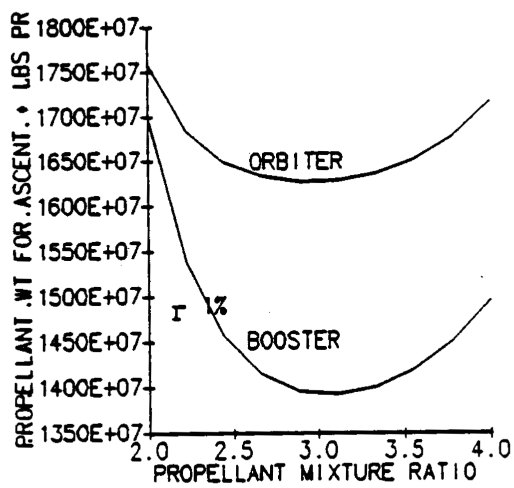
(m-33) Total Dry Weight Versus Propellant Mixture Ratio



(m-34) Gross Lift Off Weight Versus Propellant Mixture Ratio

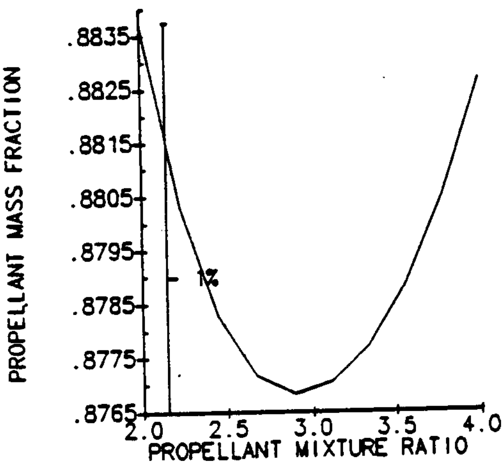


(m-35) Vehicle Dry Weight Versus Propellant Mixture Ratio

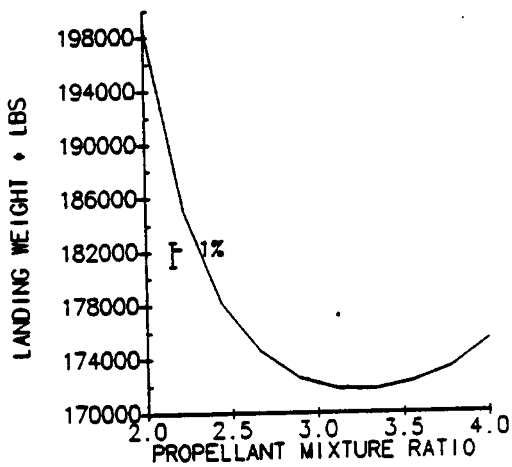


(m-36) Propellant Consumed Versus Propellant Mixture Ratio

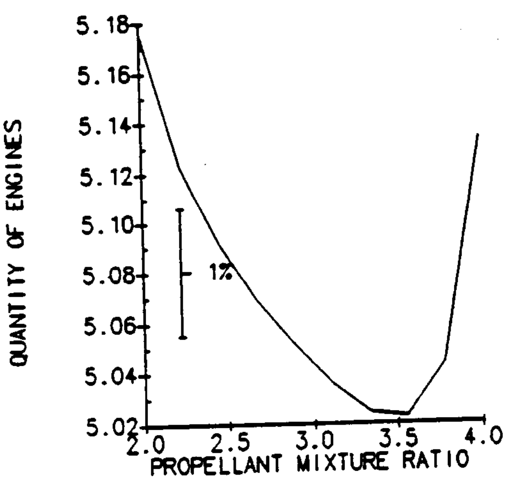
Configuration 2.M Sensitivity Studies (Continued)



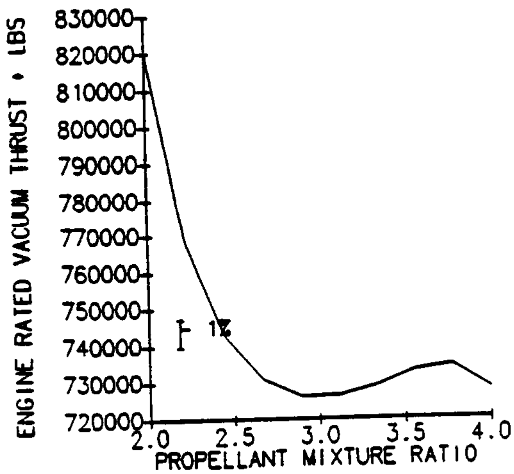
(m-37) **Propellant Mass Fraction Versus Propellant Mixture Ratio**



(m-38) **Landing Weight Versus Propellant Mixture Ratio**

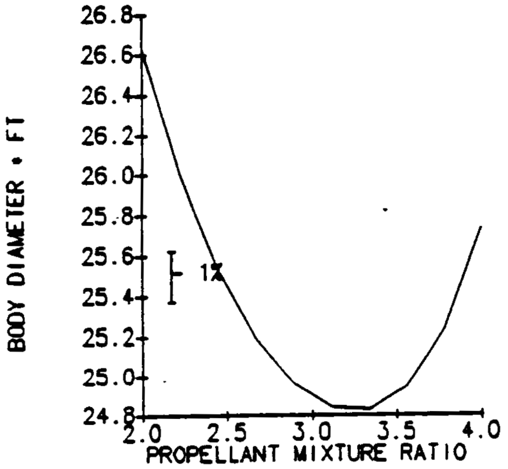


(m-39) **Number of Booster Engines Versus Propellant Mixture Ratio**

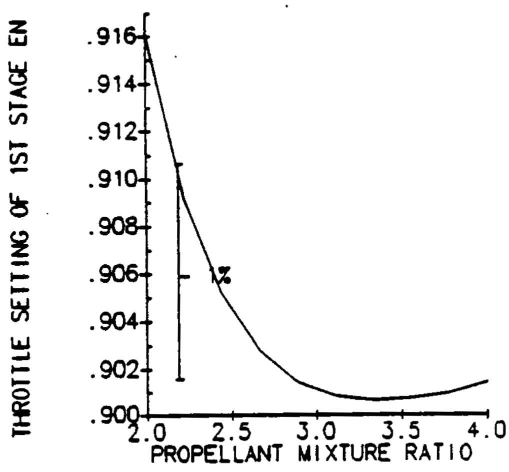


(m-40) **Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio**

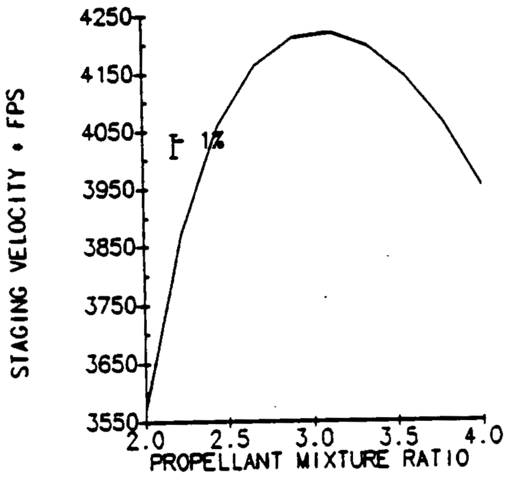
Configuration 2.M Sensitivity Studies



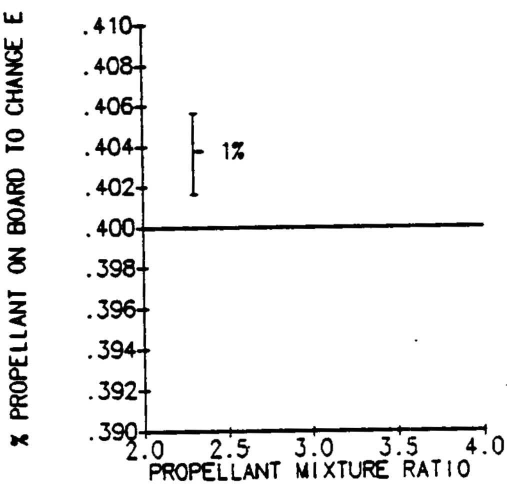
(m-41) Body Diameter Versus Propellant Mixture Ratio



(m-42) Initial Booster Throttle Setting Versus Propellant Mixture Ratio

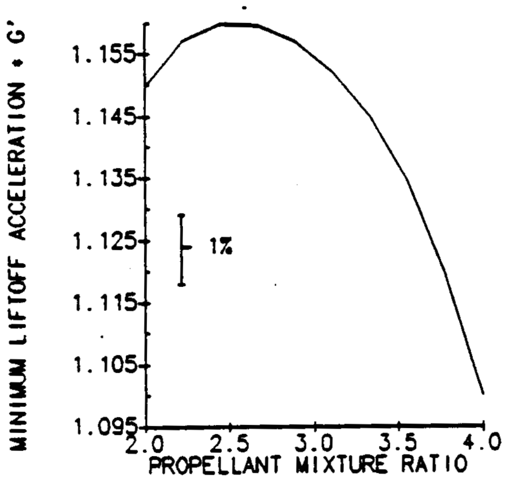


(m-43) Staging Velocity Versus Propellant Mixture Ratio

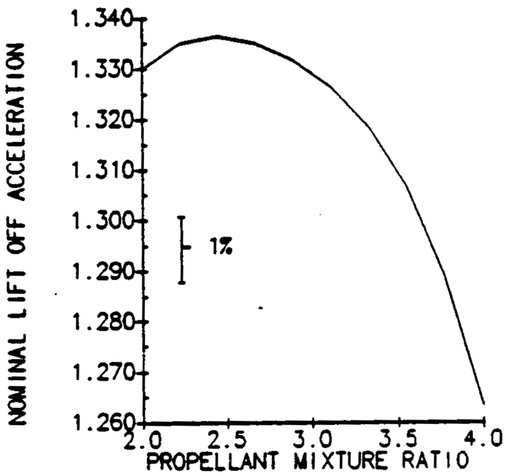


(m-44) Orbiter Propellant at Staging Versus Propellant Mixture Ratio

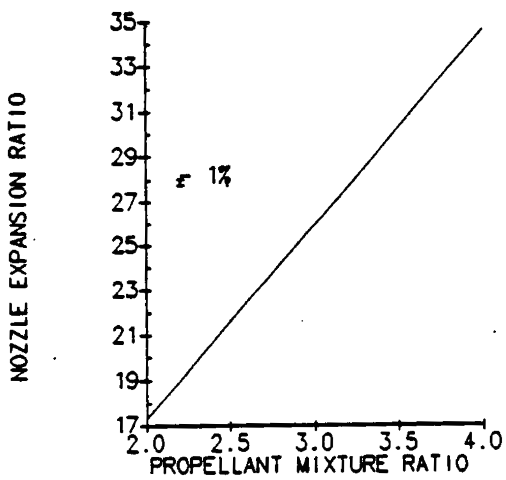
Configuration 2.M Sensitivity Studies (Continued)



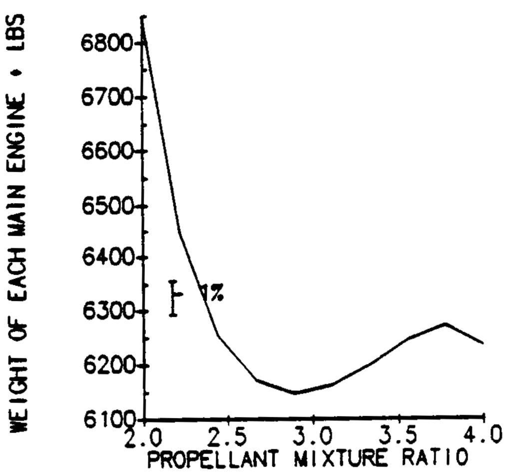
(m-45) **Engine-out Lift Off Acceleration Versus Propellant Mixture Ratio**



(m-46) **Nominal Lift Off Acceleration Versus Propellant Mixture Ratio**

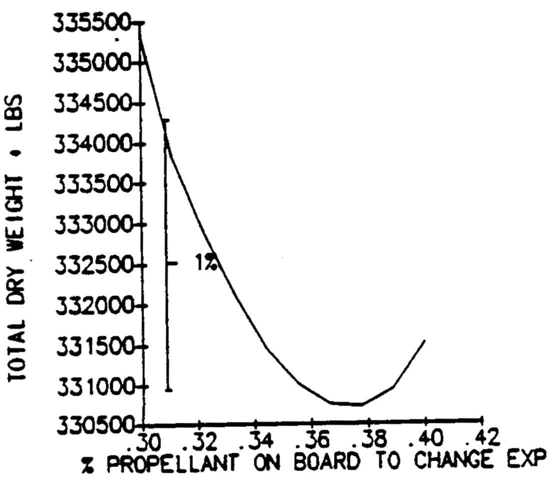


(m-47) **Nozzle Expansion Ratio Versus Propellant Mixture Ratio**

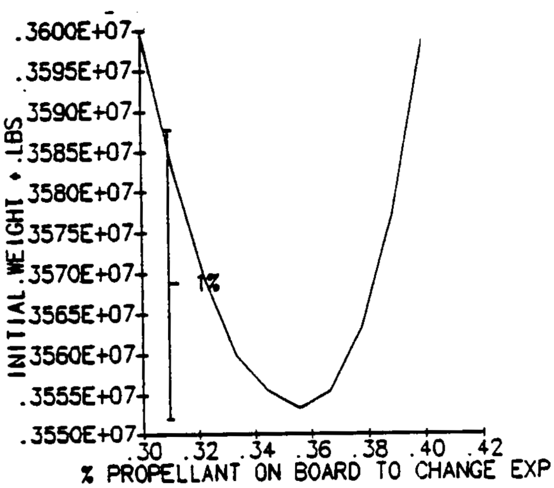


(m-48) **Booster Engine Weight Versus Propellant Mixture Ratio**

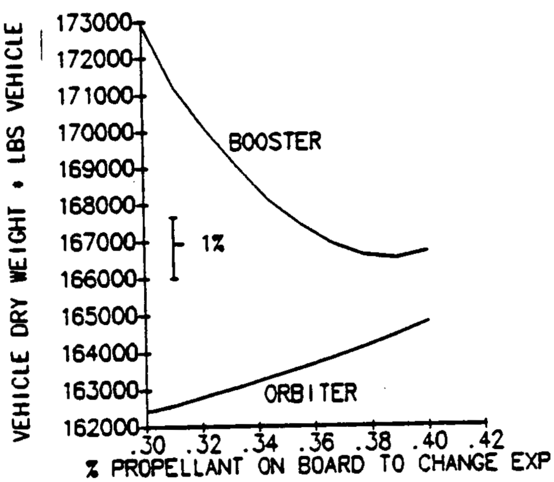
Configuration 2.M Sensitivity Studies (Continued)



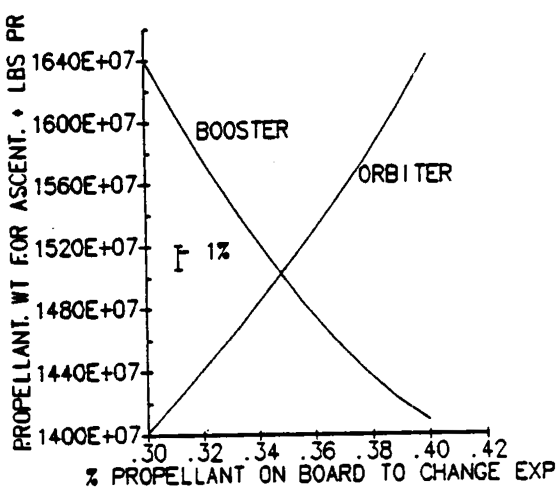
(m-49) Total Dry Weight Versus Orbiter Propellant at Staging



(m-50) Gross Lift Off Weight Versus Orbiter Propellant at Staging

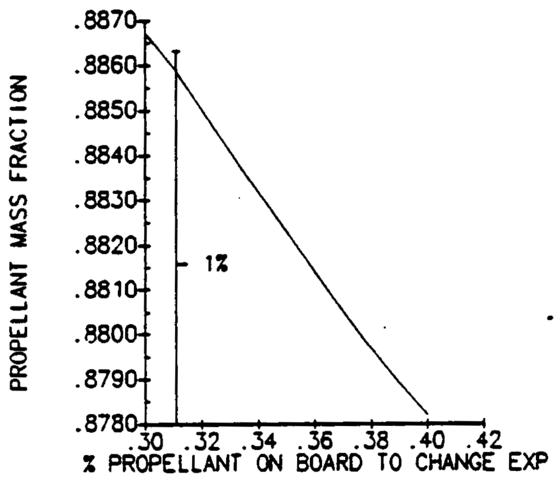


(m-51) Vehicle Dry Weight Versus Orbiter Propellant at Staging

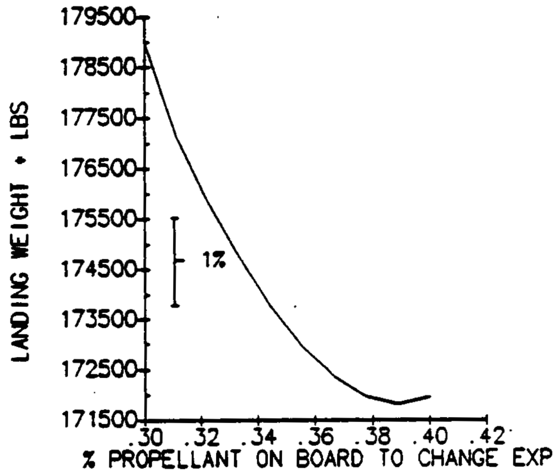


(m-52) Propellant Consumed Versus Orbiter Propellant at Staging

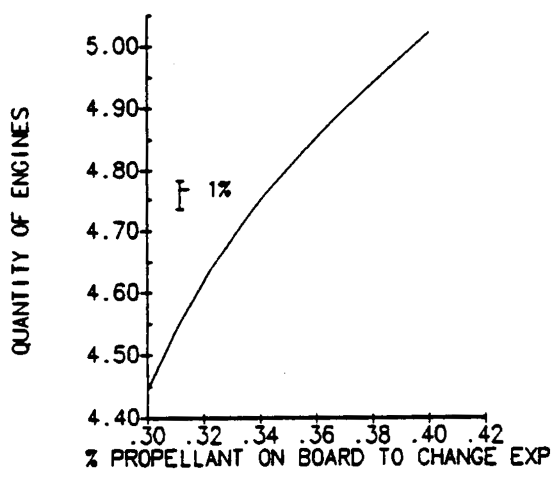
Configuration 2.M Sensitivity Studies (Continued)



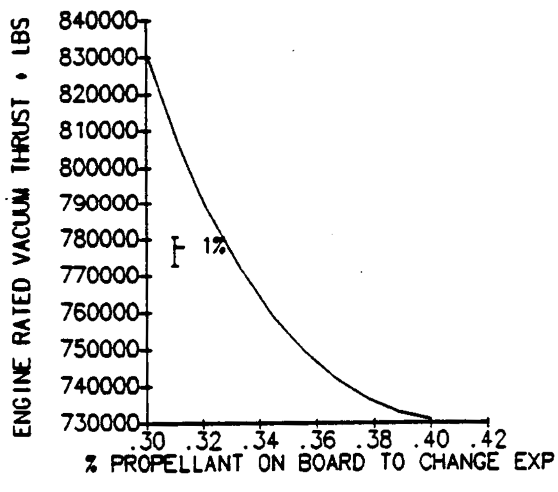
(m-53) Propellant Mass Fraction Versus Orbiter Propellant at Staging



(m-54) Landing Weight Versus Orbiter Propellant at Staging

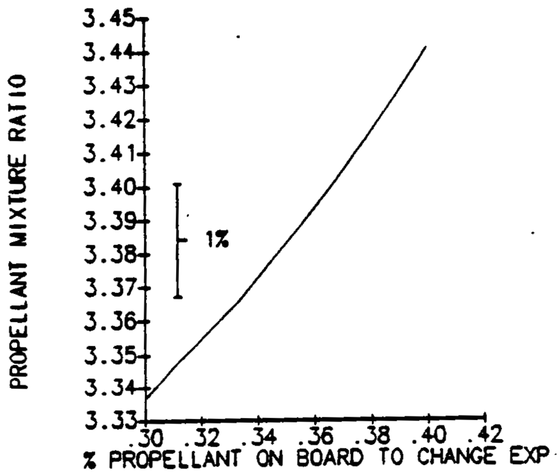


(m-55) Number of Booster Engines Versus Orbiter Propellant at Staging

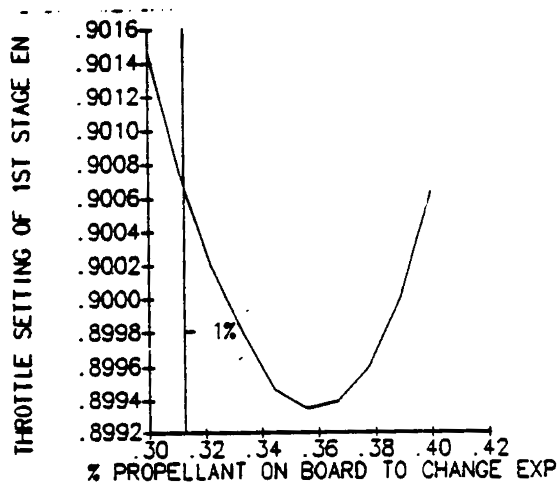


(m-56) Engine Rated Vacuum Thrust Versus Orbiter Propellant at Staging

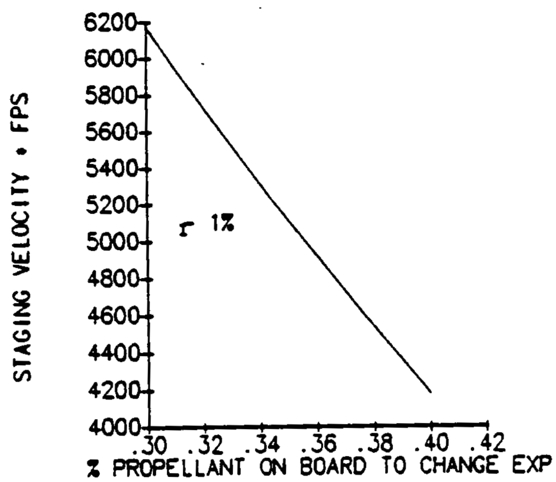
Configuration 2.M Sensitivity Studies (Continued)



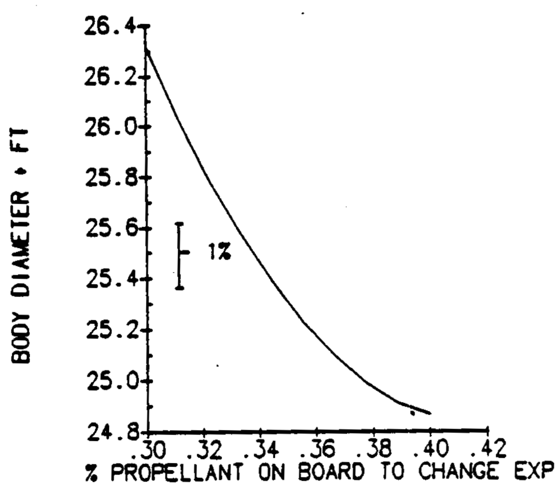
(m-57) **Propellant Mixture Ratio Versus Orbiter Propellant at Staging**



(m-58) **Initial Booster Throttle Setting Versus Orbiter Propellant at Staging**

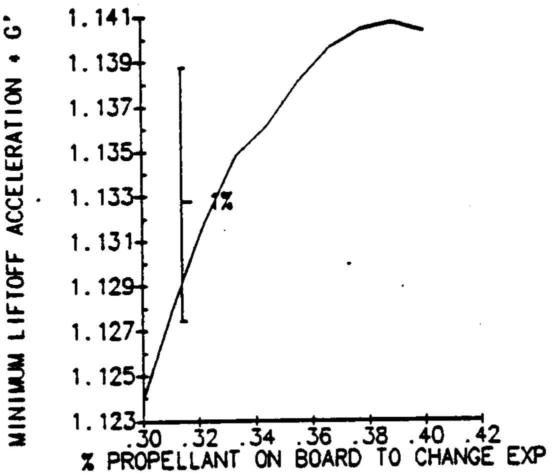


(m-59) **Staging Velocity Versus Orbiter Propellant at Staging**

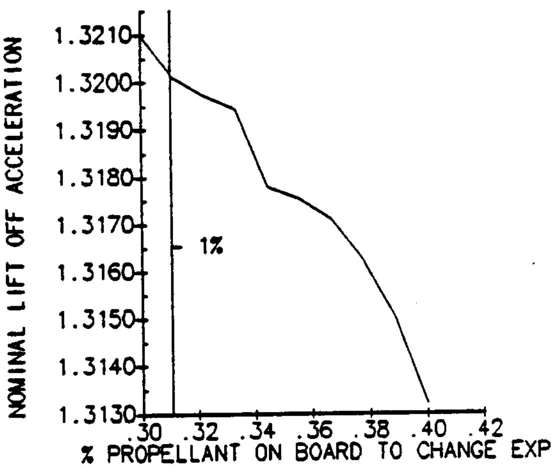


(m-60) **Body Diameter Versus Orbiter Propellant at Staging**

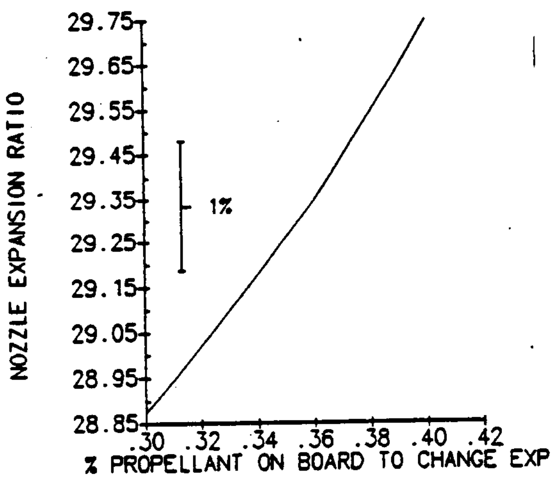
Configuration 2.M Sensitivity Studies (Continued)



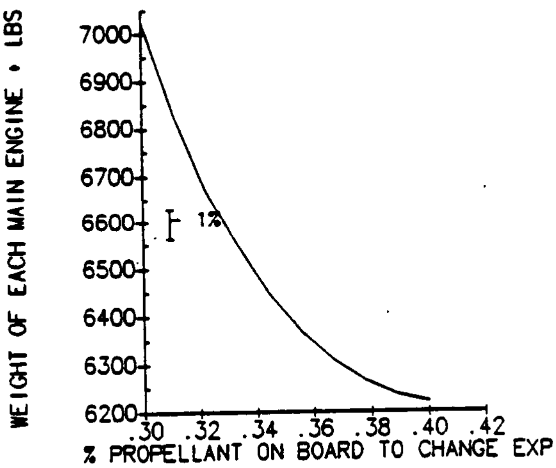
(m-61) **Engine-out Lift Off Acceleration Versus Orbiter Propellant at Staging**



(m-62) **Nominal Lift Off Acceleration Versus Orbiter Propellant at Staging**

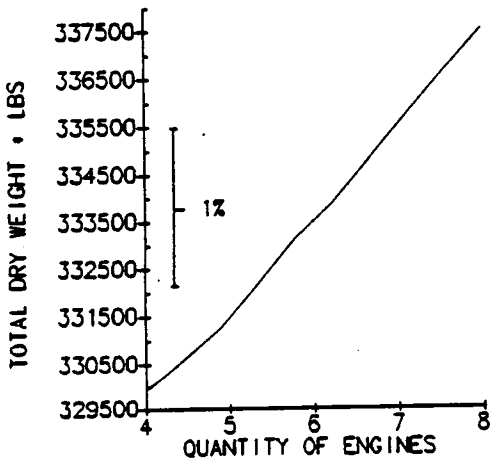


(m-63) **Nozzle Expansion Ratic Versus Orbiter Propellant at Staging**

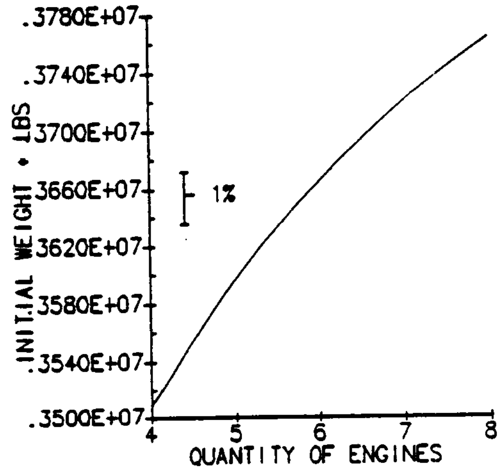


(m-64) **Booster Engine Weight Versus Orbiter Propellant at Staging**

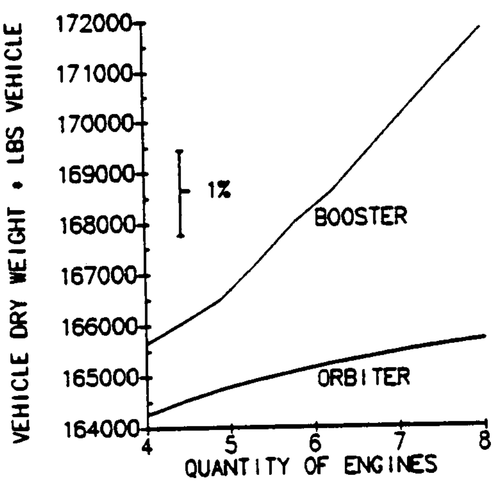
Configuration 2.M Sensitivity Studies (Continued)



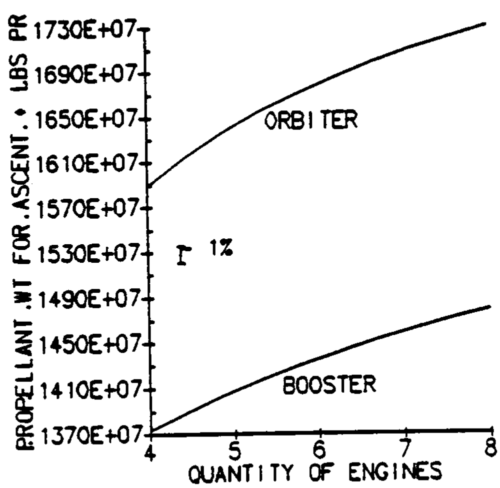
(m-65) Total Dry Weight Versus Number of Booster Engines



(m-66) Gross Lift Off Weight Versus Number of Booster Engines

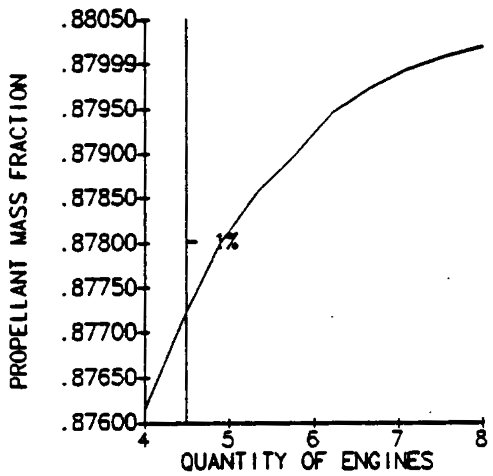


(m-67) Vehicle Dry Weight Versus Number of Booster Engines

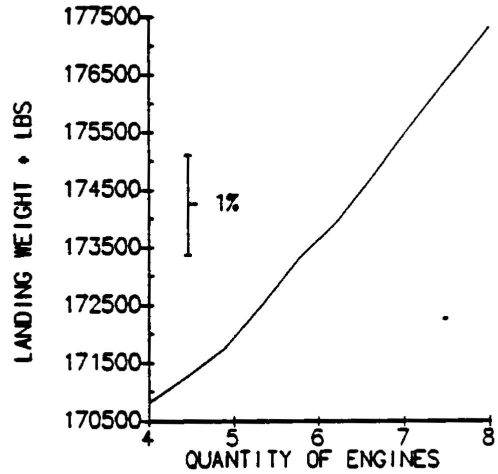


(m-68) Propellant Consumed Versus Number of Booster Engines

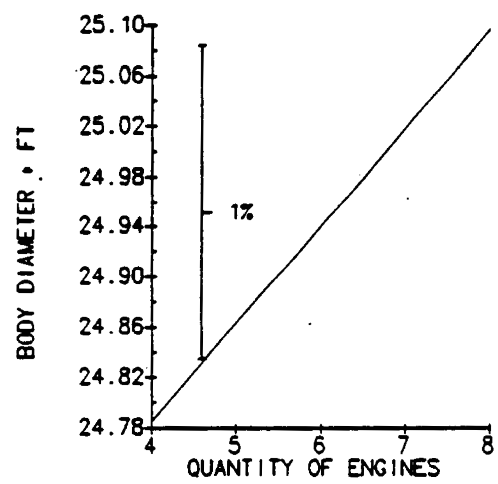
Configuration 2.M Sensitivity Studies (Continued)



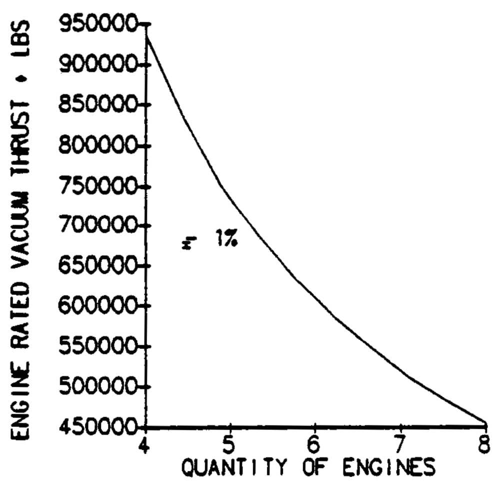
(m-69) Propellant Mass Fraction Versus Number of Booster Engines



(m-70) Landing Weight Versus Number of Booster Engines

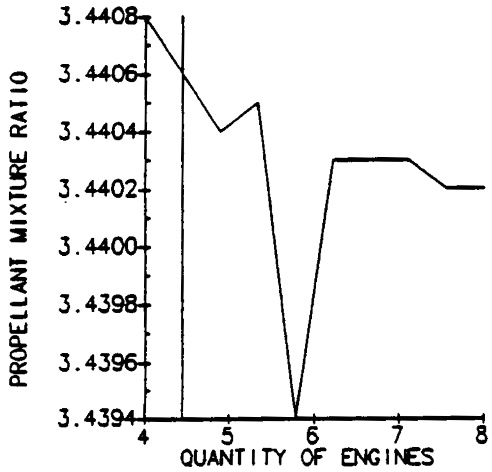


(m-71) Body Diameter Versus Number of Booster Engines

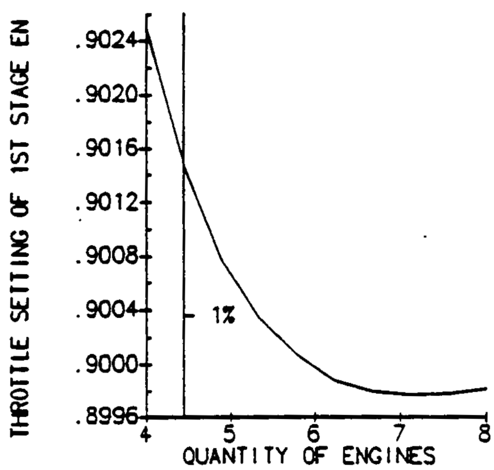


(m-72) Engine Rated Vacuum Thrust Versus Number of Booster Engines

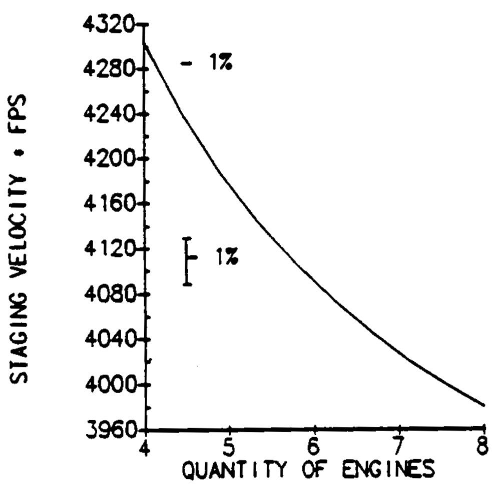
Configuration 2.M Sensitivity Studies (Continued)



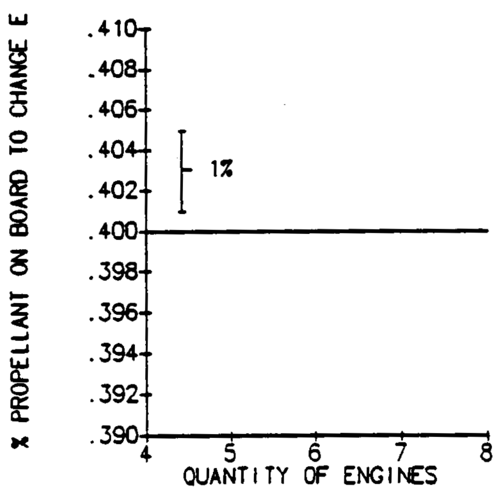
(m-73) **Propellant Mixture Ratio Versus Number of Booster Engines**



(m-74) **Initial Booster Throttle Setting Versus Number of Booster Engines**

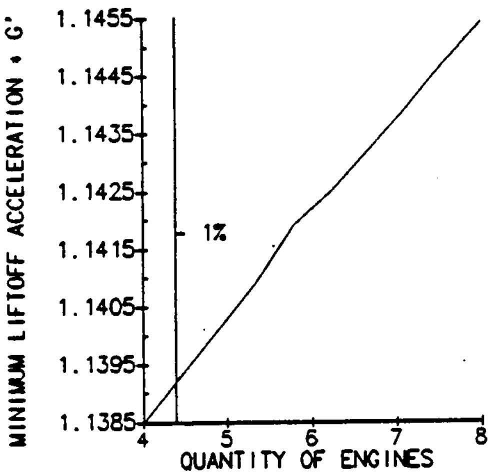


(m-75) **Staging Velocity Versus Number of Booster Engines**

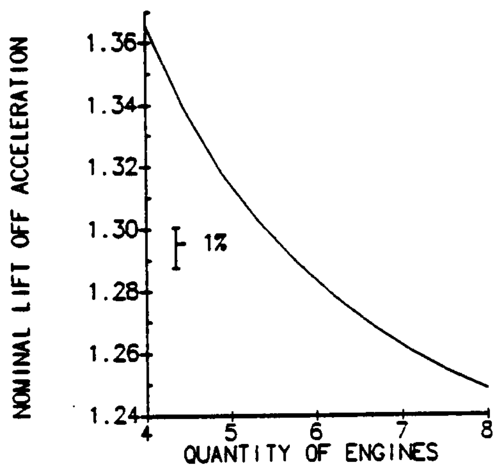


(m-76) **Orbiter Propellant at Staging Versus Number of Booster Engines**

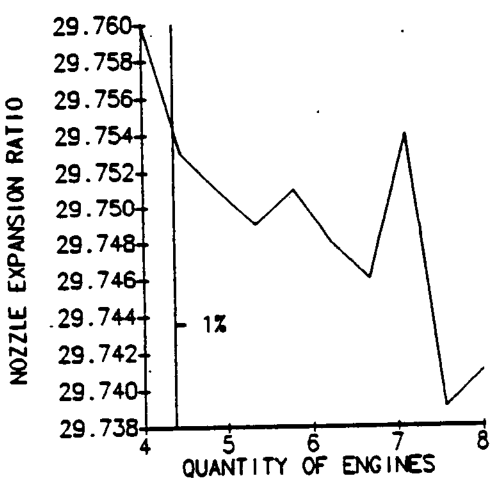
. Configuration 2.M Sensitivity Studies (Continued)



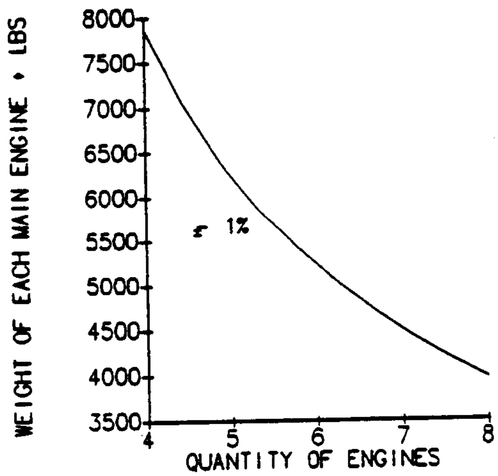
(m-77) Engine-out Lift Off Acceleration Versus Number of Booster Engines



(m-78) Nominal Lift Off Acceleration Versus Number of Booster Engines

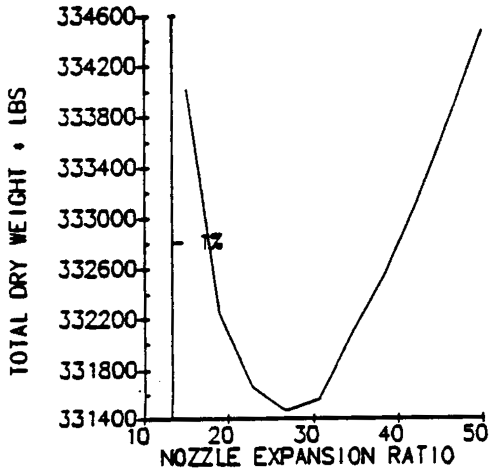


(m-79) Nozzle Expansion Ratio Versus Number of Booster Engines

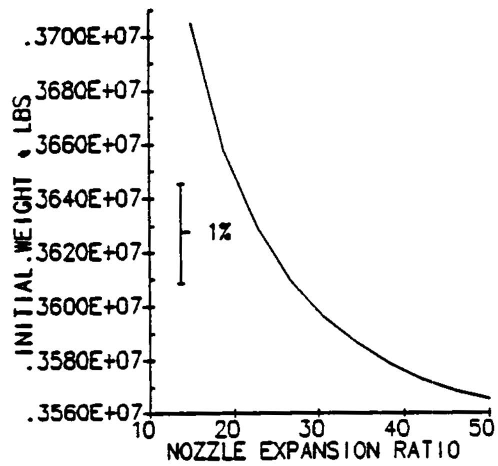


(m-80) Booster Engine Weight Versus Number of Booster Engines

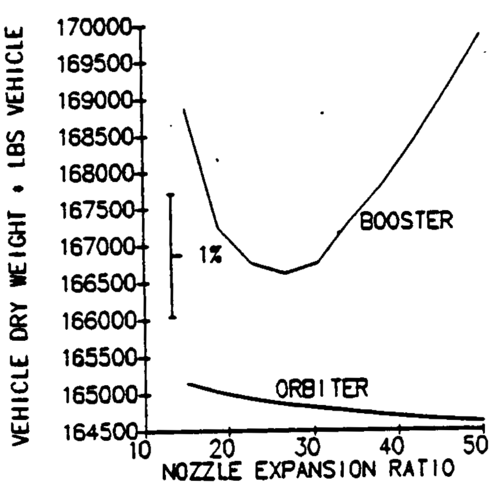
Configuration 2.M Sensitivity Studies (Continued)



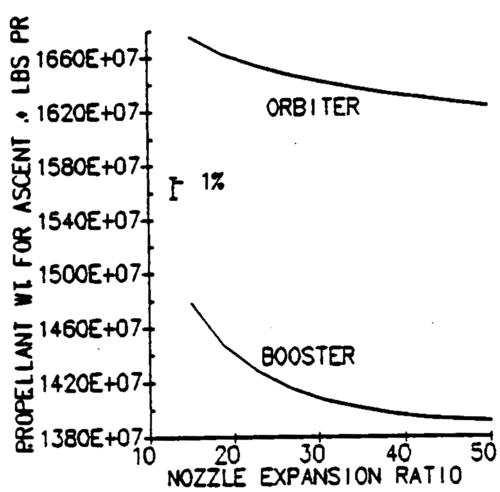
(m-81) Total Dry Weight Versus Nozzle Expansion Ratio



(m-82) Gross Lift Off Weight Versus Nozzle Expansion Ratio

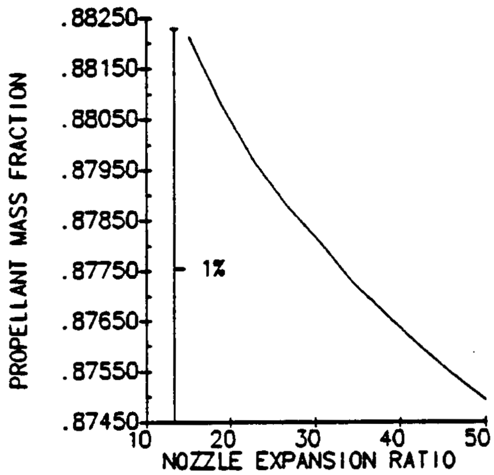


(m-83) Vehicle Dry Weight Versus Nozzle Expansion Ratio

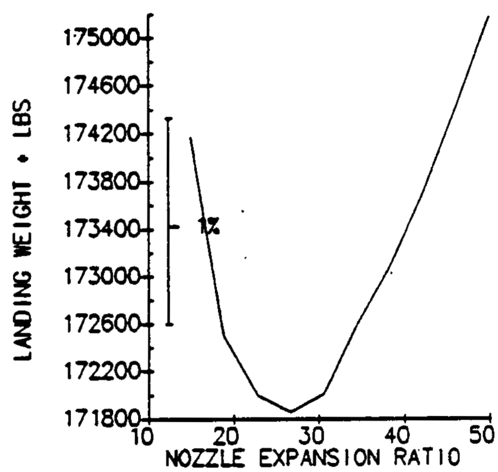


(m-84) Propellant Consumed Versus Nozzle Expansion Ratio

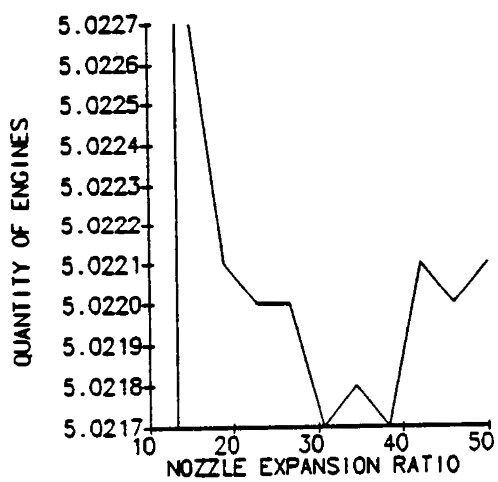
Configuration 2.M Sensitivity Studies (Continued)



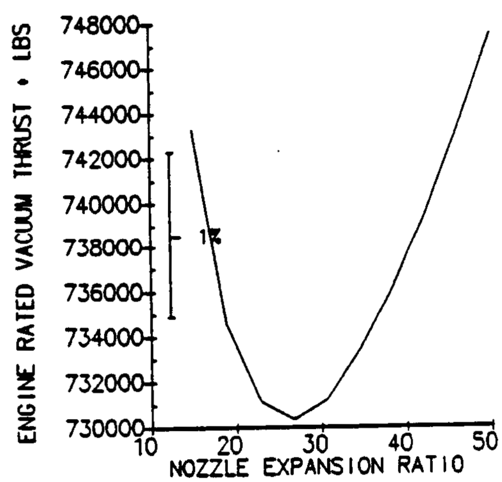
(m-85) Propellant Mass Fraction Versus Nozzle Expansion Ratio



(m-86) Weight of Hydrogen Coolant Versus Nozzle Expansion Ratio

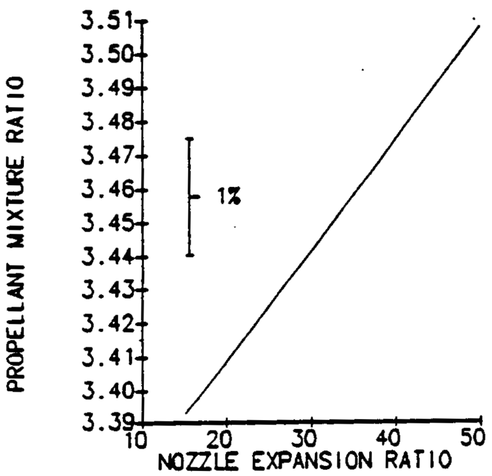


(m-87) Number of Booster Engines Versus Nozzle Expansion Ratio

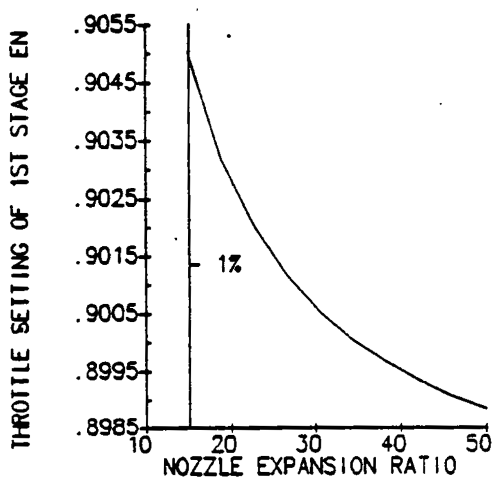


(m-88) Engine Rated Vacuum Thrust Versus Nozzle Expansion Ratio

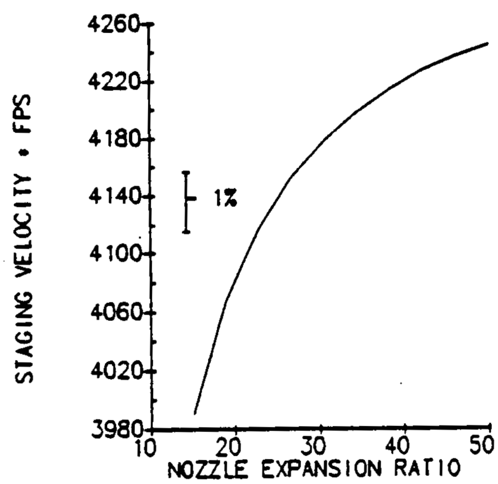
Configuration 2.M Sensitivity Studies (Continued)



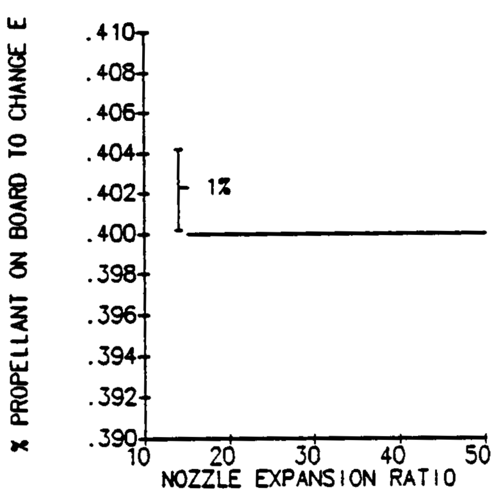
(m-89) **Propellant Mixture Ratio Versus Nozzle Expansion Ratio**



(m-90) **Initial Booster Throttle Setting Versus Nozzle Expansion Ratio**

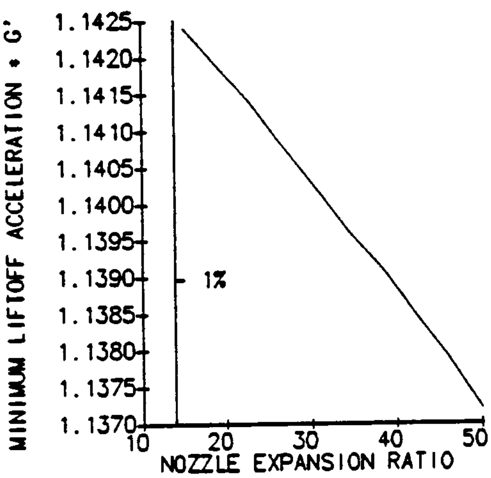


(m-91) **Staging Velocity Versus Nozzle Expansion Ratio**

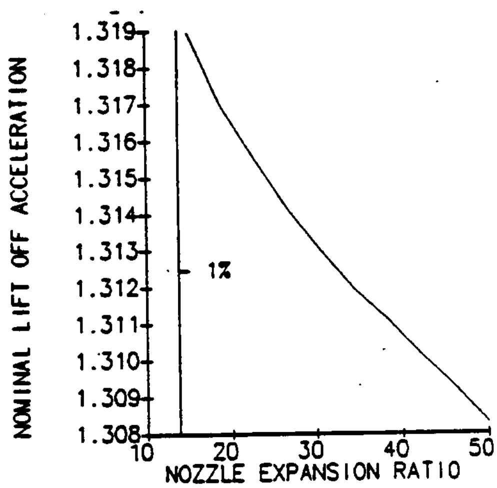


(m-92) **Orbiter Propellant at Staging Versus Nozzle Expansion Ra:io**

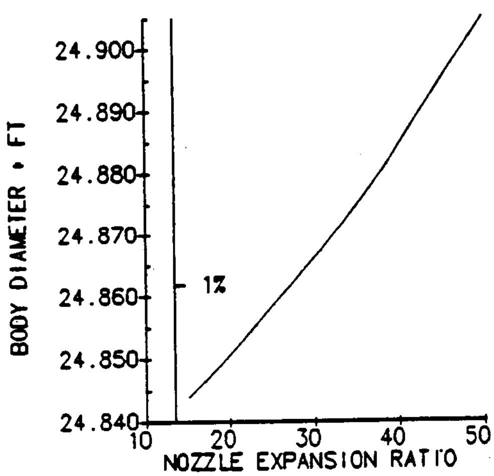
Configuration 2.M Sensitivity Studies (Continued)



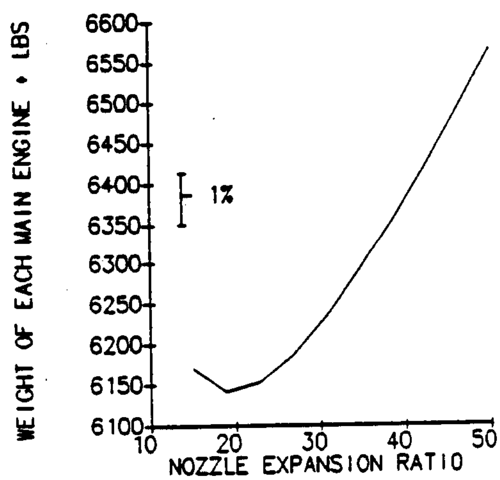
(m-93) Engine-out Lift Off Acceleration Versus Nozzle Expansion Ratio



(m-94) Nominal Lift Off Acceleration Versus Nozzle Expansion Ratio

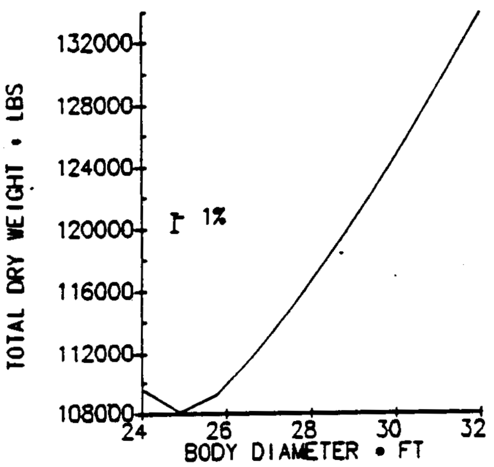


(m-95) Body Diameter Versus Nozzle Expansion Ratio

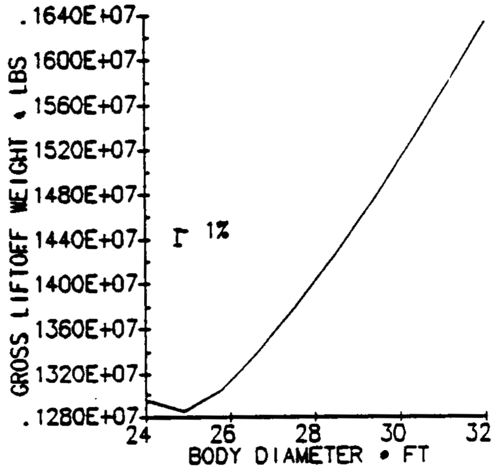


(m-96) Booster Engine Weight Versus Nozzle Expansion Ratio

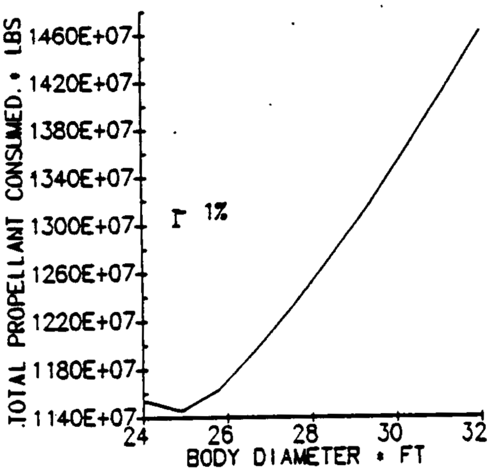
Configuration 2.M Sensitivity Studies (Continued)



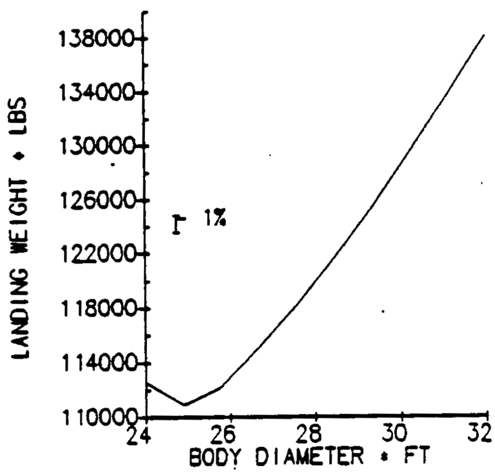
(b-1) ***Total Dry Weight Versus Body Diameter***



(b-2) ***Gross Liftoff Weight Versus Body Diameter***

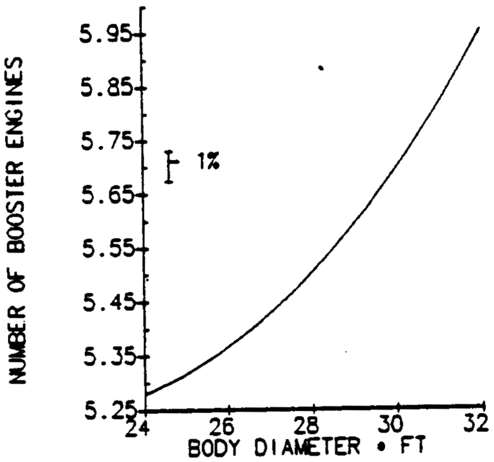


(b-3) ***Propellant Consumed Versus Body Diameter***

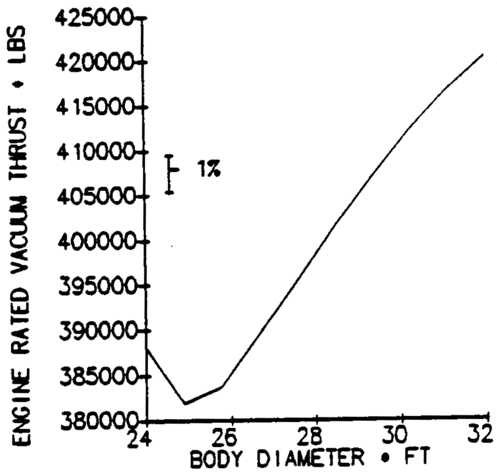


(b-4) ***Landing Weight Versus Body Diameter***

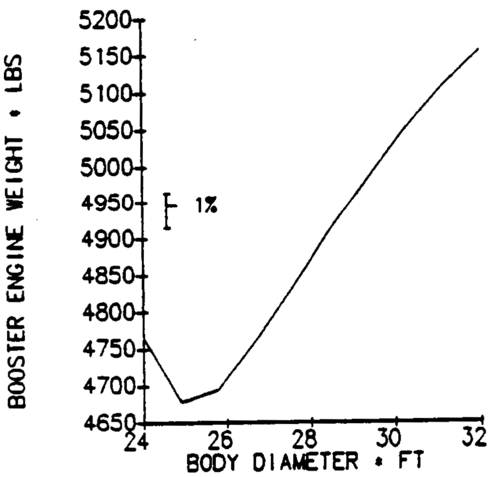
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio)



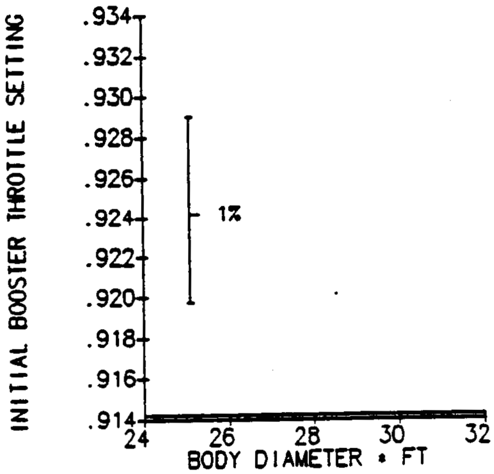
(b-5) ***Number of Booster Engines Versus Body Diameter***



(b-6) ***Engine Rated Vacuum Thrust Versus Body Diameter***

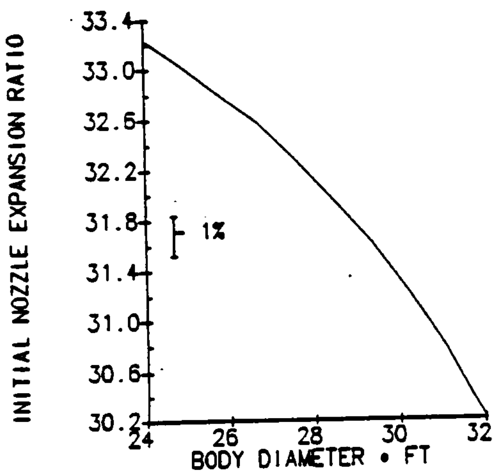


(b-7) ***Booster Engine Weight Versus Body Diameter***

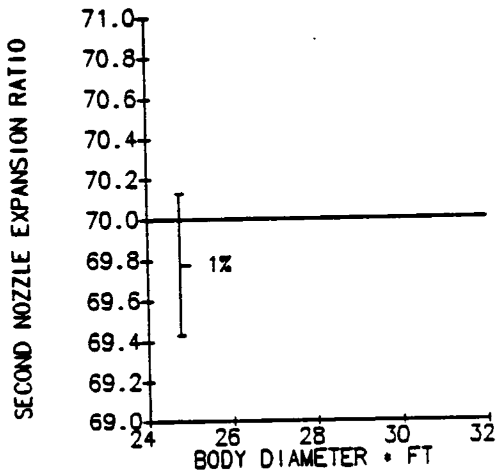


(b-8) ***Initial Booster Throttle Setting Versus Body Diameter***

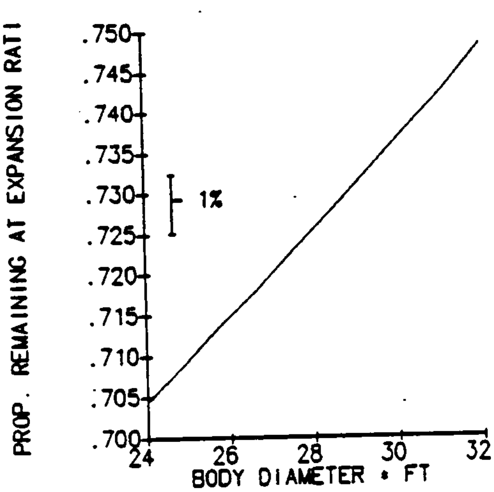
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



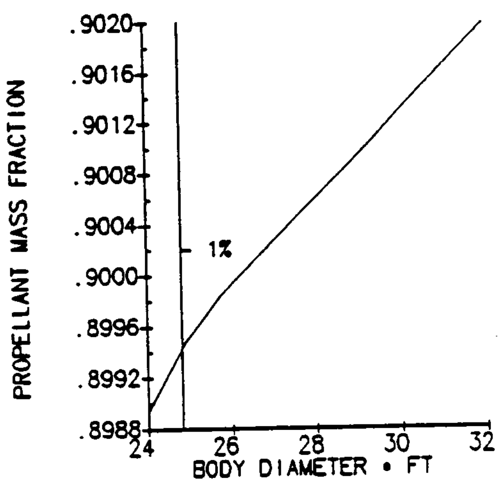
(b-9) *Initial Nozzle Expansion Ratio Versus Body Diameter*



(b-10) *Second Nozzle Expansion Ratio Versus Body Diameter*

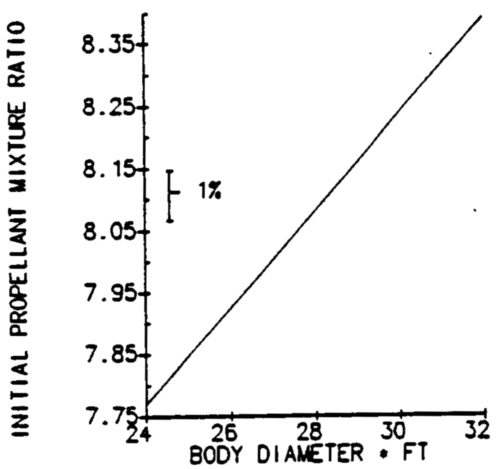


(b-11) *Propellant Remaining at Expansion Ratio Change Versus Body Diameter*

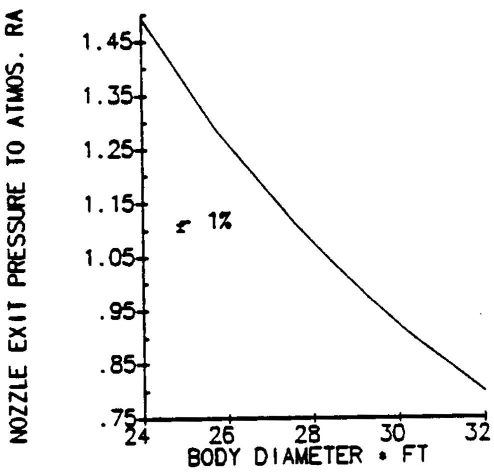


(b-12) *Propellant Mass Fraction Versus Body Diameter*

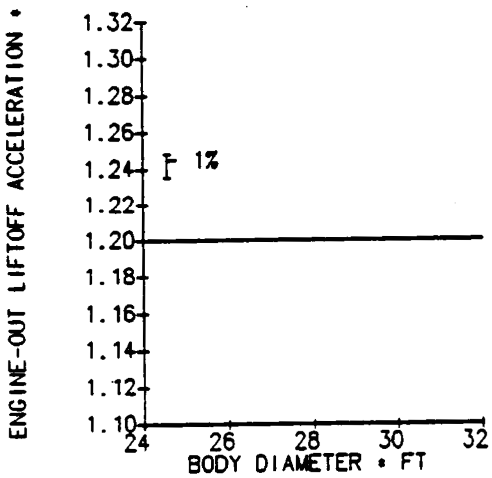
Configurati)n 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



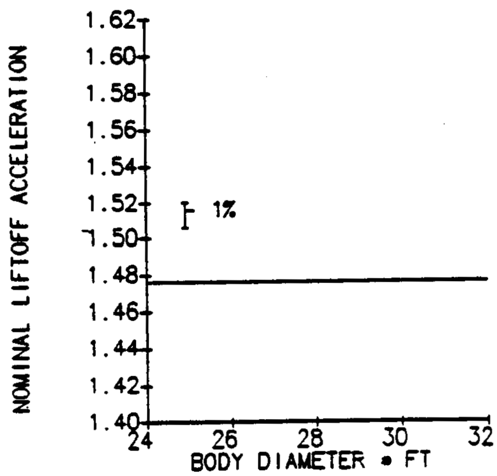
(b-13) ***Propellant Mixture Ratio Versus Body Diameter***



(b-14) ***Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Body Diameter***

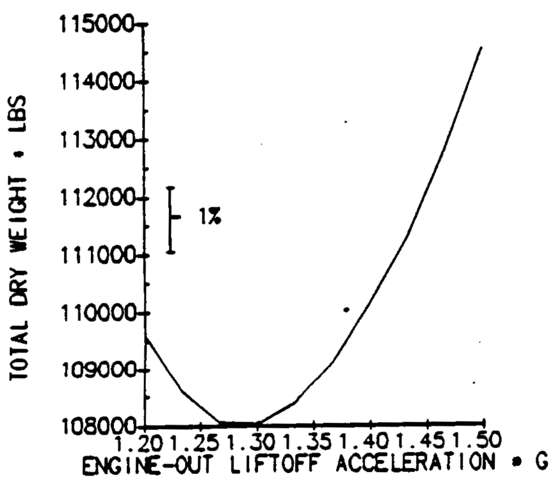


(b-15) ***Engine-out Liftoff Acceleration Versus Body Diameter***

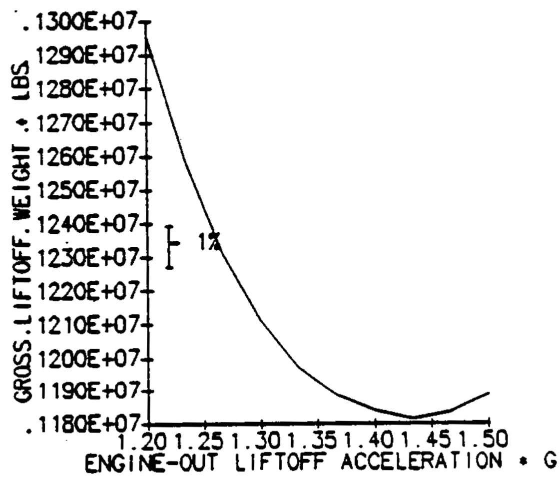


(b-16) ***Nominal Liftoff Acceleration Versus Body Diameter***

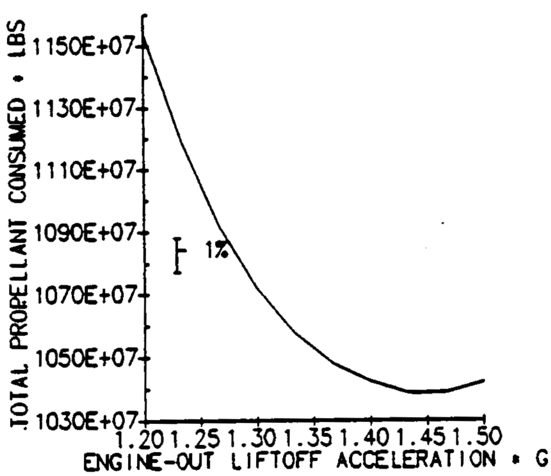
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



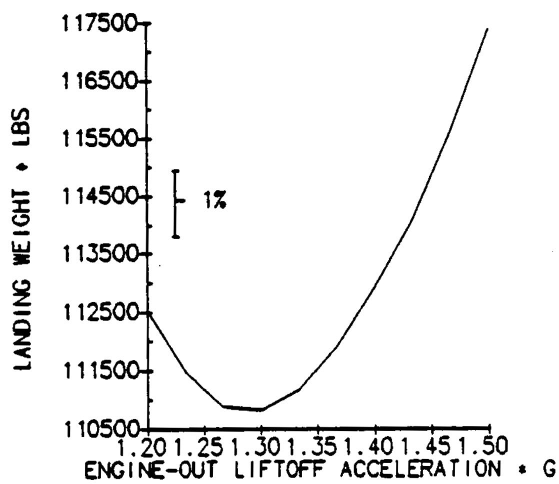
(b-17) ***Total Dry Weight Versus Engine-out Liftoff Acceleration***



(b-18) ***Gross Liftoff Weight Versus Engine-out Liftoff Acceleration***

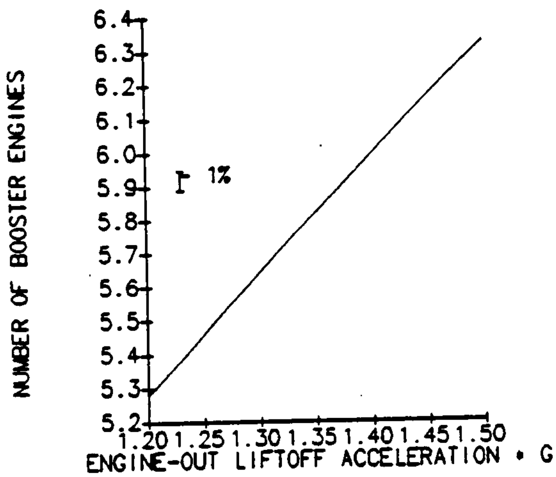


(b-19) ***Propellant Consumed Versus Engine-out Liftoff Acceleration***

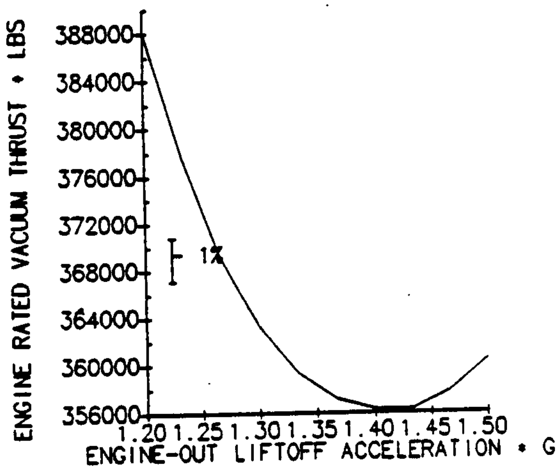


(b-20) ***Landing Weight Versus Engine-Out Liftoff Acceleration***

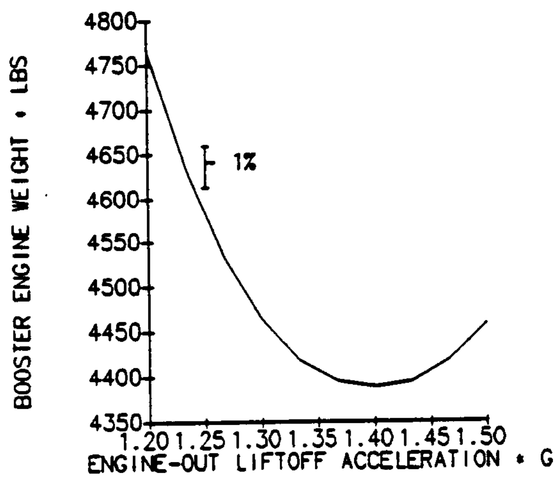
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



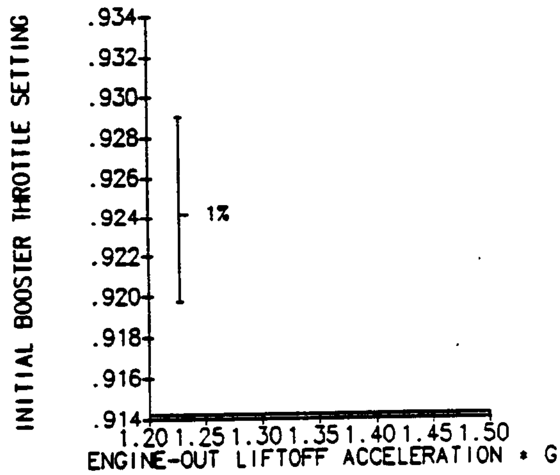
(b-21) *Number of Booster Engines Versus Engine-Out Liftoff Acceleration*



(b-22) *Engine Rated Vacuum Thrust Versus Engine-Out Liftoff Acceleration*

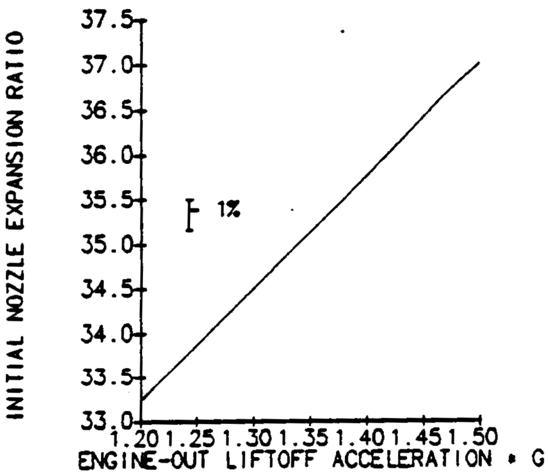


(b-23) *Booster Engine Weight Versus Engine-Out Liftoff Acceleration*

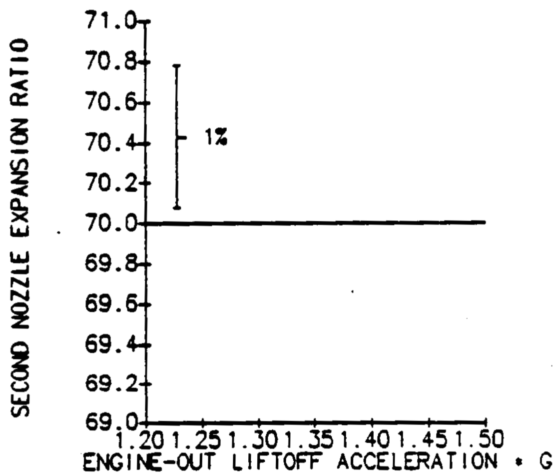


(b-24) *Initial Booster Throttle Setting Versus Engine-Out Liftoff Acceleration*

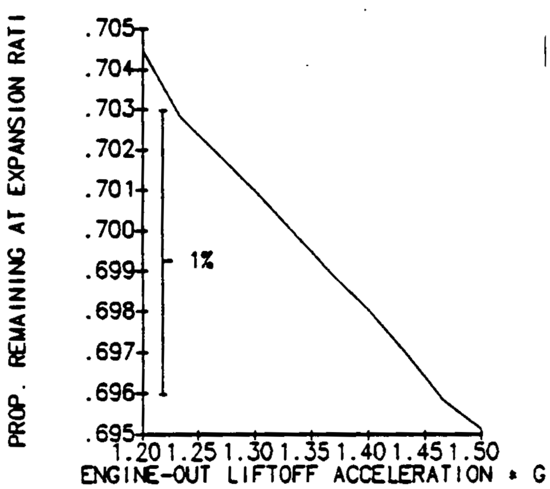
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



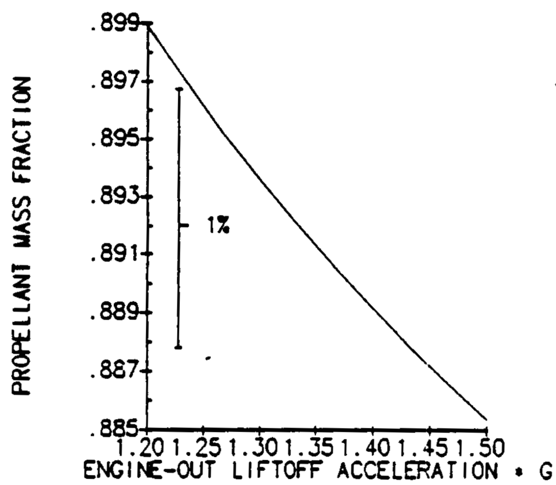
(b-25) ***Initial Nozzle Expansion Ratio Versus Engine-Out Liftoff Acceleration***



(b-26) ***Second Nozzle Expansion Ratio Versus Engine-Out Liftoff Acceleration***

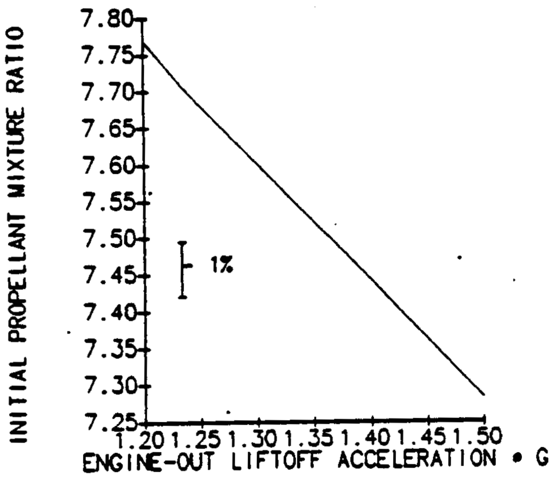


(b-27) ***Propellant Remaining at Expansion Ratio Change Versus Engine-Out Liftoff Acceleration***

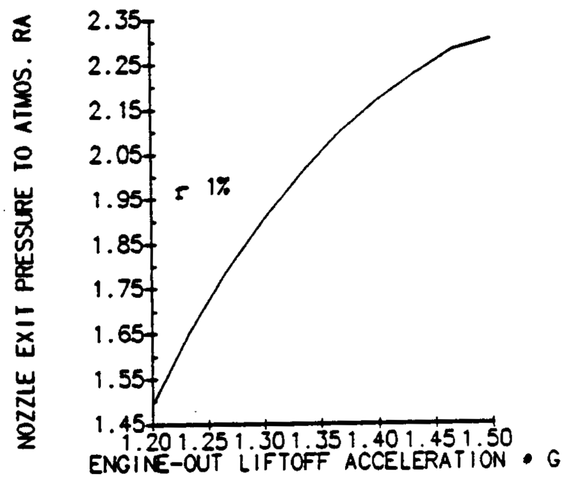


(b-28) ***Propellant Mass Fraction Versus Engine-Out Liftoff Acceleration***

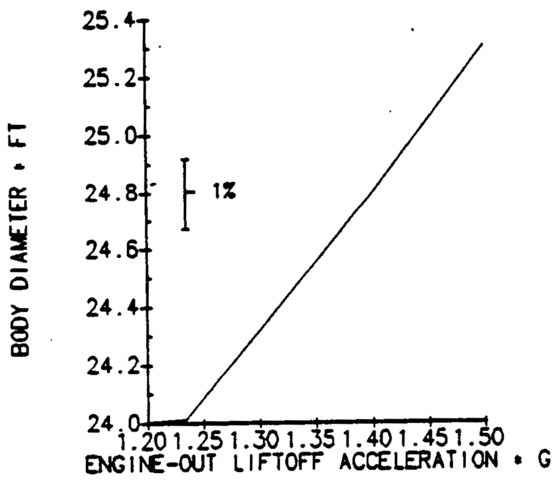
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



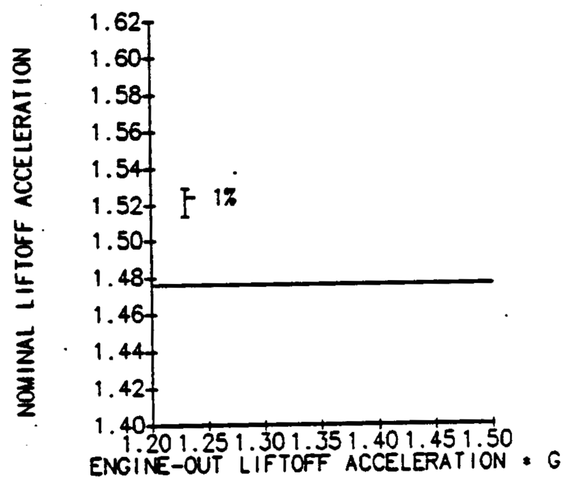
(b-29) ***Propellant Mixture Ratio Versus Engine-Out Liftoff Acceleration***



(b-30) ***Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Engine-Out Liftoff Acceleration***

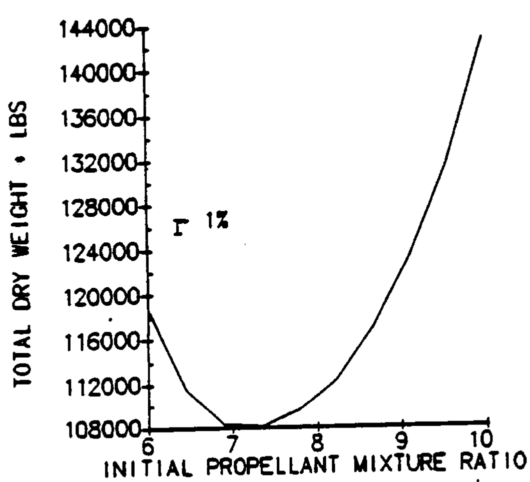


(b-31) ***Body Diameter Versus Engine-Out Liftoff Acceleration***

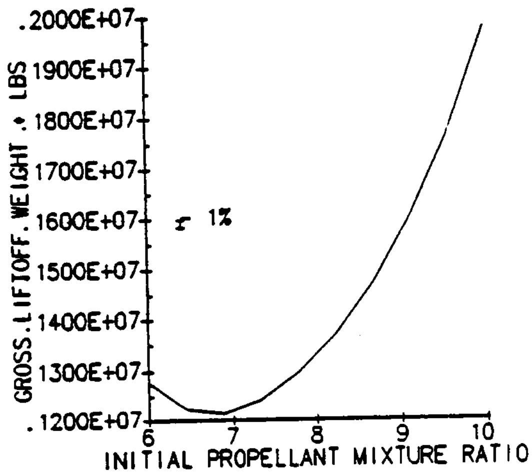


(b-32) ***Nominal Liftoff Acceleration Versus Engine-Out Liftoff Acceleration***

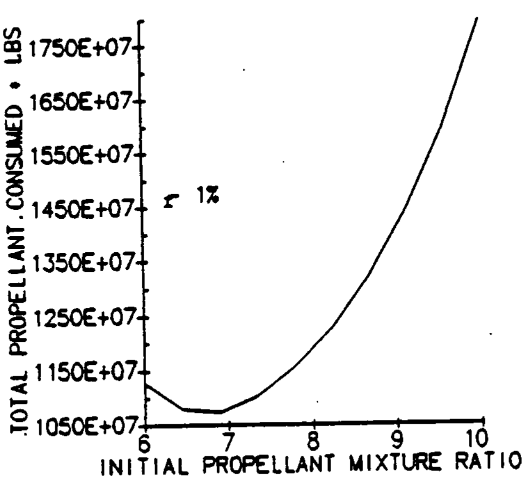
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



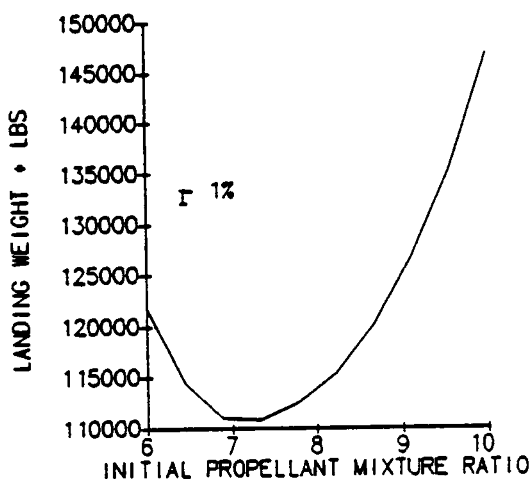
(b-33) *Total Dry Weight Versus Propellant Mixture Ratio*



(b-34) *Gross Liftoff Weight Versus Propellant Mixture Ratio*

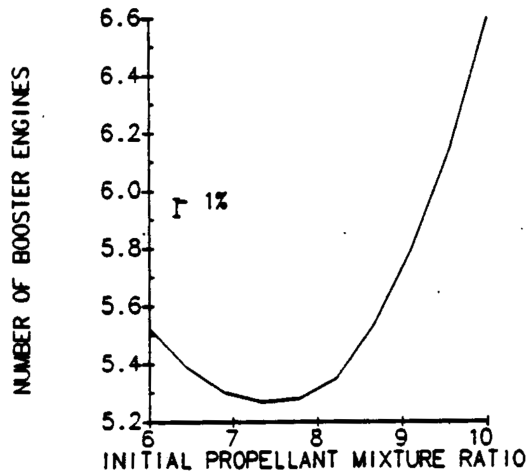


(b-35) *Propellant Consumed Versus Propellant Mixture Ratio*

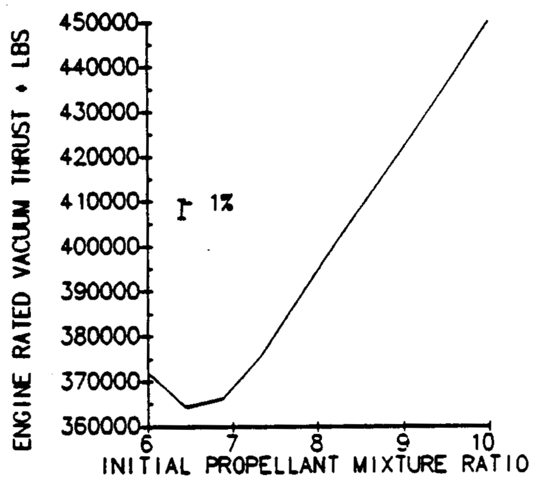


(b-36) *Landing V'eight Versus Propellant Mixture Ratio*

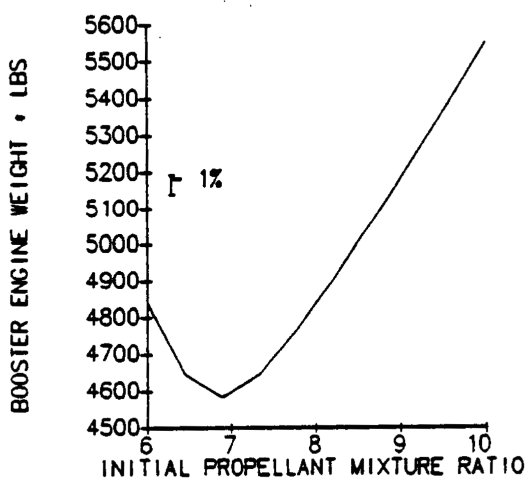
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



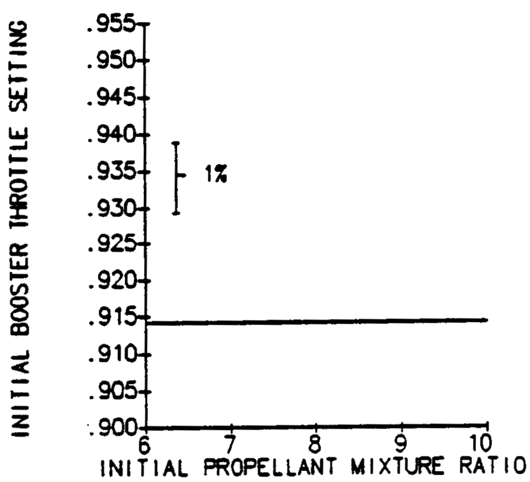
(b-37) **Number of Booster Engines Versus Propellant Mixture Ratio**



(b-38) **Engine Rated Vacuum Thrust Versus Propellant Mixture Ratio**

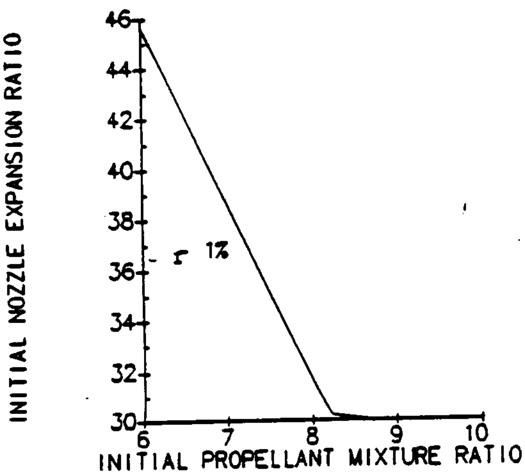


(b-39) **Booster Engine Weight Versus Propellant Mixture Ratio**

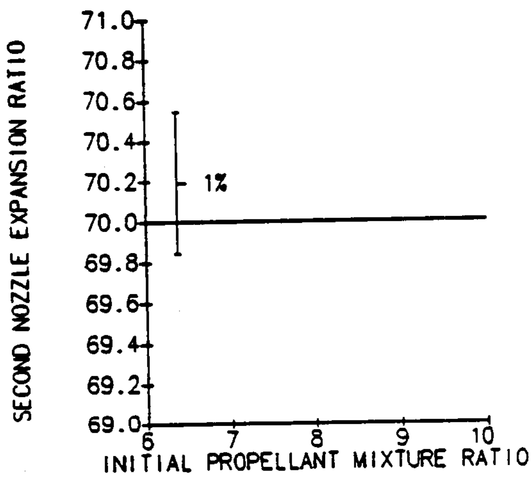


(b-40) **Initial Booster Throttle Setting Versus Propellant Mixture Ratio**

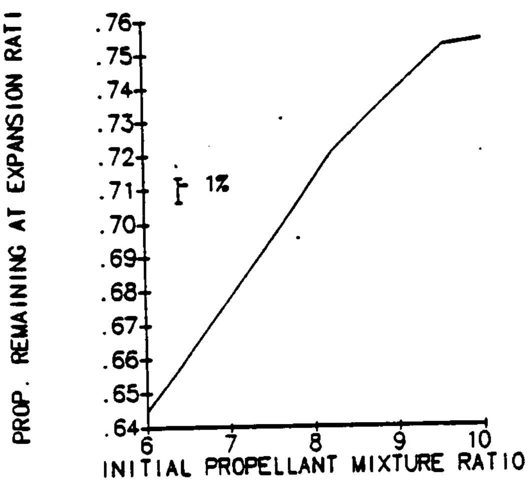
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



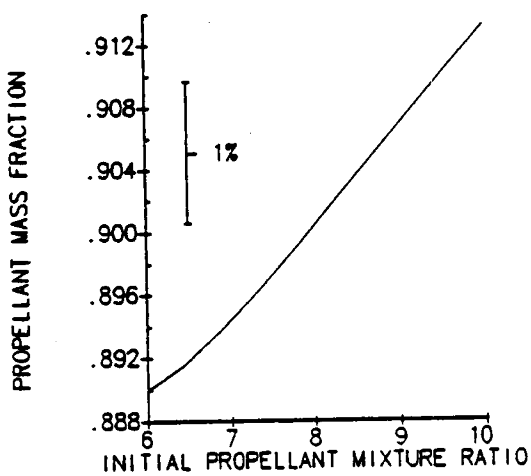
(b-41) *Initial Nozzle Expansion Ratio Versus Propellant Mixture Ratio*



(b-42) *Second Nozzle Expansion Ratio Versus Propellant Mixture Ratio*

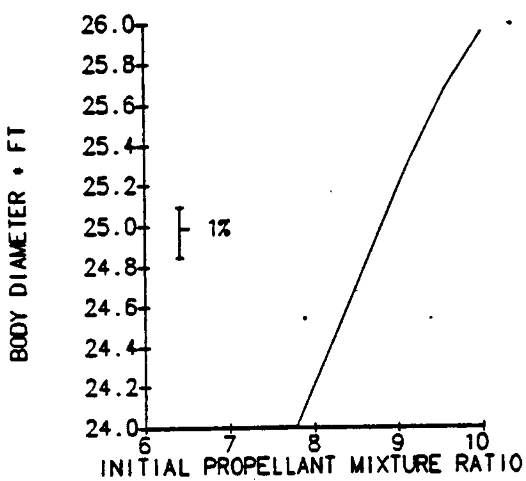


(b-43) *Propellant Remaining at Expansion Ratio Change Versus Propellant Mixture Ratio*

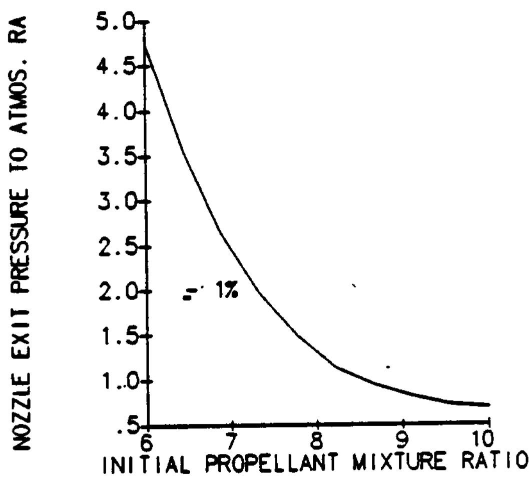


(b-44) *Propellant Mass Fraction Versus Propellant Mixture Ratio*

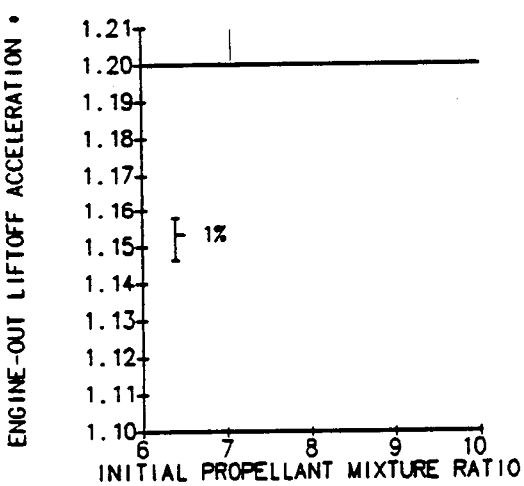
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



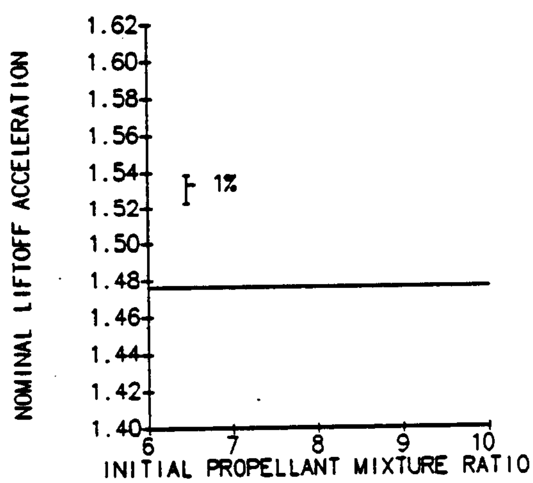
(b-45) *Body Diameter Versus Propellant Mixture Ratio*



(b-46) *Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Propellant Mixture Ratio*

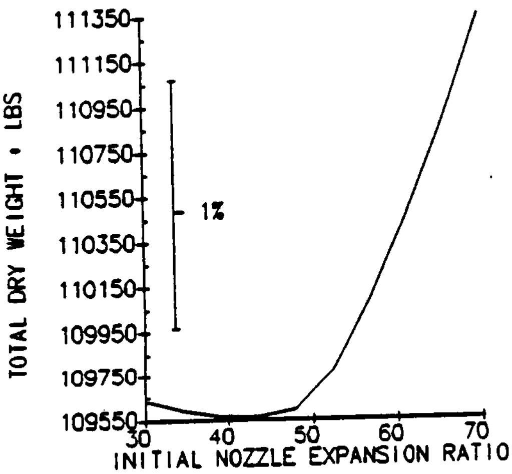


(b-47) *Engine-out Liftoff Acceleration Versus ?ropellant Mixture Ratio*

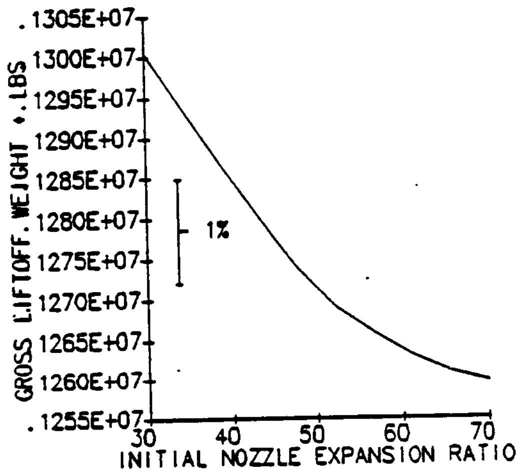


(b-48) *Nominal Liftoff Acceleration Versus Propellant Mixture Ratio*

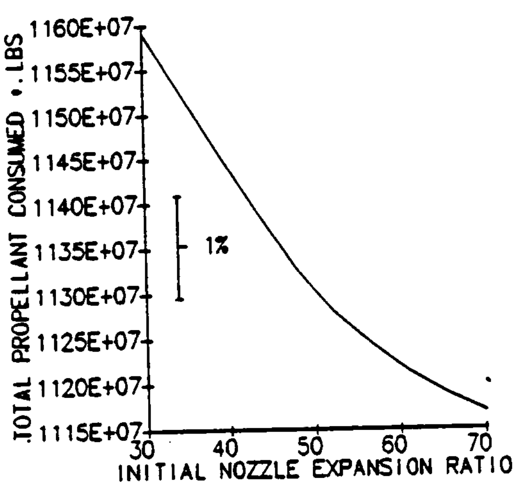
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



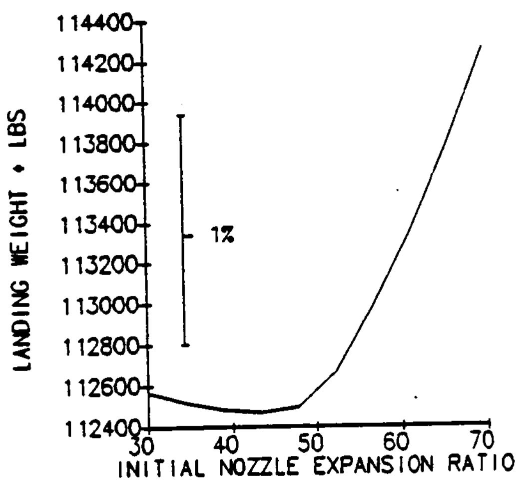
(b-49) ***Total Dry Weight Versus Initial Nozzle Expansion Ratio***



(b-50) ***Gross Liftoff Weight Versus Initial Nozzle Expansion Ratio***

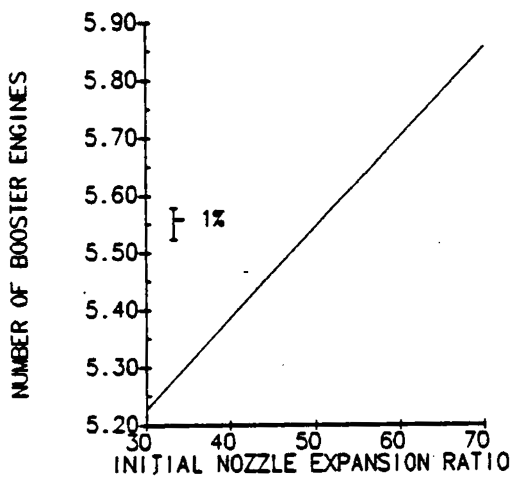


(b-51) ***Propellant Consumed Versus Initial Nozzle Expansion Ratio***

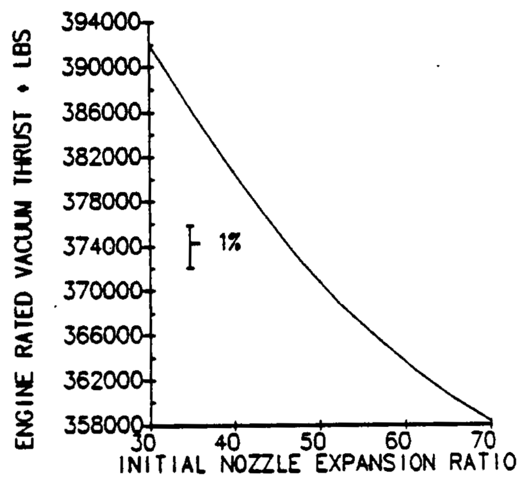


(b-52) ***Landing Weight Versus Initial Nozzle Expansion Ratio***

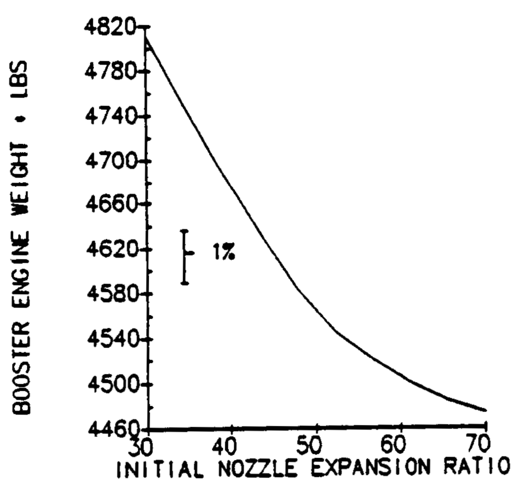
- Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



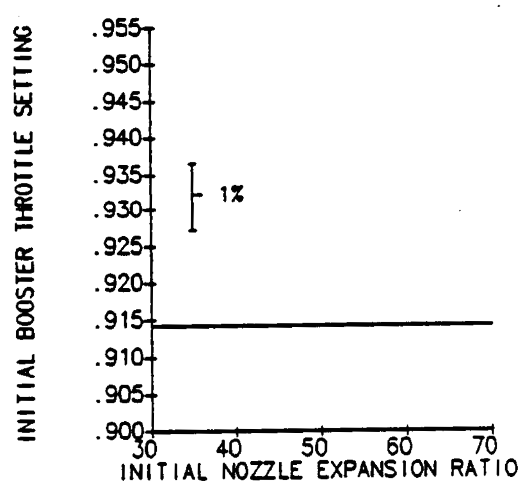
(b-53) Number of Booster Engines Versus Initial Nozzle Expansion Ratio



(b-54) Engine Rated Vacuum Thrust Versus Initial Nozzle Expansion Ratio

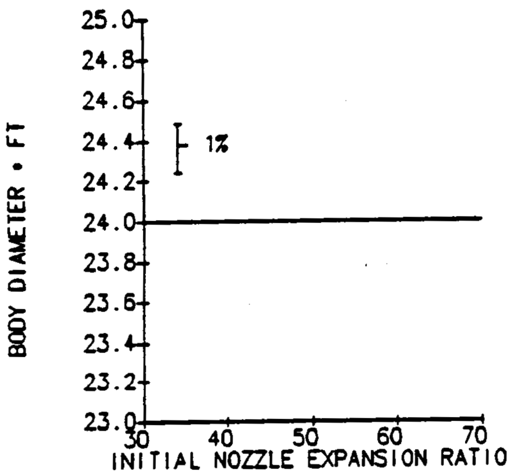


(b-55) Booster Engine Weight Versus Initial Nozzle Expansion Ratio

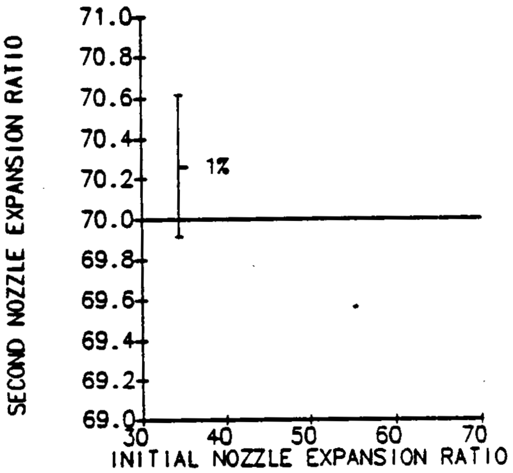


(b-56) Initial Booster Throttle Setting Versus Initial Nozzle Expansion Ratio

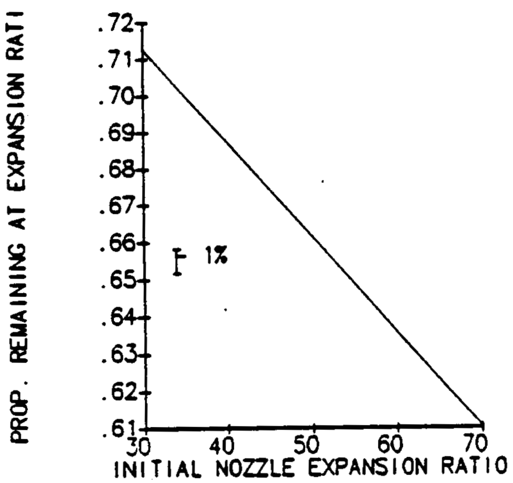
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



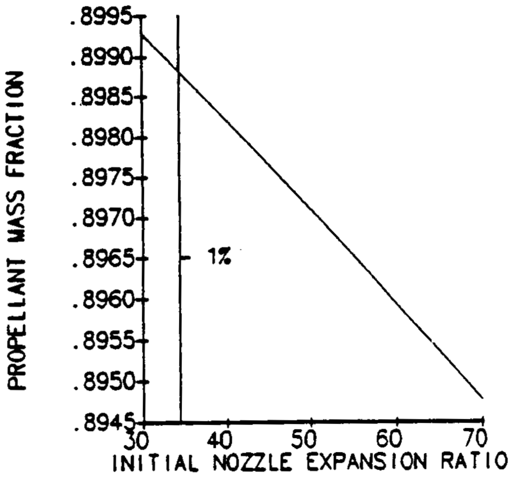
(b-57) **Body Diameter Versus Initial Nozzle Expansion Ratio**



(b-58) **Second Nozzle Expansion Ratio Versus Initial Nozzle Expansion Ratio**

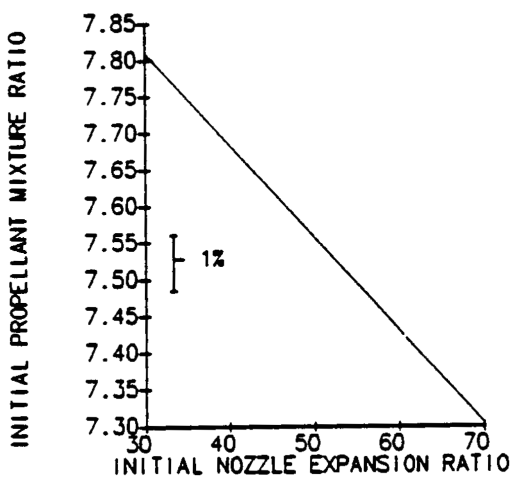


(b-59) **Propellant Remaining at Expansion Ratio Change Versus Initial Nozzle Expansion Ratio**

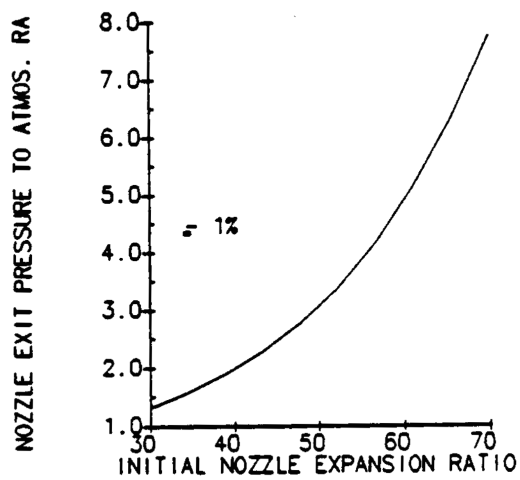


(b-60) **Propellant Mass Fraction Versus Initial Nozzle Expansion Ratio**

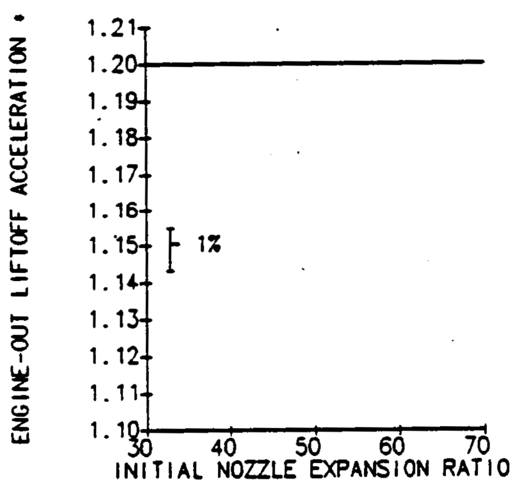
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



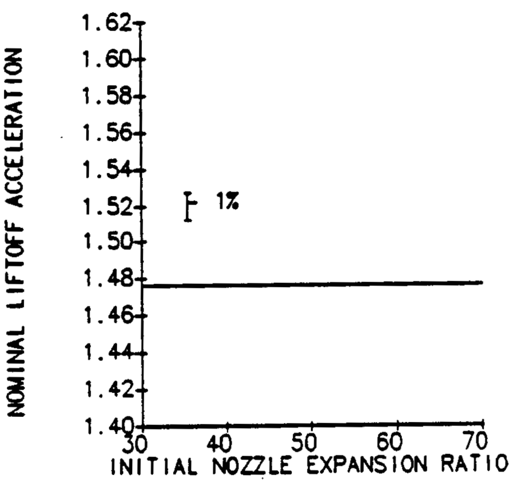
(b-61) **Propellant Mixture Ratio Versus Initial Nozzle Expansion Ratio**



(b-62) **Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Initial Nozzle Expansion Ratio**

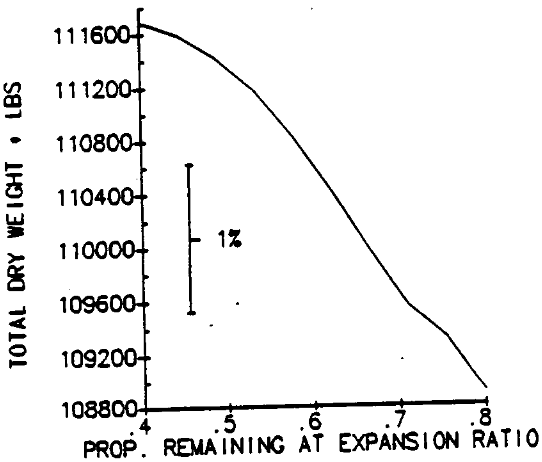


(b-63) **Engine-out Liftoff Acceleration Versus Initial Nozzle Expansion Ratio**

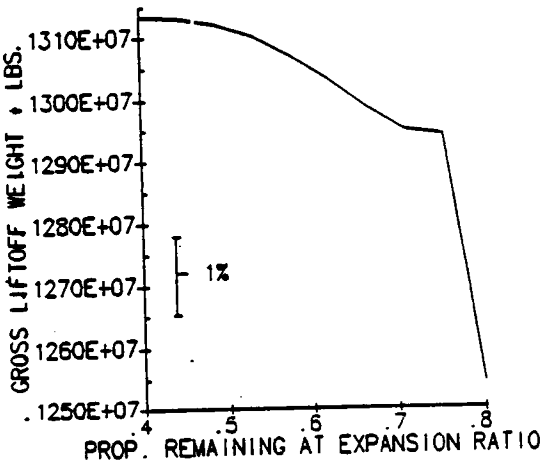


(b-64) **Nominal Liftoff Acceleration Versus Initial Nozzle Expansion Ratio**

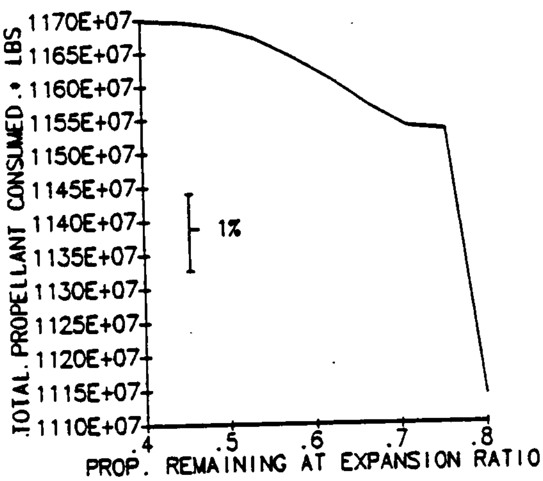
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



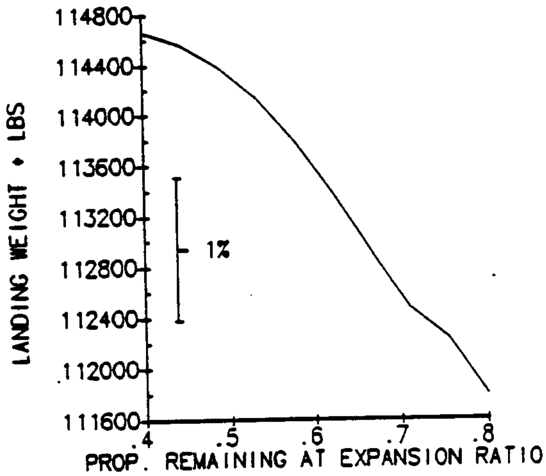
(b-65) ***Total Dry Weight Versus Propellant Remaining at Expansion Ratio Change***



(b-66) ***Gross Liftoff Weight Versus Propellant Remaining at Expansion Ratio Change***

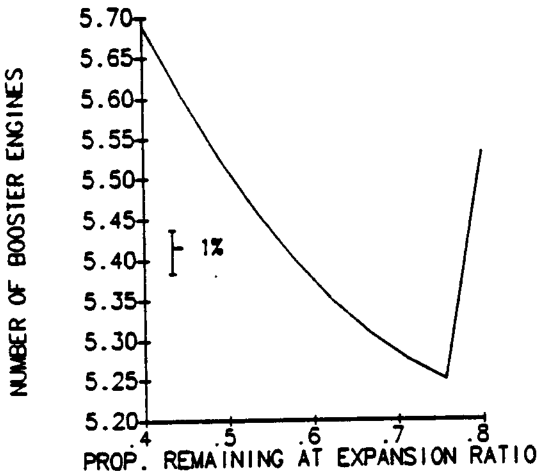


(b-67) ***Propellant Consumed Versus Propellant Remaining at Expansion Ratio Change***

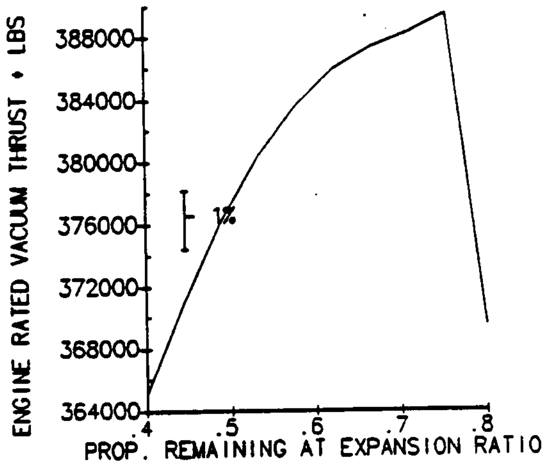


(b-68) ***Landing Weight Versus Propellant Remaining at Expansion Ratio Change***

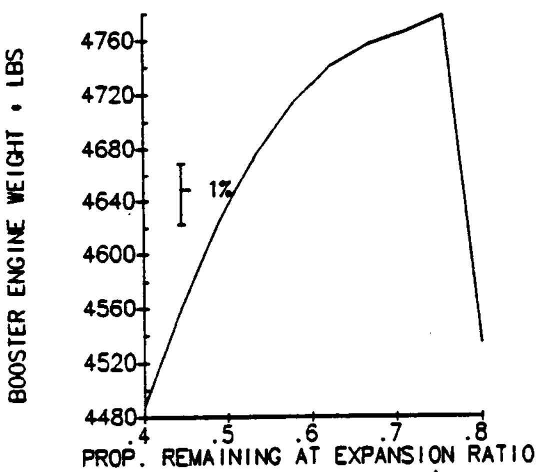
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



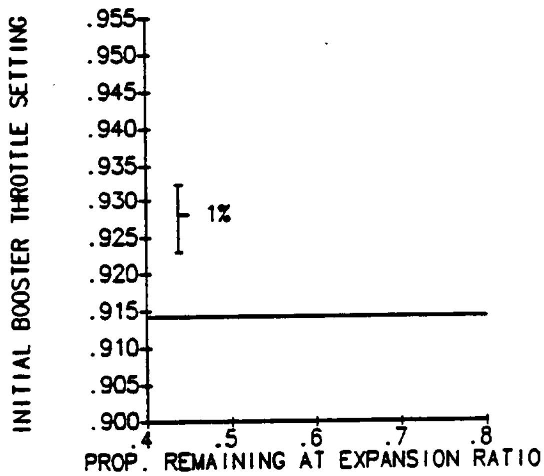
(b-69) ***Number of Booster Engines Versus Propellant Remaining at Expansion Ratio Change***



(b-70) ***Engine Rated Vacuum Thrust Versus Propellant Remaining at Expansion Ratio Change***

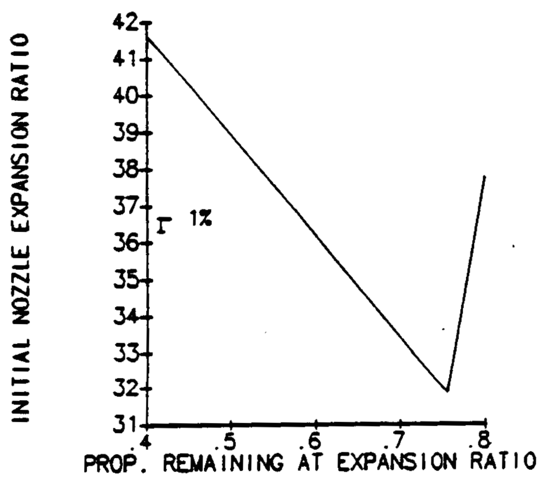


(b-71) ***Booster Engine Weight Versus Propellant Remaining at Expansion Ratio Change***

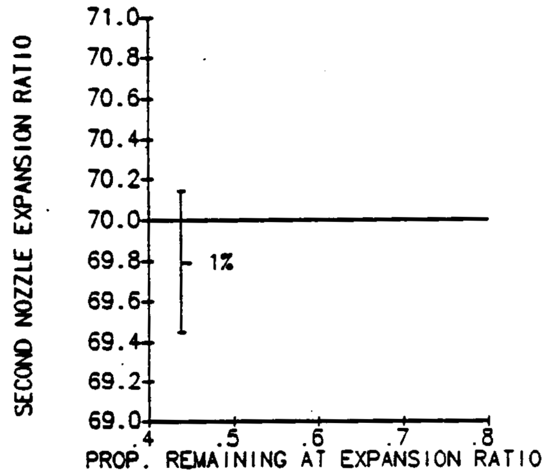


(b-72) ***Initial Booster Throttle Setting Versus Propellant Remaining at Expansion Ratio Change***

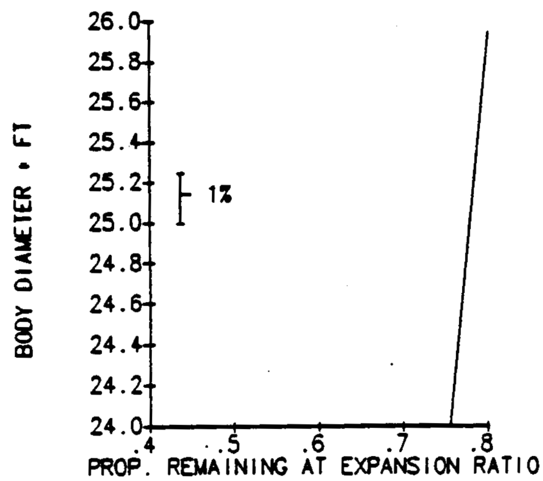
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



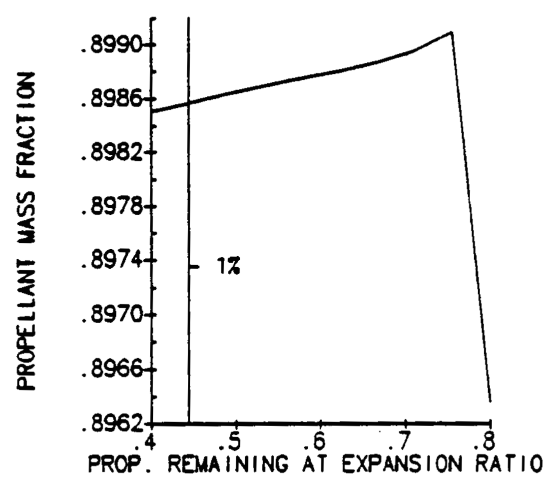
(b-73) *Initial Nozzle Expansion Ratio Versus Propellant Remaining at Expansion Ratio Change*



(b-74) *Second Nozzle Expansion Ratio Versus Propellant Remaining at Expansion Ratio Change*

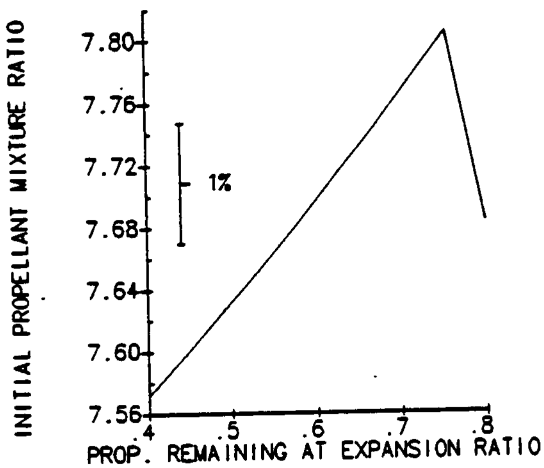


(b-75) *Body Diameter Versus Propellant Remaining at Expansion Ratio Change*

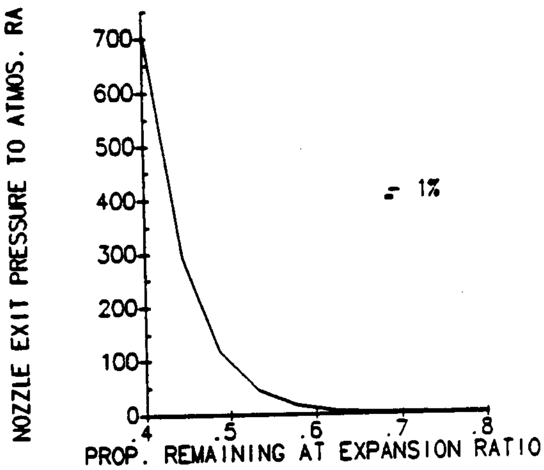


(b-76) *Propellant Mass Fraction Versus Propellant Remaining at Expansion Ratio Change*

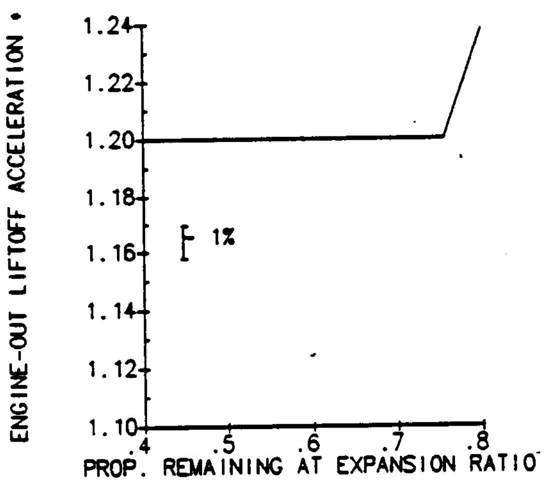
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



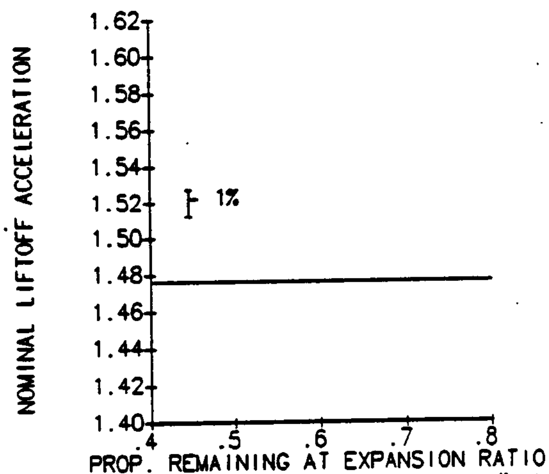
(b-77) *Propellant Mixture Ratio Versus Propellant Remaining at Expansion Ratio Change*



(b-78) *Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Propellant Remaining at Expansion Ratio Change*

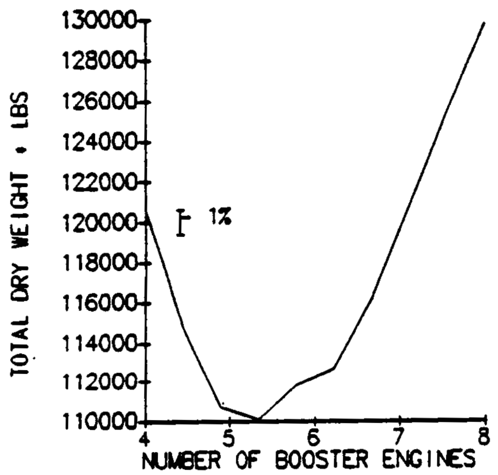


(b-79) *Engine-Out Liftoff Acceleration Versus Propellant Remaining at Expansion Ratio Change*

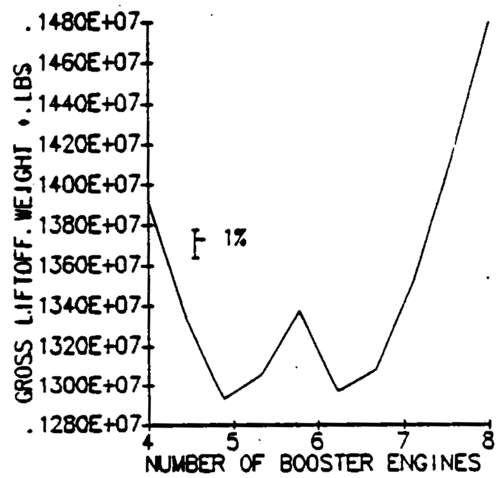


(b-80) *Nominal Liftoff Acceleration Versus Propellant Remaining at Expansion Ratio Change*

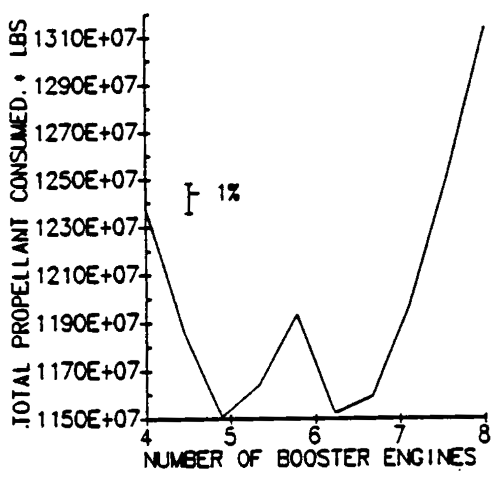
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



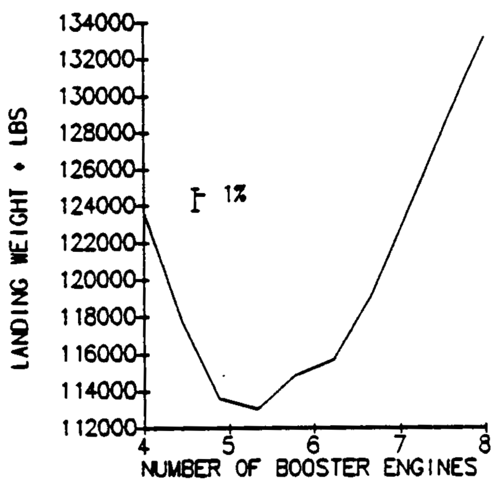
(b-81) *Total Dry Weight Versus Number of Booster Engines*



(b-82) *Gross Liftoff Weight Versus Number of Booster Engines*

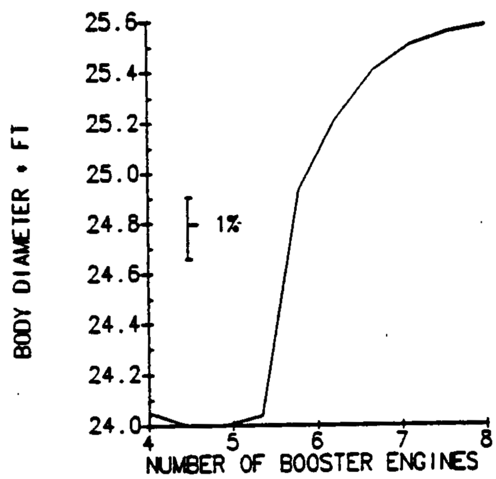


(b-83) *Propellant Consumed Versus Number of Booster Engines*

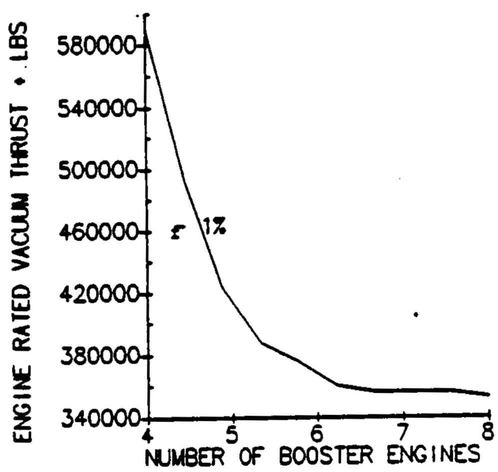


(b-84) *Landing Weight Versus Number of Booster Engines*

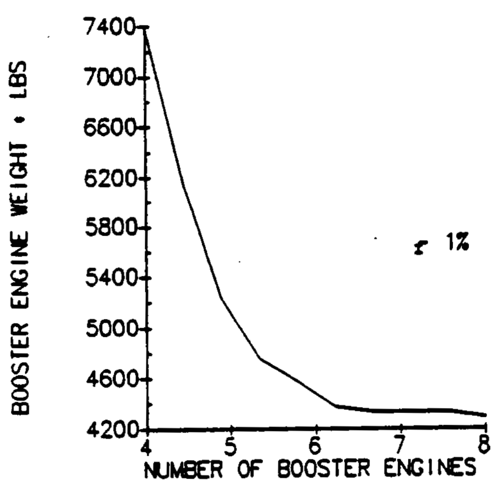
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



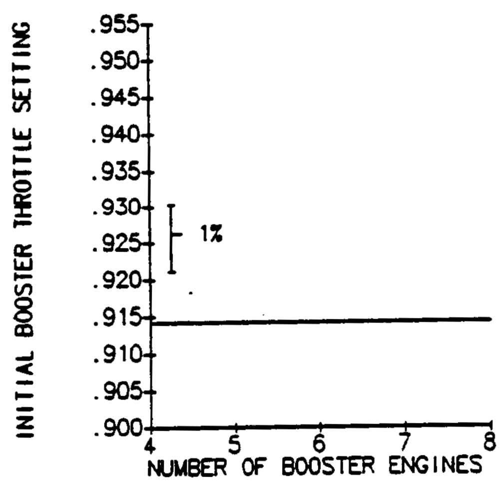
(b-85) ***Body Diameter Versus Number of Booster Engines***



(b-86) ***Engine Rated Vacuum Thrust Versus Number of Booster Engines***

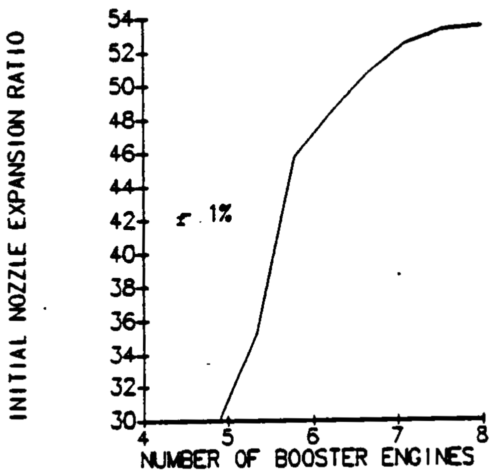


(b-87) ***Booster Engine Weight Versus Number of Booster Engines***

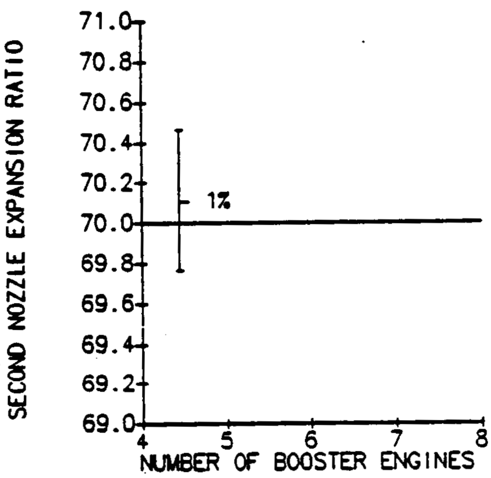


(b-88) ***Initial Booster Throttle Setting Versus Number of Booster Engines***

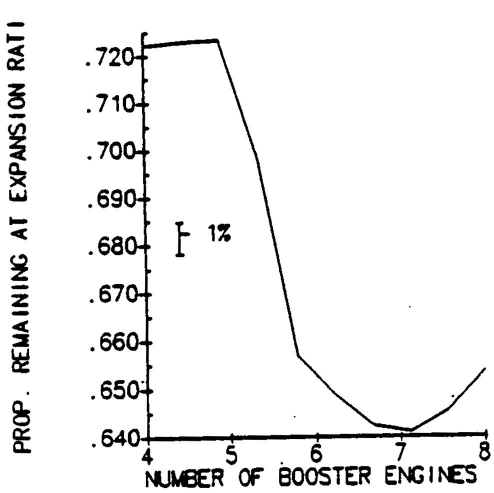
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



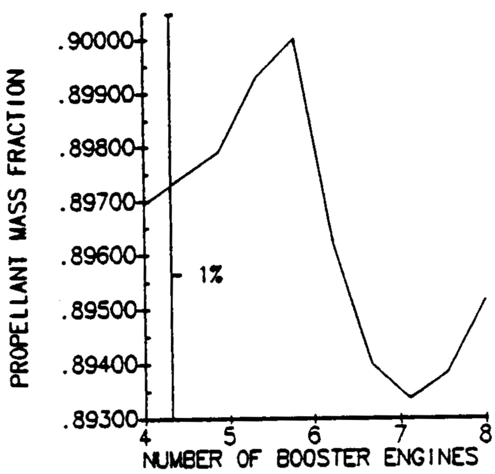
(b-89) *Initial Nozzle Expansion Ratio Versus Number of Booster Engines*



(b-90) *Second Nozzle Expansion Ratio Versus Number of Booster Engines*

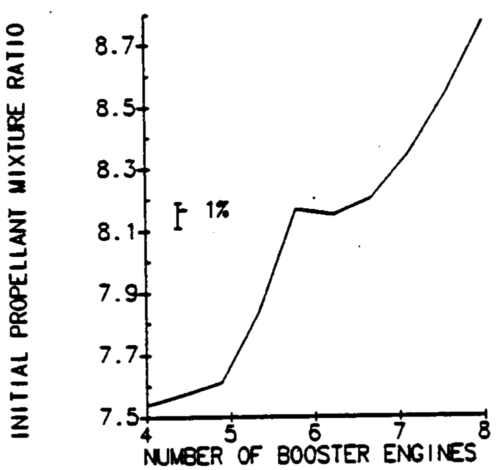


(b-91) *Propellant Remaining at Expansion Ratio Change Versus Number of Booster Engines*

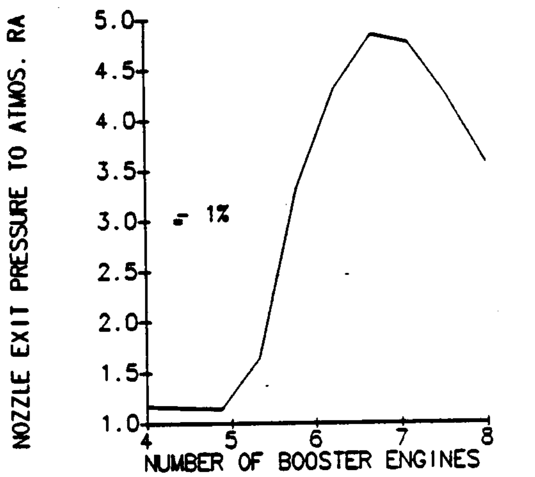


(b-92) *Propellant Mass Fraction Versus Number of Booster Engines*

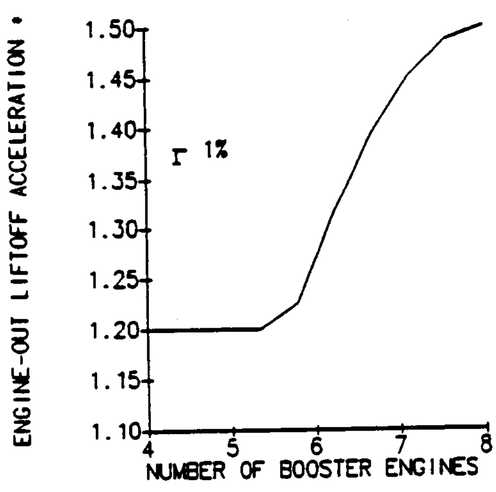
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



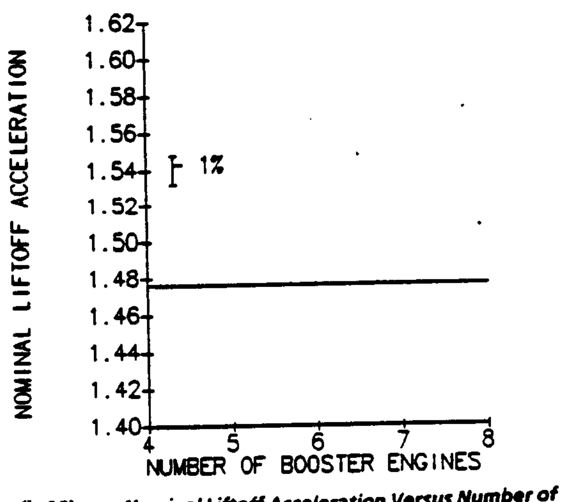
(b-93) Propellant Mixture Ratio Versus Number of Booster Engines



(b-94) Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Number of Booster Engines

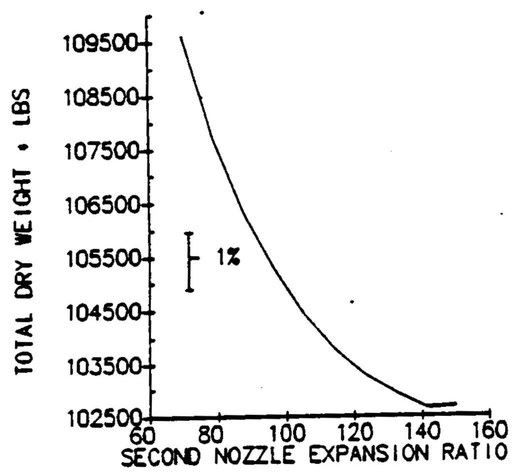


(b-95) Engine-Out Liftoff Acceleration Versus Number of Booster Engines

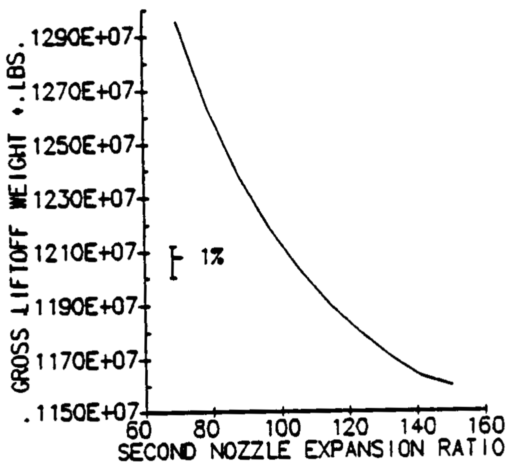


(b-96) Nominal Liftoff Acceleration Versus Number of Booster Engines

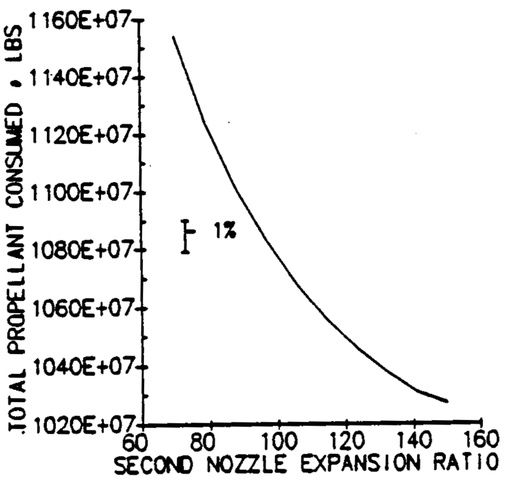
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



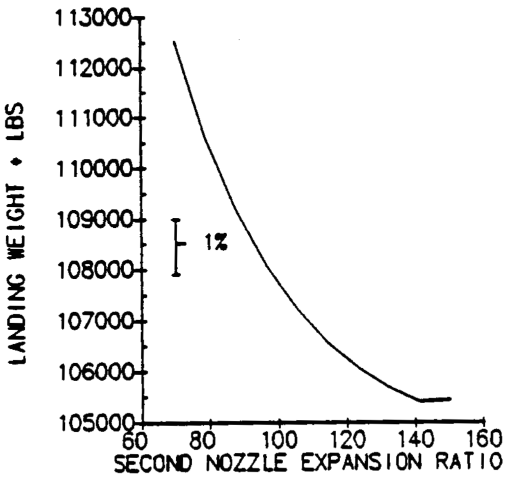
(b-97) *Total Dry Weight Versus Second Nozzle Expansion Ratio*



(b-98) *Gross Liftoff Weight Versus Second Nozzle Expansion Ratio*

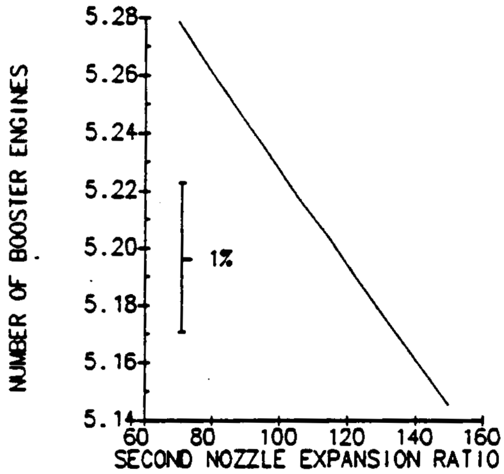


(b-99) *Propellant Consumed Versus Second Nozzle Expansion Ratio*

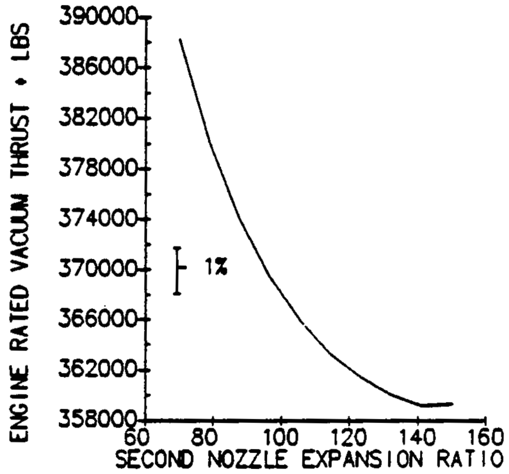


(b-100) *Landing Weight Versus Second Nozzle Expansion Ratio*

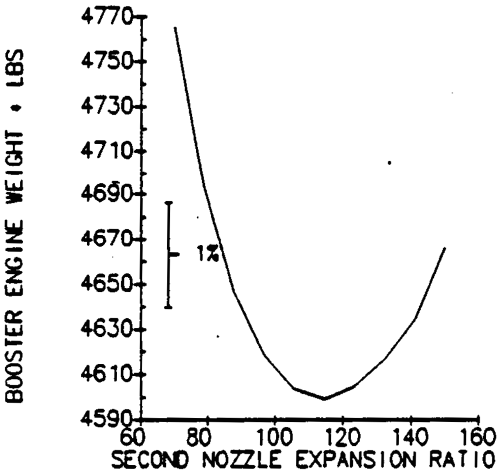
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



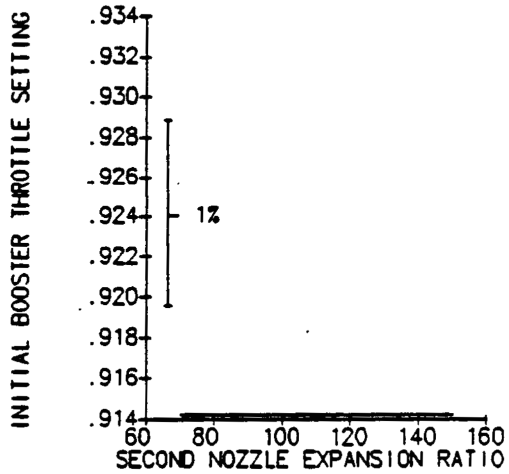
(b-101) ***Number of Booster Engines Versus Second Nozzle Expansion Ratio***



(b-102) ***Engine Rated Vacuum Thrust Versus Second Nozzle Expansion Ratio***

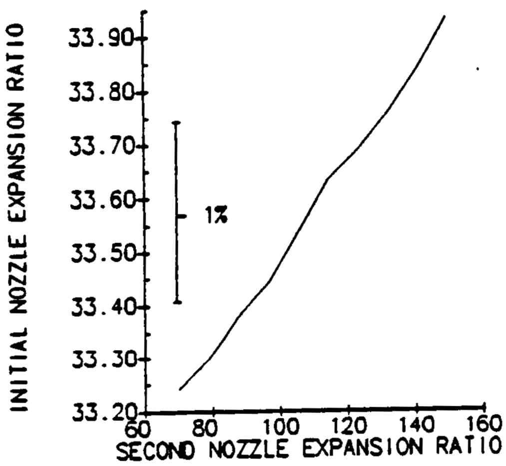


(b-103) ***Booster Engine Weight Versus Second Nozzle Expansion Ratio***

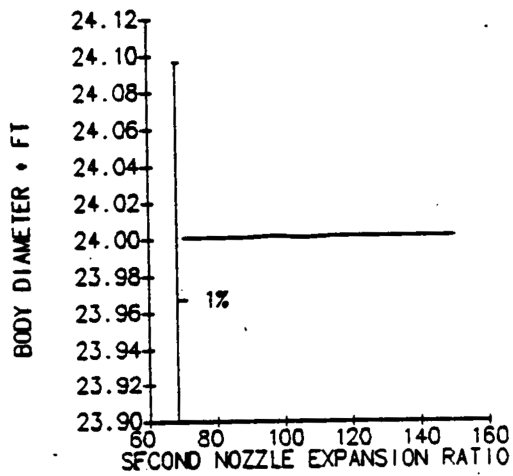


(b-104) ***Initial Booster Throttle Setting Versus Second Nozzle Expansion Ratio***

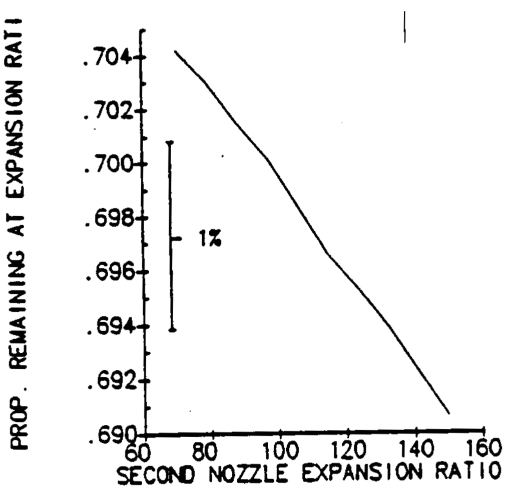
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



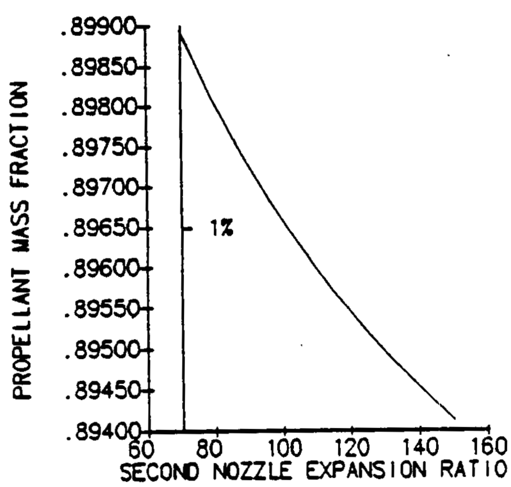
(b-105) *Initial Nozzle Expansion Ratio Versus Second Nozzle Expansion Ratio*



(b-106) *Body Diameter Versus Second Nozzle Expansion Ratio*

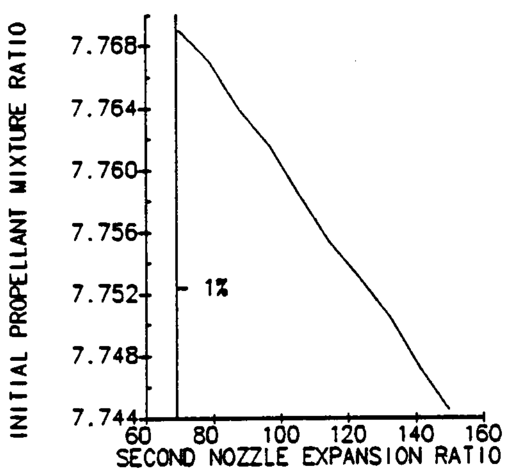


(b-107) *Propellant Remaining at Expansion Ratio Change Versus Second Nozzle Expansion Ratio*

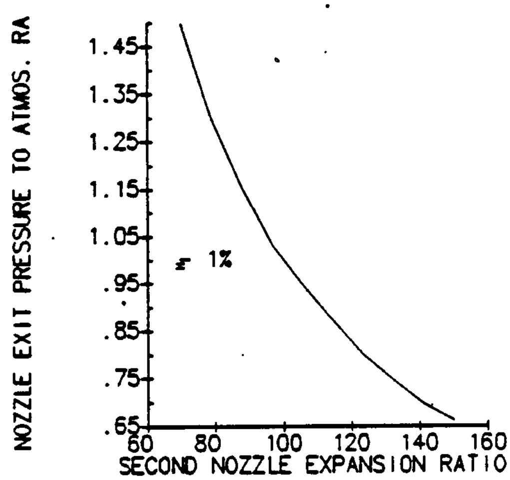


(b-108) *Propellant Mass Fraction Versus Second Nozzle Expansion Ratio*

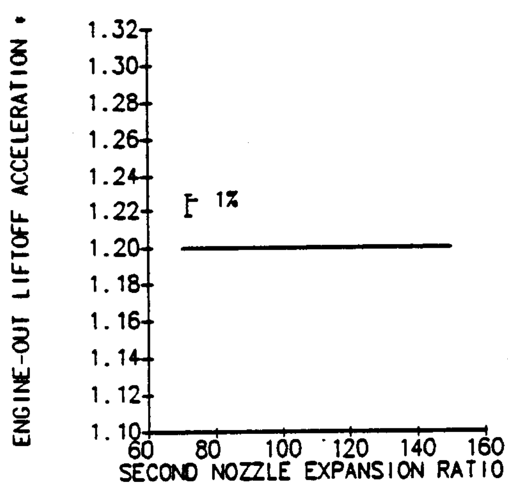
Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)



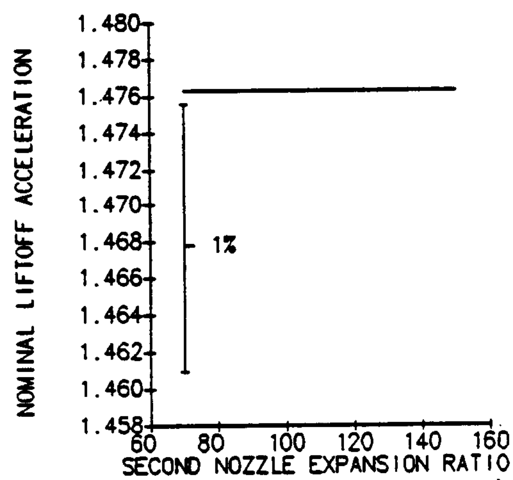
(b-109) ***Propellant Mixture Ratio Versus Second Nozzle Expansion Ratio***



(b-110) ***Nozzle Exit Pressure to Atmospheric Pressure Ratio Versus Second Nozzle Expansion Ratio***



(b-111) ***Engine-Out Liftoff Acceleration Versus Second Nozzle Expansion Ratio***



(b-112) ***Nominal Liftoff Acceleration Versus Second Nozzle Expansion Ratio***

Configuration 1.B Sensitivity Studies (Fixed Mixture Ratio) (Continued)

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2. G. B. Devereux, E. K. Bair, "Space Transportation Main Engine Configuration Study", Aerojet Tech Systems Company, January 1987, NAS8-3867

3. "Extended Liquid Engine Simulation", Air Force Rocket Propulsion Laboratory, AFRPL-TR-85-055.

4. "Space Transportation Main Engines for Single-Stage Vehicles", NASA Langley Research Center, AIAA-87-1949

GLOSSARY

ALS	Advanced Launch System
$\mathcal{R}$	aspect ratio $= \dfrac{(\text{span})^2}{\text{reference area}}$
D	body diameter
D_{nozzle}	nozzle exit diameter
$d_{powerhead}$	engine powerhead diameter
ETR	Eastern Test Range
GLOW	gross liftoff weight
GSE	Government-supplied equipment
I_{sp}	specific impulse (in seconds)
KSC	Kennedy Space Center
l/d	body length-to-body diameter ratio or finesse ratio
L/D	Lift-to-Drag ratio
LOX	liquid oxygen
MR	Mixture Ratio - weight of oxidizer: weight of fuel
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NBP	near boiling point
OME	orbital maneuvering engine
OMS	Orbital Maneuvering System
P/A	Propulsion/Avionics
P_c	chamber pressure
ROM	rough order of magnitude
$S_{body\ flap}$	body flap area
SC	subcooled
S_F	vertical fin reference area

GLOSSARY (Continued)

$S_{flaperons}$	flaperon area
shp	shaft horsepower
S_{ref}	wing reference area
SSME	Space Shuttle main engine
SSTO	single stage to orbit
t/c	thickness-to-chord ratio
TPS	thermal protection system
VAFB	Vandenberg Air Force Base
$V_{staging}$	staging velocity
λ'	propellant mass fraction $= \dfrac{\text{weight of propellant}}{\text{weight of propellant + inert weight}}$
λ	taper ratio $= \dfrac{\text{tip chord}}{\text{root chord}}$

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