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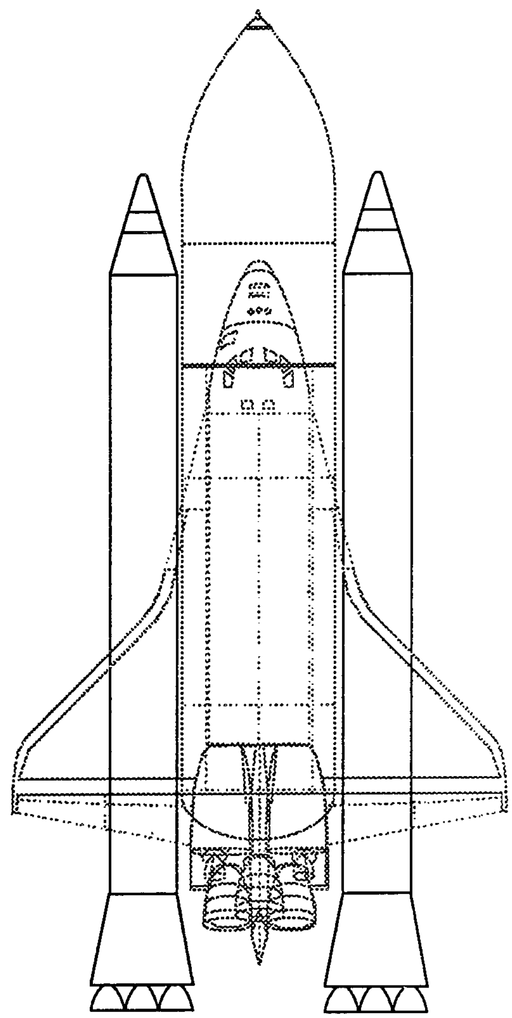
Executive Summary

Liquid Rocket Booster (LRB) for the Space Transportation System (STS) Systems Study



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FOREWORD

This document provides the Executive Summary, Volume I, for the Liquid Rocket Booster (LRB) for the Space Transportation Systems (STS) Study performed under NASA Contract NAS8-37136. The report was prepared by Manned Space Systems, Martin Marietta Corporation, New Orleans, Louisiana, for NASA/Marshall Space Flight Center (MSFC).

The MSFC Contracting Representative is Larry Ware. The Martin Marietta Study Manager is Thomas Mobley.

ACRONYMS AND ABBREVIATIONS

ALS	Advanced Launch System
ALMMH	Aluminized Mono Methyl Hydrazine
CH4	Methane
CSTI	Civil Space Technology Initiative
DDT&E	Design, Development, Test, and Evaluation
ET	External Tank
FSS	Fixed Service Structure
GHe	Gaseous Helium
GMA	Gas Metal Arc
GSE	Ground Support Equipment
GVTA	Ground Vibration Test Article
IR&D	Independent Research and Development
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCC	Life Cycle Cost
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LO2	Liquid Oxygen
LRB	Liquid Rocket Booster
MAF	Michoud Assembly Facility
MFG	Manufacturing
MLP	Mobile Launch Platform
MMH	Mono Methyl Hydrazine
MPS	Main Propulsion System
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
N204	Nitrogen Tetroxide
NSTS	National Space Transportation System
P/A	Propulsion and Avionics
P/A & S	Propulsion and Avionics and Structure
R&T	Research and Technology
RP-1	Rocket Propellant
SETA	Single Engine Test Article

SOFI	Spray-On Foam Insulation
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STA	Structural Test Article
STBE	Space Transportation System Booster Engine
STS	Space Transportation System
TCA	Thrust Chamber Assembly
TPS	Thermal Protection System
TVC	Thrust Vector Control
VAB	Vehicle Assembly Building

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1.0 STUDY OVERVIEW

In October 1987, NASA/MSFC awarded Martin Marietta Manned Space Systems a contract to study the feasibility of replacing the Space Transportation System (STS) solid rocket boosters (SRBs) with liquid rocket boosters (LRBs), Figure 1.0-1. The main objectives of a LRB substitution for the SRB were increased STS safety and reliability and increased payload performance to 70.5K lb to low earth orbit (LEO) with minimum impacts to the STS. The basic scope of work was directed to the definition of optimum liquid rocket booster concepts for replacing SRB's within the current STS operational constraints and envelopes.

The initial contract was phased in two parts. Part 1 was designated for establishment of a baseline configuration and system trade studies. Part 2 further defined the baseline, incorporating the results of the trade studies and preliminary analyses which were performed on the various systems. Life cycle costs (LCC) were developed for the program and new technology requirements were identified.

In July, 1988 a six month extension, Part 3, of the study was awarded so that concepts could be further optimized, alternate applications for LRB could be explored, and planning and technical support for a pressure-fed propulsion system test bed could be provided. Figure 1.0-2 illustrates the LRB definition study flow.

Two booster engine designs were studied. The first engine design was a turbo pump-fed engine with state-of-the-art design, and the second was a pressure-fed engine which might provide a lower cost alternative to the pump-fed concept. Both booster concepts were carried through to completion of conceptual design and all system impacts and program costs were identified. Applications for LRB use in the Advanced Launch System (ALS) program were studied using the pump-fed LRB baseline concept and variations on the baseline concept. Support for the Pressure-Fed Booster Test Bed (PFBTB) included test program planning and costs and technical support.

1.1 LRB STUDY OBJECTIVES

The overall objective of the study was to access the feasibility of replacing the STS Solid Rocket Boosters with Liquid Rocket Boosters. Feasibility required acceptable technical risk, program costs, and a program plan which supports STS requirements. Three major goals were identified to direct booster design and operation: 1) increased STS safety and reliability; 2) STS/LRB integration with minimum impact; and 3) increased STS performance. Table 1.1-1 Summarizes the LRB Study Objectives.

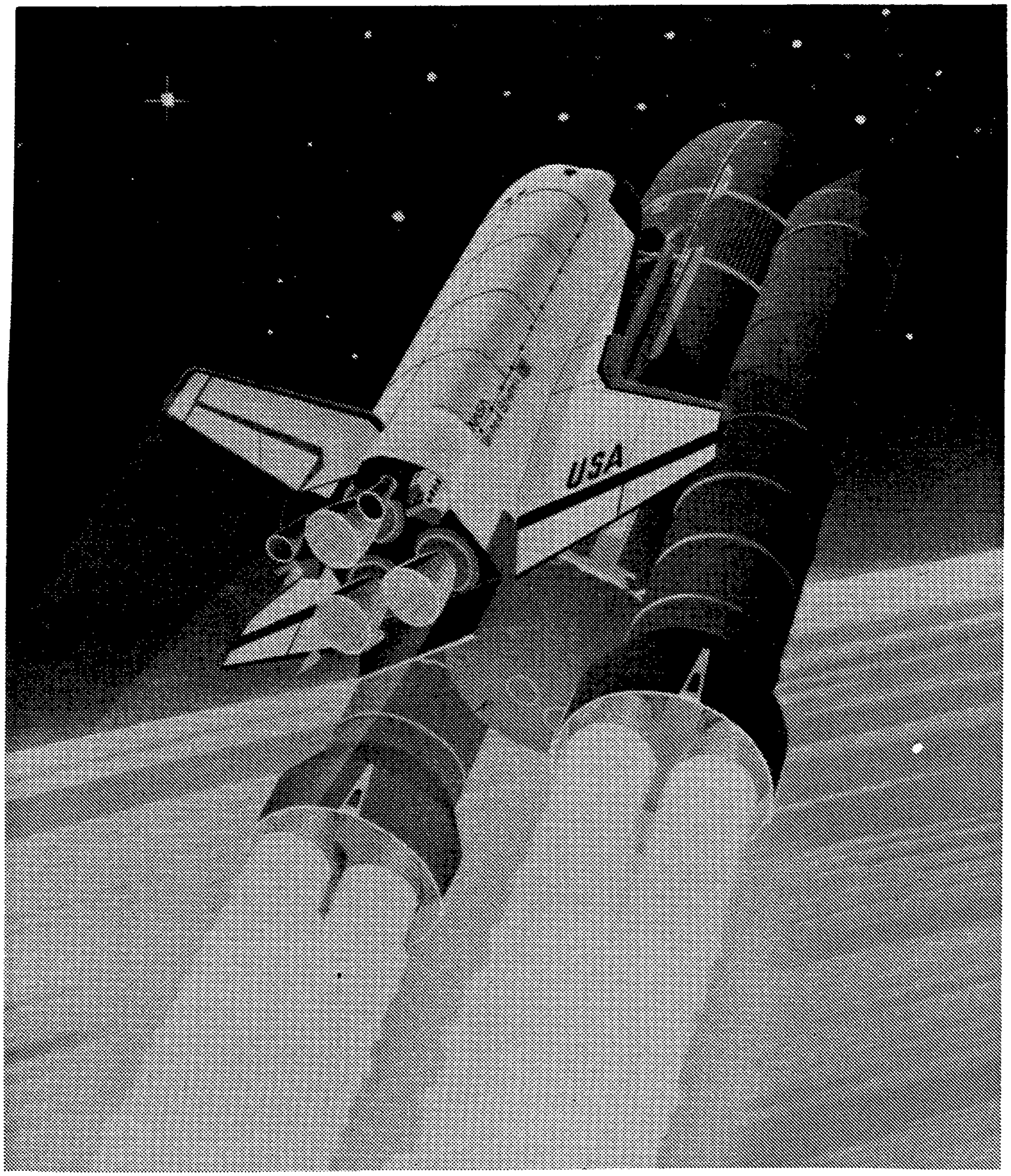

Figure 1.0-1 STS/LRB

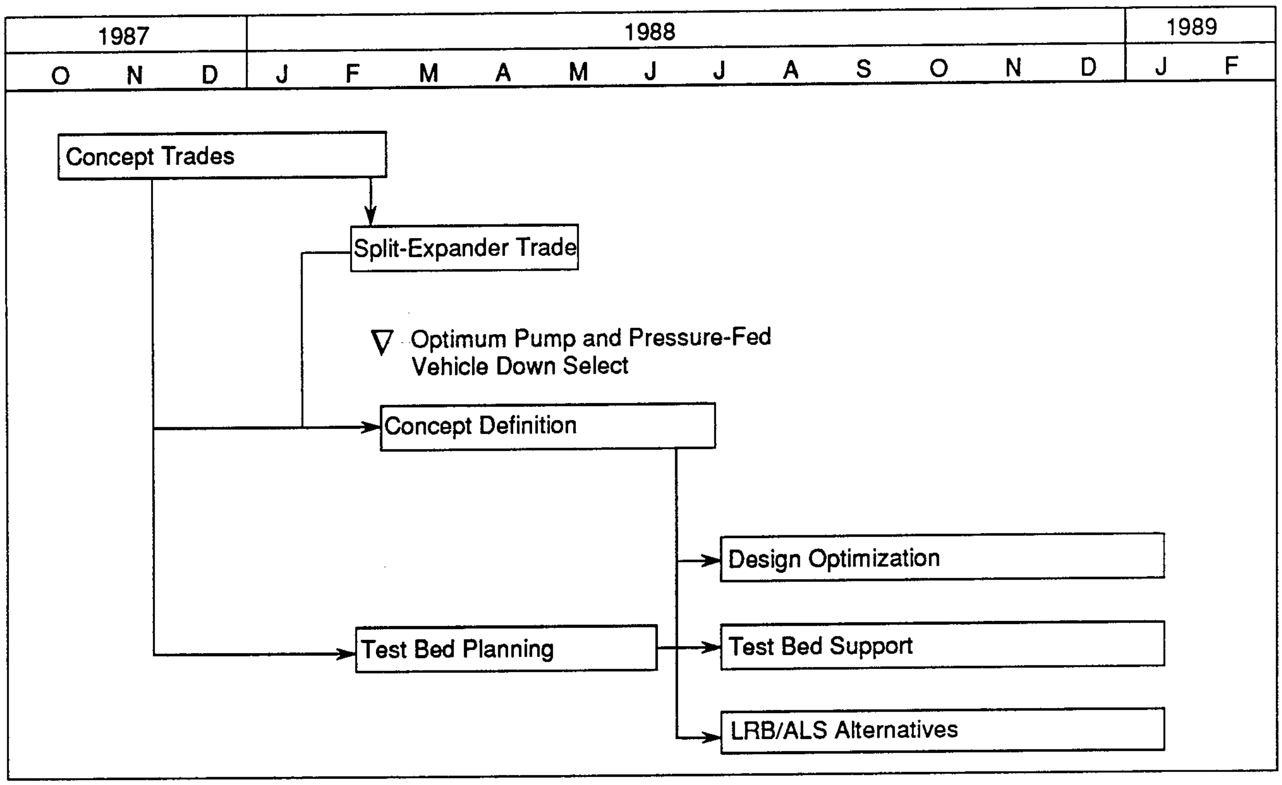

Figure 1.0-2 LRB Definition Study Flow

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Assess the Feasibility of Replacing the STS Solid Rocket Boosters (SRB) with Liquid Rocket Boosters (LRB)

- **Increase STS Safety and Reliability**
  - Post Ignition Hold Down
  - Engine Out Intact Abort
  - Boost Phase Abort Options
- **STS Integration with Minimum Impact**
  - Operate Within STS Lift-Off/Ascent Constraints
  - Avoid Orbiter Down Time Modifications
  - Minimize ET Modifications
  - No Significant Launch Pad Modifications
- **Increase STS Performance**
  - 70,500 lb to 160nm, 28.5° Inclination
  - No Boost Phase SSME Throttle Requirement
  - Increase Performance Margin to Facilitate Trajectory Planning

Table 1.1-1 LRB Study Objectives Summary

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Increased STS Safety and Reliability - The inclusion of a liquid booster in the shuttle vehicle presents the opportunity to significantly improve the STS mission safety and reliability. Liquid propulsion systems can be fully tested prior to vehicle assembly. Engine characteristics and performance can be verified prior to flight, significantly reducing the risk of out of specification performance or engine failure. In addition, liquid engines can be shut-down prior to liftoff or during first stage ascent if an anomaly is detected. This capability significantly increases STS abort options over the current solid boosters.

STS/LRB Integration Impacts - Integration impacts to the operational Space Transportation System represent a significant cost and schedule consideration for the use of liquid boosters in place of solids. Integration impacts include modifications to the orbiter, external tank, KSC facilities and ground support equipment (GSE), modified or additional vehicle prelaunch processing requirements, and modified or additional flight operations. These integration impacts are often off-set by reduced processing requirements and safety risks compared to the use of solid boosters.

A primary objective of the study was to define a LRB such that no structural modifications are required for the orbiter. Modifications to the orbiter avionics/software was to be minimized. Because a new external tank (ET) was used for each flight, structural modifications to the ET are acceptable, but major modifications requiring major testing and recertification programs should be avoided as the cost and schedule impacts would be significant.

To eliminate orbiter structural modifications and minimize ET impacts, designing the LRB to fly within the current STS vehicle load requirements became a primary goal. Numerous analyses were performed to define LRB vehicle dimensional limits and flight trajectory parameters to insure orbiter loads were not exceeded. Evaluation of LRB configurations with regard to ET design loads also provided a significant discriminator between proposed configurations.

Impacts to the current STS launch facilities and GSE also had an influence on LRB concept selection. Vehicle length and diameter defined modification requirements to the vehicle assembly building (VAB), mobile launch pad (MLP), and the launch pad service structure and flame bucket. All modifications resulted in STS cost and schedule impacts.

Increased STS Performance - The study ground rules stipulated a booster vehicle which provided first stage performance such that the shuttle orbiter could carry 70,500 pounds to a 160 nautical mile circular orbit at 28 1/2 degree orbital inclination. The orbiter engines are to be operated at 104% power level. The capability for an intact abort with one LRB engine out was also a ground rule.

Because the orbiter is limited to 65,000 pounds of payload at liftoff, the increased capability is meant to provide increased payload weight to higher orbits or inclinations. This increased performance provides large benefits in flight profile flexibility and abort capability at nominal payload manifests.

1.2 LRB STUDY TEAM

Martin Marietta assembled an outstanding study team to insure the delivery of excellent study products. Each team member brought an expertise unique to the objective of the study. Table 1.2-1 summarizes the team responsibilities during the study. Martin Marietta is a STS prime contractor with intimate understanding of the STS. Aerojet is a recognized leader in propulsion system and engine technology and is a Space Transportation System Booster Engine (STBE) contractor. Honeywell is responsible for STS flight control analysis under contract to the STS integration contractor in addition to their avionics system design capability. Pioneer Systems is currently the advanced recovery systems contractor for MSFC. Remtech, Inc. was added to the study team because of their in-depth understanding of STS lift-off and ascent environments and analytical capabilities. Pratt & Whitney, another STBE contractor, joined the effort for a point design vehicle analysis with split-expander cycle engines.

1.3 LRB STUDY RESULTS SUMMARY

The overall result of the LRB study was to demonstrate that Liquid Rocket Boosters are a viable alternative to the Solid Rocket Boosters for the Space Shuttle System. Table 1.3-1 summarizes the more significant findings of the study effort. LO2/RP-1 was found to be the optimum propellants for both the pump and pressure-fed boosters for use with the shuttle vehicle. Methane fuel was a very close second option for the pump-fed booster. The primary driver in these propellant selections was ease of integration into the operational STS. LO2/LH2 boosters are significantly larger vehicles, but have considerable merit if commonality between the STS and Advanced Launch System is considered.

Study data indicated that the LRB should be an expendable vehicle. This conclusion was significantly influenced by predicted low cost engines and avionics systems. Vehicle recovery and refurbishment cost risks also were a driver in the recommendation.

Martin Marietta Manned Space Systems - STS/LRB Integration - LRB Vehicle Design/Integration - LRB Test Bed
Aerojet Tech Systems Company - Engine Design & Analysis - Propulsion Systems Analysis
Honeywell, Inc. - Avionics System Design & Analysis - Flight Control Analysis
Pioneer Systems, Inc. - Recovery System Design & Analysis
Remtech, Inc. - Liftoff/Ascent Environments Analysis
Pratt & Whitney - Point Design Engine Analysis

Table 1.2-1 MMC LRB Team Responsibilities

• LO2/RP-1 is the Recommended Propellant for Both the Pump and Pressure-Fed Systems • Both Pump and Pressure-Fed Vehicles are Expendable • Both Vehicles Can Be Flown Within Current STS Constraints • There are No Enabling Technology Requirements for the Pump-Fed System • Technology Requirements for the Pressure-Fed System Involve High Specific Strength Materials, Large Propellant Tank Pressurization Systems Demonstration and Large, Low Pc Thrust Chamber Characterization • High Potential Exists for the STS/LRB Program and ALS Program to Mutually Develop a Liquid Rocket Booster Common to Both Launch Vehicles
Liquid Rocket Boosters are a Viable Alternative to Solid Rocket Boosters for the Space Shuttle System

Table 1.3-1 LRB Study Results Summary

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Although no enabling technology requirements were identified with the pump-fed LRB, the pump-fed engine technology programs in the Advanced Launch System (ALS) program are considered to be essential to the development of a viable, low cost pump-fed engine applicable to the LRB program. The technologies required for the pressure-fed vehicle include: 1) material development and low cost manufacturing techniques for large, high pressure propellant tanks; 2) the demonstration of large, high flow pressurization systems; and 3) the characterization of large, low combustion pressure engines.

2.0 TRADE STUDIES SUMMARY

Systems trades were performed to select the optimum concepts for each major system in the LRB configuration. The major systems evaluated were avionics, propulsion, structures, and vehicle recovery. Several trades provided significant discriminators in the development of the optimum LRB concepts. These included propellant selection, pressurization system selection, recovery vs expendable vehicle, cryogenic tank location, and material selection. Table 2.0-1 lists the major system trades performed during the study. Appendix D, "LRB Trade Study Documentation", presents a detailed summary of all trades.

2.1 PROPELLANT SELECTION

A detailed trade study was conducted to select the optimum propellants for both the pump and pressure-fed LRB. The detailed trade criteria and scoring is contained in Appendix D. The following paragraphs summarize the results of the propellant trade.

Pump-Fed: Four propellant combination finalist were selected as detailed trade candidates for the pump-fed LRB (N204/MMH, LO2/RP-1, LO2/CH4 and LO2/LH2). Preliminary sizing analyses were performed to provide vehicle configuration data for the trade study. The candidate vehicles are illustrated in Figure 2.1-1. Data was developed to rank each concept in the areas of costs, STS impacts, operational complexity, safety, environmental impact, and technical risk. Table 2.1-1 illustrates the ranking achieved by each candidate in the detailed scoring provided in Appendix D. The number in each column indicates the candidate position among the four. Duplicate rankings were given for very close candidate scores. As shown in Table 2.1-1, LO2/RP-1 was first in all categories except STS impact and technical risk, where LO2/RP-1 was second. The number one candidate in these categories was N204/MMH. However, N204/MMH ranked last in all other categories. It should be noted that these rankings are associated with LRB use with

Trade #	Trade Name	Trade #	Trade Name
A-1	Avionics Architecture	P-9	Engine Cycles
A-2	Exp. vs Reusable Avionics	R-1A/B	Expendable vs Recoverable
A-3	Thrust Vector Control Studies	S-1	Common Bulkhead
A-4	Engine Control Electronics	S-2	Fwd LRB/ET Attachment
A-5	STS Avionics Interfaces	S-3	Dome Optimization
A-6	Software Development Concepts	S-4	Unpress. Structure Construction
P-1	Propellant Trades	S-5	Cryogenic Tank Location
P-2A/B	Press. System Study	S-6	Tank Wall Design
P-5	TVC Trade	S-8A/B	Materials Trade
P-6	TVC Actuators Trade	S-9	Aft Skirt & Tie Down Attach
P-7	APUs	S-10	Filament Wound Composite Tank
P-8A/B	Expendable vs Reusable Propellant		

Table 2.0-1 Major System Trades

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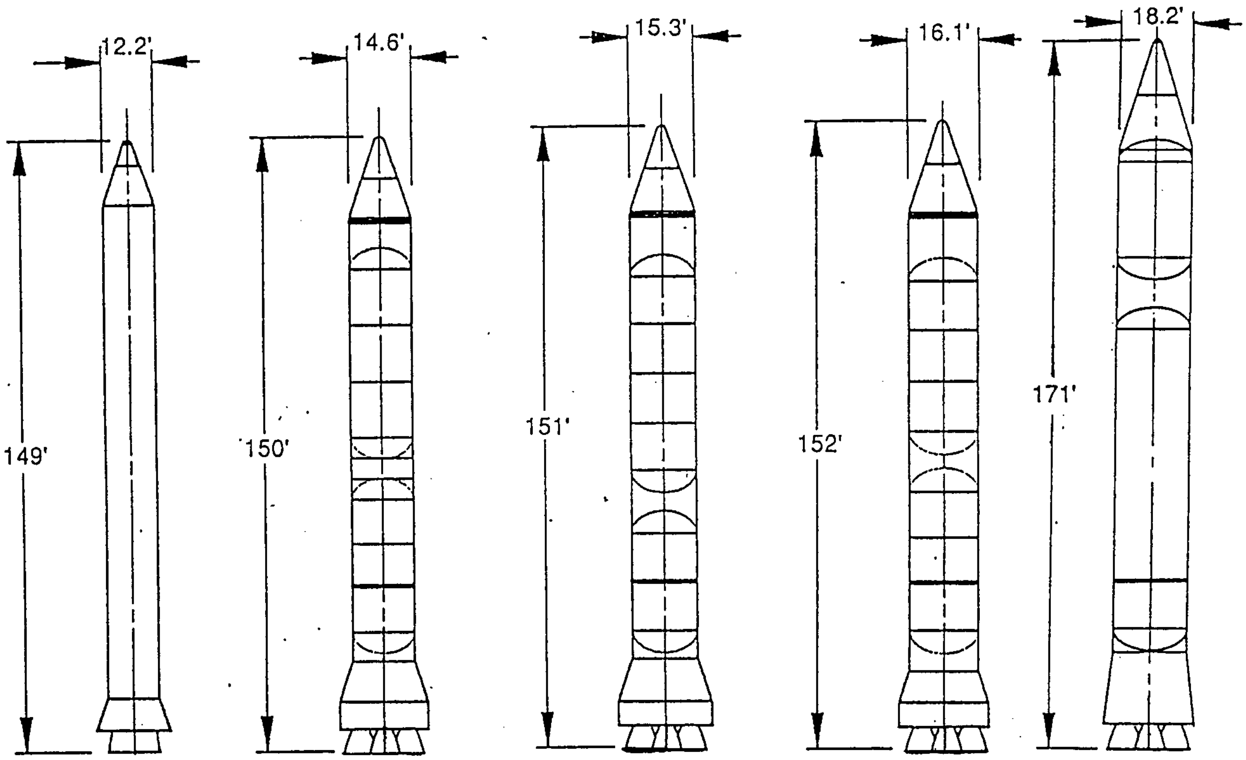

Figure 2.1-1 LRB Pump-Fed Vehicle Options

Criteria	N2O4 MMH	**LO2 RP-1**	LO2 CH4	LO2 LH2
Costs	4	**1**	1	3
STS Impacts	1	**2**	3	3
Operational Complexity	4	**1**	2	2
Safety	4	**1**	2	3
Environmental Impact	4	**1**	1	1
Technical Risk	1	**2**	2	2
Total	18	**8**	11	14

Note: Scores Do Not Reflect Magnitude of Discriminators

Table 2.1-1 Pump-Fed Candidate Ranking

the STS. Consideration of STS/ALS compatibility would improve the total score of LO2/LH2.

Pressure-Fed - Five propellant combinations were selected for detailed trade candidates for the pressure-fed LRB (N204/ALMMH, N204/MMH, LO2/RP-1, LO2/C3H8, and LO2/CH4). Figure 2.1-2 illustrates the vehicle configurations for each propellant combination. The LO2/RP-1 propellant accrued the best total score as shown in Table 2.1-2. Detailed scoring of the pressure-fed propellant trade is provided in Appendix D.

2.2 PRESSURIZATION SYSTEM

Numerous pressurization system concepts were analyzed to provide the most viable options for the pressure-fed LRB booster. The most promising candidates used stored cryogenic helium with various heat sources to raise the pressurant temperature and volume prior to delivery to the propellant tanks. Appendix D provides the detailed trade study data for the pressurization system selected. The pressurization system design is presented in Volume II, Part 1, Systems Definition Handbook.

2.3 LRB MATERIALS - SELECTION

Study data regarding material selections for the LRB show that Weldalite ™049 is a design enhancement for the pump-fed LRB, providing increased system performance. Weldalite ™049 is an enabling technology for a pressure-fed LRB operating with 1000 psi propellant tank pressures. The structural mass of a large scale pressure-fed booster system and its effect on vehicle performance is a primary driver in material selection. Because of the relatively low mass of the pump-fed booster compared to the pressure-fed, both Weldalite ™049 and 2219 aluminum are viable material options.

2.4 EXPENDABLE VS RECOVERABLE

Vehicle recovery trades studies were performed for both the pump and pressure-fed LRB concepts. The trades considered total vehicle recovery and partial (propulsion and avionics) recovery. Both trades demonstrated a preference for expendable LRB vehicles based on the LRB/STS study mission model, recovery risk , and refurbishment cost.

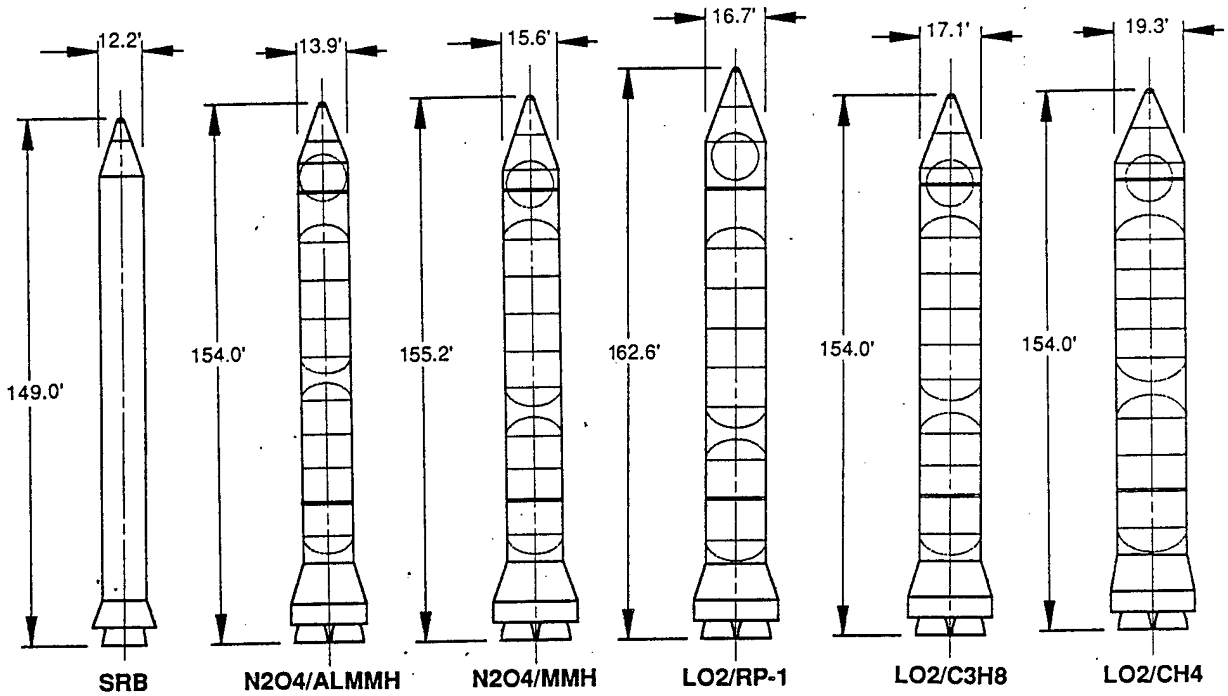

Figure 2.1-2 LRB Pressure-Fed Vehicle Options

Criteria	N2O4 ALMMH	N2O4 MMH	LO2 RP-1	LO2 C3H8	LO2 CH4
Costs	5	4	1	1	3
STS Impacts	1	2	3	3	5
Operational Complexity	4	4	1	2	2
Safety	4	4	1	2	3
Environmental Impact	4	4	1	1	1
Technical Risk	5	1	2	3	3
Total	23	19	9	12	17

Note: Scores Do Not Reflect Magnitude Of Discriminators

Table 2.1-2 Pressure-Fed Candidate Ranking

3.0 CONFIGURATION DEFINITION

The Space Shuttle flight system consists of the orbiter with main engines (SSMEs), an external tank (ET) supplying propellants to the SSMEs and two solid fuel rocket boosters (SRBs) attached to either side of the ET. Each of the SRBs supply 2.65 million pounds of thrust at launch. In this study, liquid rocket boosters (LRBs), with up to 3.0 million pounds of thrust each, were defined to replace the SRBs. The study results show that the use of the LRBs enhances the safety and reliability of the entire shuttle system and increases performance with a minimum of impacts to the orbiter, ET, and existing ground and launch facilities.

Baseline configurations for two LRB concepts, a turbopump-fed engine design, and a pressure-fed engine design, are shown in Figure 3.0-1. These two configurations were selected after extensive trade studies were completed for the propulsion, structural, and mechanical systems.

As shown, the pump-fed LRB is slightly longer, 3 in., than the SRB, and the diameter is 183 in. (15.1 ft) as compared to 146 in. (12.2 ft) for the SRB. The pressure-fed LRB is 162.5 in. (13.5 ft) longer than the SRB and the diameter is 194.0 in. (16.1 ft). The forward and aft ET attach points and aft skirt tie-down to the launch pad remain the same as SRB. Table 3.0-1 presents LRB vehicle configuration data. Detailed mass properties data for the LRB are contained in Volume II, Part 1, Systems Definition Handbook.

3.1 LRB STRUCTURAL ARRANGEMENTS

Figure 3.1-1 presents the structural arrangements of both the pressure and pump-fed LRB. The vehicles are divided into six major structural assemblies, i.e., nose cone, forward skirt, LO2 tank, intertank, RP-1 tank, and aft skirt/thrust structure. All major assemblies are monocoque construction. Design details are provided in the Final Report Volume II, Part 1, Systems Definition Handbook. Complete engineering drawing packages for both the pump and pressure-fed vehicles are provided in Appendix J.

3.2 ALTERNATE LRB APPLICATIONS

The potential exists to reduce LRB/STS program costs through shared development of liquid booster systems in cooperation with the Advanced Launch System (ALS) program. The ALS contractors have identified vehicle options which use liquid booster

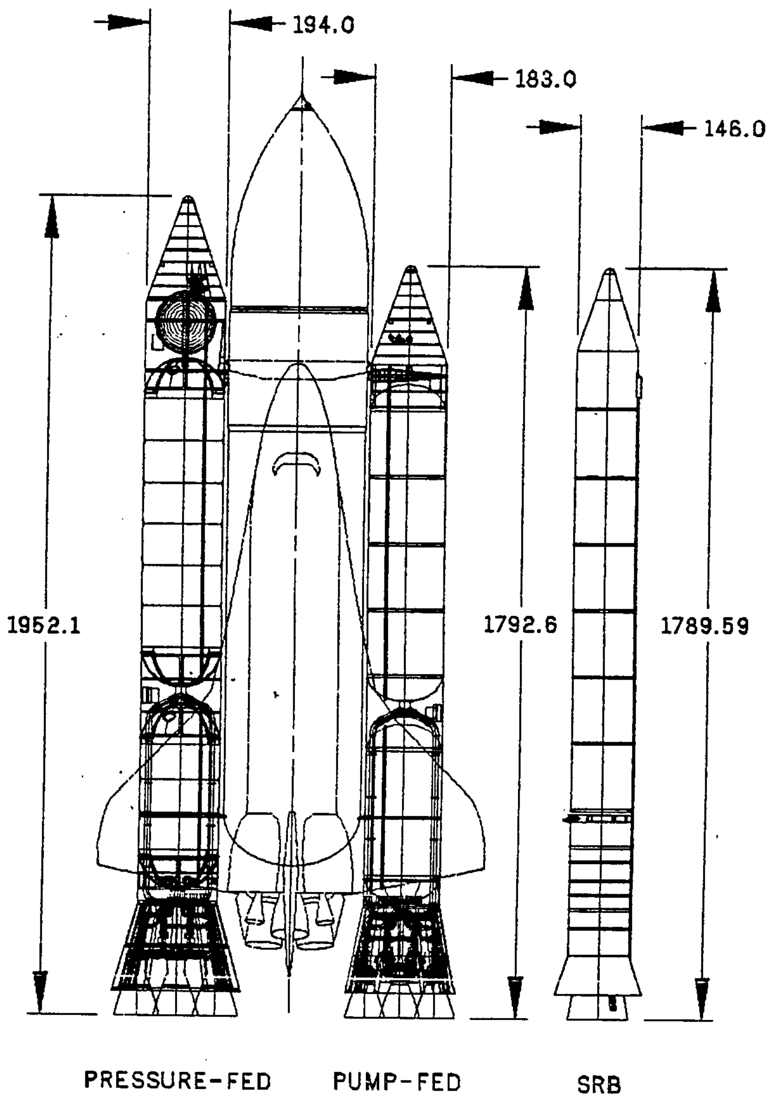

Figure 3.0-1 LRB Baseline Configuration

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	Pump-Fed	Pressure-Fed
Vehicle Dimensions		
Length (in.)	1,792.6	1,952.0
Diameter (OD - in.)	183.0	194.0
Engine Exit Area (in.2)	7,359	9,365
Propellant Volumes (ft3)		
LO2	10,768	12,012
RP-1	5,798	6,328
Feedline	253	253
Weight (lb)		
Structure	77,840	165,160
Propulsion System	36,770	45,290
Other Subsystems	8,700	9,580
Dry Weight	123,310	220,030
Usable Impulse Propellant		
LO2	707,236	798,800
RP-1	272,014	299,200
Residuals Gases and Liquids	5,340	5,910
Helium - Pressure System	None	10,600
RP-1 Engine Out Bias	7,770	None
Propellant - Pressure System	None	24,720
GLOW	1,115,670	1,359,260

Table 3.0-1 LRB Vehicle Configuration Summary

Construction Details of Both Pump & Pressure-Fed Vehicles Ease Fabrication While Meeting All Strength, Stiffness, & Dimension Constraints

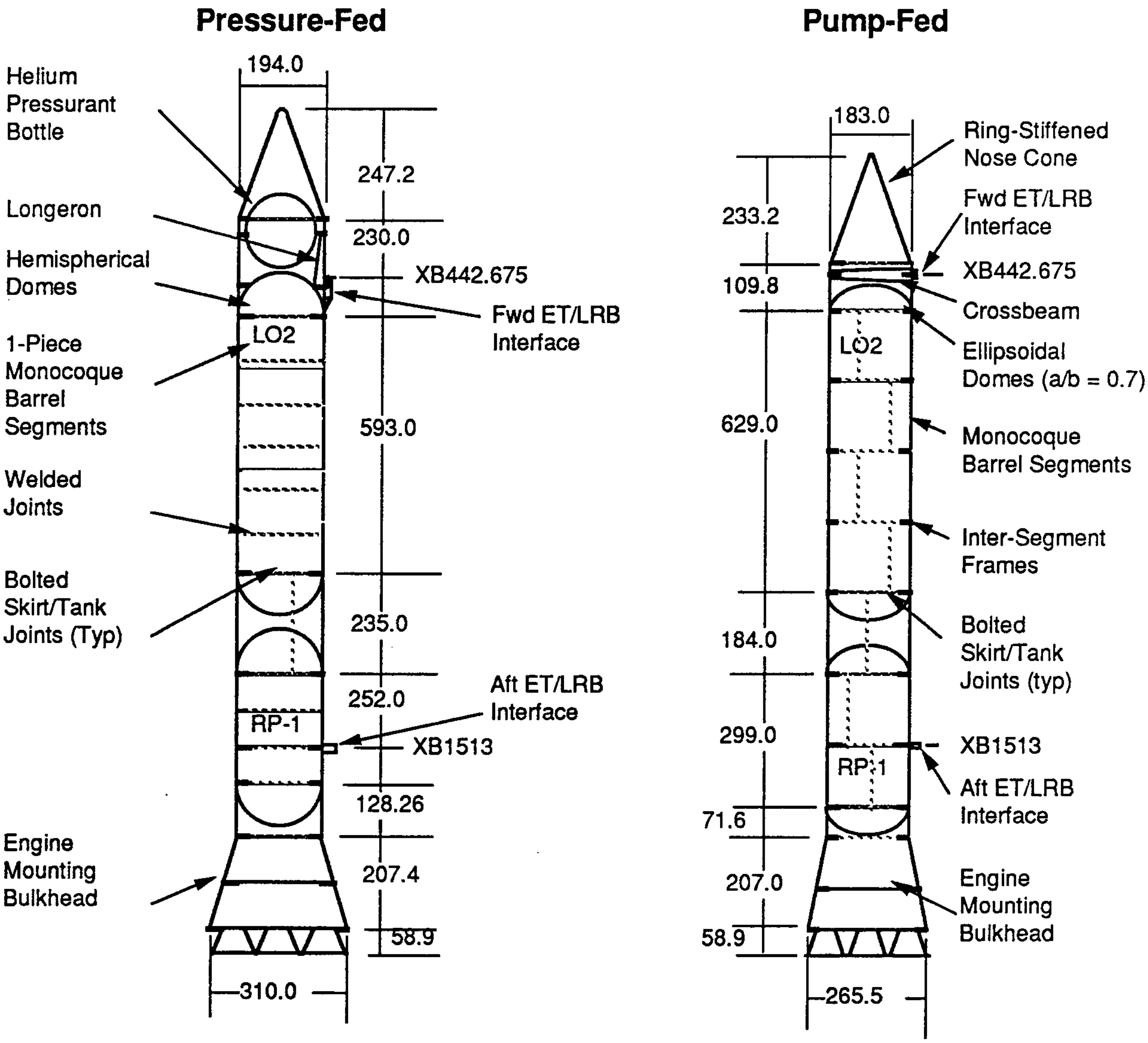

Figure 3.1-1 Structural Arrangements

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strap-ons for first stage flight. Current ALS activities are evaluating common fuels and common engines for both the boosters and the core vehicle. To evaluate the merit of common STS/ALS liquid rocket boosters, three LRB/ALS vehicle configurations were conceptually defined. The LCC of each concept was estimated to compare combined program costs.

STS/ALS configuration option 1 (Figure 3.2-1) has a LO2/LH2 core stage with two pump-fed LO2/RP-1 liquid rocket boosters. The LO2/RP-1 boosters are identical to the LRB Definition Study recommended vehicles. This option provides minimum integration impact to the STS, meets all LRB study goals, and allows for optimization of the core stage engine to meet ALS requirements.

STS/ALS configuration option 2 (Figure 3.2-2) has a LO2/LH2 core stage and a LO2/LH2 booster with a STS optimized engine. The LO2/LH2 LRB was sized to meet LRB/STS requirements. This configuration increases the STS impacts over the option 1, but provides for common booster and core stage propellants. This configuration also allows for optimization of the ALS core stage engine.

STS/ALS configuration option 3 (Figure 3.2-3) has common LO2/LH2 engines for both the core stage and the booster. The engine size cannot be optimized for the ALS core, ALS booster and the STS booster. Optimization can be increased by developing smaller engines and using more engines on each element, but this approach quickly results in negative cost impacts. This option provides common engine development for both programs, but compromises the design of both vehicles.

Table 3.2-1 presents the STS/LRB performance data for all three STS/ALS options. Table 3.2-2 provides similar data for ALS/LRB performance. The data show that LRB configurations can be developed for each option to meet the performance requirements for both the STS and ALS programs. The life cycle costs (LCC) data , (Figure 3.2-4 & 5), indicates that, within the accuracy of the data, no clear LCC discriminator is established among the three options. However, significant Design, Development, Test and Evaluation (DDT&E) cost savings can be realized by development of a common engine (option 3).

It should be recognized that the STS/ALS booster commonality data is preliminary. All STS cost impacts for a large LO2/LH2 booster have not been included as illustrated in Table 3.2-3.

3.3 TECHNOLOGY REQUIREMENTS

There are no enabling technology requirements for the LO2/RP-1 pump-fed LRB. Several enhancing technologies have been identified as follows:

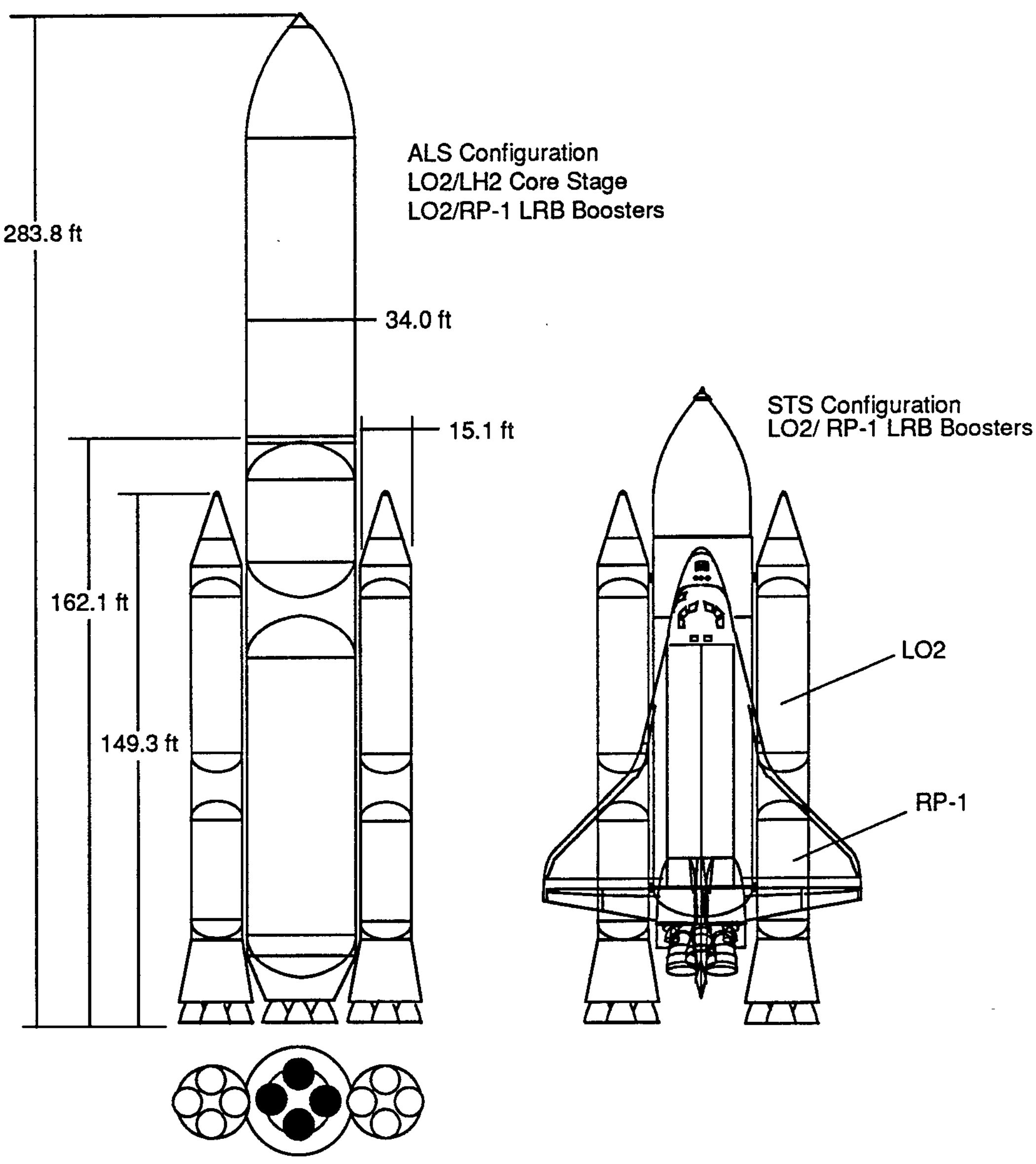

Figure 3.2-1 ALS/LRB Option 1

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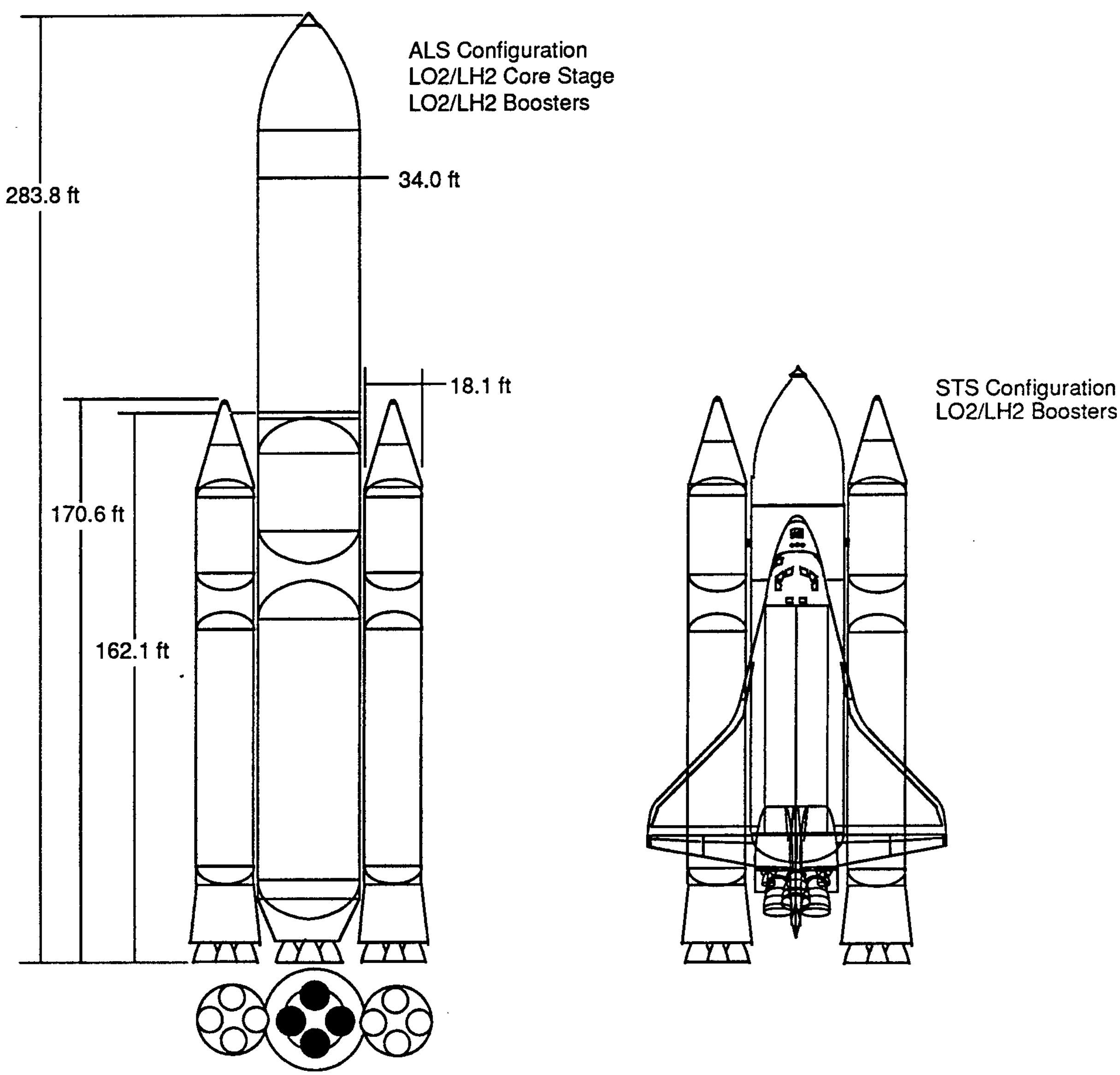


Figure 3.2-2 ALS/LRB Option 2

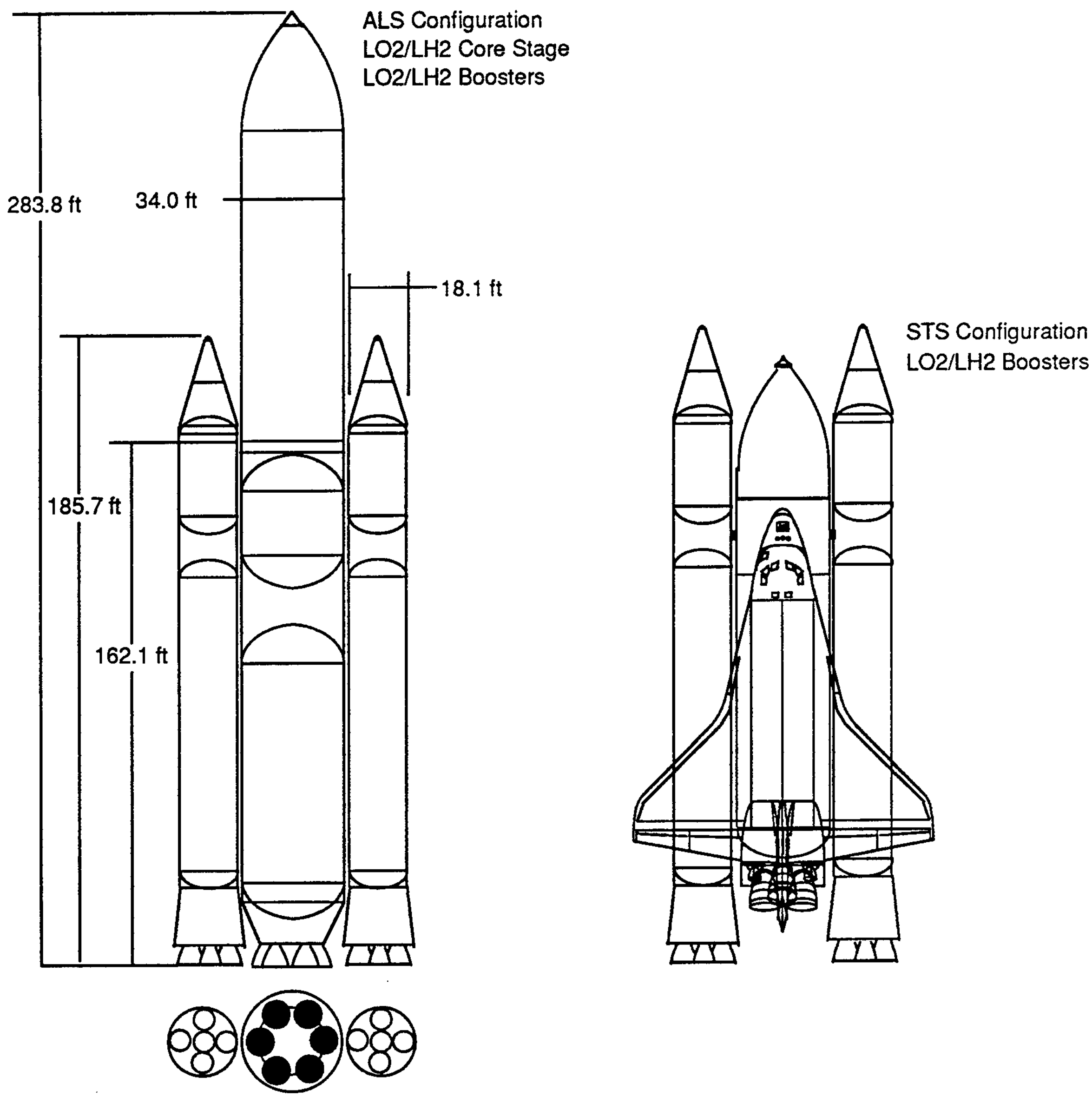


Figure 3.2-3 ALS/LRB Option 3

	LO2/RP1 Option 1	LO2/LH2 Option 2	LO2/LH2 Option 3
PAYLOAD	**72,667 lb**	**71,925 lb**	**75,890 lb**
Manager's Reserve	2,167 lb	1,425 lb	5,390 lbs
Thrust / Weight @ T-0 sec	1.262	1.409	1.247
Gross Lift-Off Weight (GLOW)	4,143,786 lb	3,464,87 lb	3,678,022 lb
Max Dynamic Pressure	703 psf	680 psf	612 psf
Burn Time	130.6 sec	120.9 sec	158 sec
Coast Time	2.4 sec	2.4 sec	2.4 sec
Jettison Weight	258,110 lb	270,559 lb	300,232 lb
LRB Engine-Out Capability	Make Mission	Make Mission	Make Mission
Sea Level (Vac) Isp @NPL	266.3 (322.3) sec	379.4(424.1)	391.2(419.8)sec
Useable Propellant Wgt/Booster	969,980 lb	624,670 lb	714,100 lb
Mixture Ratio	2.6 :1	6.0 :1	6.0 :1
Engine Exit Area	51.11 ft2	30.0 ft2	19.15 ft2
Booster Lift-off Weight (BLOW)	1,099,035 lb	759,950 lb	864,216 lb
Booster Outside Diameter	15.30 ft	18.0 ft	18.0 ft
Booster Length	151.0 ft	176.2 ft	191.9 ft

Table 3.2-1 STS/LRB Performance

	Option 1	Option 2	Option 3
Performance Data			
Payload (lb)	110,100	102,520	109,140
Orbit 80 x 150 nm @ 28.5°			
Core Propulsion			
Propellant	LO2/LH2	LO2/LH2	LO2/LH2
Vac ISP (sec) with 2% FPR	441.0	441.0	441.0
No. Engines	4	4	6
Total SL Thrust (lb)	2,337,500	2,337,500	2,438,800
Total VAC Thrust (lb)	2,877,200	2,877,200	3,000,000
Boosters Propulsion	(2)	(2)	(2)
Propellant	LO2/RP-1	LO2/LH2	LO2/LH2
Vac Isp (Sec)	323.4	424.1	419.8
No. Engines/Booster	4	4	5
Total SL Thrust (lb)	5,480,000	4,959,700	4,439,000
Total VAC Thrust (lb)	6,345,600	5,394,800	4,763,350
Weights (lb)			
Fairing	19,000	19,000	19,000
Core Propellant	2,500,900	2,500,900	2,500,900
Booster Propellant	1,939,800	1,249,700	1,428,200
GLOW	5,196,600	4,510,200	4,726,010
Core Dry	329,300	329,300	329,300
Boosters Dry	247,440	261,100	290,800

Table 3.2-2 ALS/LRB Performance

- All Booster Cost Estimates Are Included
- Only Core Vehicle Engine Cost Estimates Are Included
- Major Cost Discriminators Include
  - RP-1 Versus LH2 Booster (Structures And TPS)
  - Engine Quantities, Thrust Levels And Resulting Cost Relationships

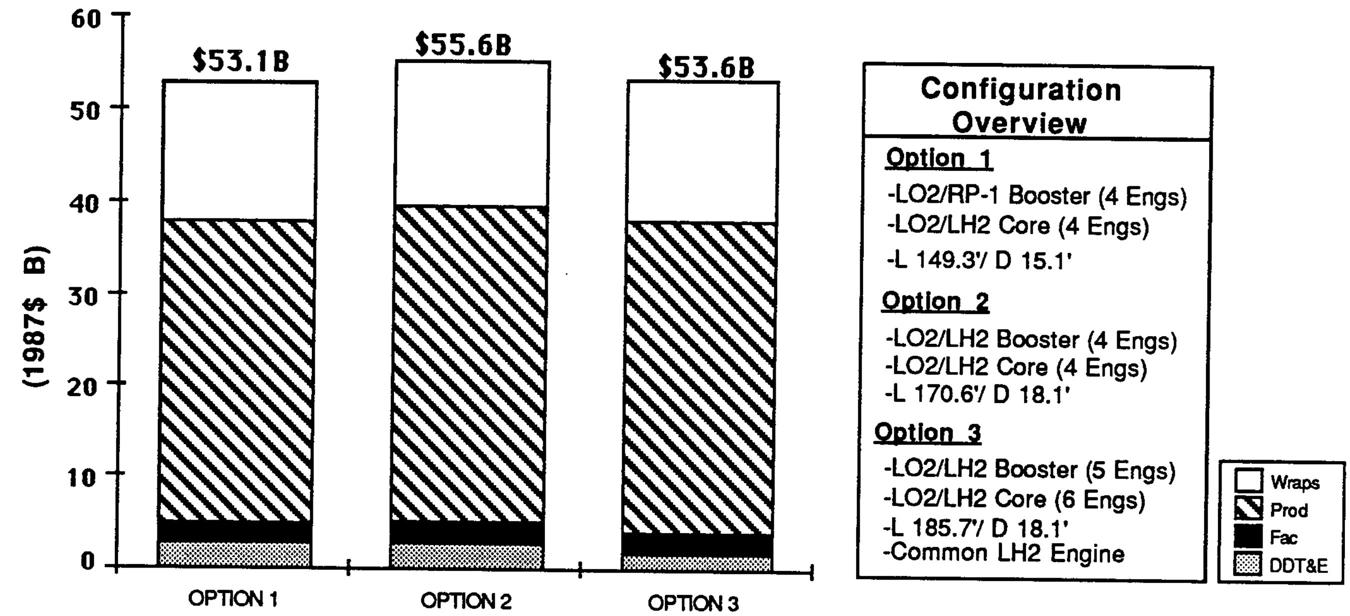


Figure 3.2-4 Shared NSTS/ALS LCC Estimates

NSTS 244 Units
NSTS ALS 994 Units

Booster Subsystem	AVERAGE UNIT COSTS			
	NSTS	NSTS/ALS		
	Baseline Pump	Option 1	Option 2	Option 3
		LO2/RP-1 LO2/LH2	LO2/LH2 LO2/LH2	LO2/LH2* LO2/LH2*
Structures	$4.4 M	$3.2 M	$3.8 M	$3.9 M
Propulsion	$2.8 M	$2.2 M	$2.3 M	$2.3 M
Power	$1.2 M	$1.0 M	$1.0 M	$1.0 M
Avionics	$6.3 M	$4.9 M	$4.9 M	$5.5 M
Booster Engines	$14.8 M	$10.6 M	$10.9 M	$10.1 M
TPS	$0.3 M	$0.2 M	$0.5 M	$0.5 M
Asemble & CK Out	$1.6 M	$1.2 M	$1.2 M	$1.2 M
Sustaining Tooling	$0.5 M	$1.3 M	$1.4 M	$1.5 M
Initial Spares	$0.9 M	$0.8 M	$0.8 M	$0.8 M
Sustaining Engr.	$1.7 M	$1.4 M	$1.5 M	$1.5 M
Program Mgmt.	$1.4 M	$1.2 M	$1.2 M	$1.2 M
TOTAL	$36.0 M	$28.0 M (4 Engs)	$28.6 M (4 Engs)	$29.5 M (5 Engs)
Core ALS Engines		$13.7 M (4 Engs)	$13.7 M (4 Engs)	$12.1 M (6 Engs)
Average Unit Cost (2-LRBs / Core Engines Only)		$69.7M	$70.9M	$71.1M

* Common LO2/LH2 Engines
• Government Wraps Excluded (Add 40%)

Figure 3.2-5 LRB Average Unit Cost Estimates With Program Sharing

- Costs For Options 2 & 3 Will Grow Due To Orbiter, ET, And Integration Impacts

  - <u>ET Impacts :</u>
    - Lengthen Intertank To Provide Required LRB Beam Clearances
    - Redesign Of ET LRB Beam
    - Redesign Of Thrust Panels On The Intertank
    - Additional Testing And Modeling Of Loads On ET Due To Extended LRBs
    - Re-Evaluation Of Lightening Protection Location (ET Or LRB)
    - Redesign Of ET/LRB Attach Frame (2080) Due To Dual Cryogenic Tank Shrinkage
    - MLP Modifications To Allow For LRB Translation Due To Cryogenic Shrinkage
  - <u>Orbiter Impacts:</u>
    - Additional Wind Tunnel Testing For 18.2 Ft Diameters (Orbiter Wing Loads)
    - Command Signaling Impacts For Non-Symetrical Engine Configuration (Option 3)
  - <u>Integration Impacts:</u>
    - JSC Integration Impacts For Narrow Trajectory Allowances
    - KSC (NSTS) Launch Delays For Missing Narrow Launch Windows

Hydrogen Booster Impacts To Other NSTS Elements Need Careful Consideration

Table 3.2-3 NSTS Additional Cost Impacts For Common Fuel ALS Options

1) High specific strength aluminum lithium, Weldalite™ 049;
2) Electromechanical Thrust Vector Control (TVC) actuator systems;
3) Low cost autonomous avionics; and
4) Flex seal nozzle gimbaling.

The pressure-fed LRB has several enabling technology requirements. These include:

1) High specific strength aluminum lithium, Weldalite™ 049;
2) Large propellant tank pressurization systems; and
3) Relatively low Pc (300-800 psi), high thrust combustion chamber assemblies.

The enhancing technologies mentioned above also apply to the pressure-fed vehicle.

3.3.1 Material

The development of Weldalite™ 049 is ongoing at this time under several Independent Research and Development (IR&D) projects. This research and development needs to be expanded to characterize the material strength properties of very thick welds (1.0 to 3.0 inches).

3.3.2 Propulsion System Development

The pressurization system and thrust chamber assembly technologies are being developed with Civil Space Technology Initiative (CSTI) funding at MSFC. Both pressurization system and thrust chamber technology programs have been awarded and will initiate in June, 1989. A test simulator is being designed and developed at MSFC to accommodate the firing of two 750K pound thrust chambers. These efforts are described in more detail in Volume II, Part 2 "Pressure-Fed Booster Test Bed Support."

3.3.3 Manufacturing Development

There are no mandatory new technology requirements for manufacture of the structural elements of a pump-fed LRB if currently qualified materials (i.e. 2219 Aluminum) are used. Only those usual items of development for new products (e.g. weld schedules and SOFI spray routines) would be required. Use of Weldalite™ 049 as the primary structural material would require the development and qualification of all the fabrication processes. This development, discussed in Volume II, should be considered an enhancing technology for the pump-fed LRB as 2219 Aluminum is a viable backup material.

For the pressure-fed LRB, the manufacturing development required for Weldalite™ 049 is enabling technology as the lighter weight material is required for the LRB to make mission requirements. Other manufacturing development items identified for the pressure-fed LRB are thick wall welding, flow turned aluminum barrels, and one piece domes for the helium pressurant tank.

4.0 STS IMPACTS SUMMARY

The proposed LRB configurations minimize the impacts on the current shuttle vehicle. Orbiter system impacts are electrical wiring, data processing, data display, telemetry, and software. External tank impacts are limited to electrical wiring and local external TPS modifications. The discussion of STS impacts in the following paragraphs applies to the baseline LO2/RP-1 pump and pressure-fed LRBs described in the final report.

4.1 ORBITER

Table 4.1-1 presents potential orbiter impacts identified during the course of the study. Two of the issues, i.e., orbiter wing loads and ascent flex stability, have been resolved by analysis for the baseline configurations.

Orbiter Wing Load - Preliminary wind tunnel data developed at MSFC indicates that LRB diameters up to 18 feet can be flown within the STS wing load design constraints. Although 18 ft diameters are acceptable, reduced flexibility in trajectory shaping and increases in technical risk due to reduced analysis margins, make smaller diameters highly preferred.

ET/Orbiter Electrical Interface - Multiple liquid engines require additional data transfer between the LRB and the Orbiter as compared to the SRB. Therefore, additional electrical cabling and modifications to ET Orbiter electrical interface is required. Preliminary analysis indicates that the ET/Orbiter umbilical plates are adequate to accommodate the modified and/or additional electrical connectors needed.

- Wing Load Issue Resolved
- ET/Orbiter Electrical Interface
- Data Recording/Telemetry
- Ascent Linear Stability Margins
- Pump-Fed Ascent Flex Stability Issue Resolved

Table 4.1-1 STS Impacts - Orbiter

- ET/SRB Electrical Interface
- ET LO2 Tank TPS For LRB Nose Cone Shock Attachment (Pressure-Fed Only)
- LO2 Aft Dome Allowable Issue Resolved
- ET/LRB Structural Interface Loads Within STS Limits

Table 4.1-2 STS Impacts - External Tank

Data Recording/Telemetry - The increased instrumentation used for multiple liquid engines will result in increased data recording and telemetry requirements during ascent. Specific requirements are beyond the scope of this study.

Ascent Linear Stability - Flight analyses of the STS with the baseline LRBs have indicated that STS ascent linear stability margins are exceeded due to propellant sloshing. The baseline vehicles designs do not include slosh baffles at this time. The magnitude of the slosh problem does not present a significant concern, and can be accommodated with standard design techniques.

Ascent Flex Stability - A LO2/RP-1 pump-fed LRB designed to tank pressure loads was determined to have a flex stability problem well outside of the orbiter's control capability. This vehicle also had a bending motion at SSME ignition which exceeded the dimensional limits imposed by Mobile Launch Pad (MLP) and Fixed Service Structure (FSS) interfaces. Redesign of the vehicle to meet these excursion requirements, and to maintain the ET lift-off loads within acceptable limits, resulted in a more rigid LRB design. This updated LO2/RP-1 pump-fed configuration was analyzed and showed no ascent flex stability concerns.

4.2 EXTERNAL TANK

Table 4.2-1 presents potential external tank impacts identified during the course of the study. Load and stress analyses documented in Volume II and Appendix A, Stress Report, show that the baseline LRB configurations do not exceed any ET load limits. No structural modifications to the ET are required for the LO2/RP-1 boosters..

ET/SRB Electrical Interface: As discussed for the orbiter, increased data requirements for the LRB also impact the ET/SRB electrical interface and cable bundles. These impacts can be accommodated by the current ET/SRB umbilicals with modified electrical connectors.

ET Thermal Protection System (TPS): The increased length of the pressure-fed LRB will result in a booster nose cone aerodynamic shock impingement on the ET at a different location than the SRB. The shift in the shock impingement location could result in a minor modification to the ET TPS design.

4.3 KSC FACILITIES- LAUNCH FACILITY MODIFICATIONS

Modifications to accommodate pump and pressure fed LRB launch operations will be required for the VAB, MLP and for the launch pad. Modifications are required due to the increased diameter of both pump and pressure-fed LRBs and to provide fueling services to the LRBs for LO2 and RP-1 (pump-fed) and LO2, RP-1 and GHe for the pressure fed LRB.

New facilities will be required for LRB ground operations processing at the launch site to permit the use of LRBs with no impact to the projected combined LRB/SRB NSTS launch schedule. The new ET/LRB horizontal Processing Facility will provide checkout and storage areas for both ETs and LRBs. In addition, a new MLP will be required prior to LRB initial operating capability. The decision for additional facilities takes into consideration the transition period required during which both SRBs and LRBs will be processed in the VAB and at the pad.

Figures 4.3-1 and 4.3-2 summarize the launch facility modifications and identify new facility requirements.

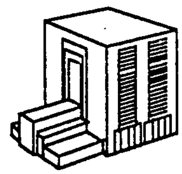
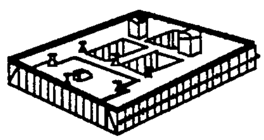
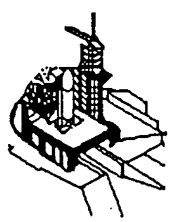
FACILITY	IMPACT AREAS
Vehicle Assembly Building (VAB) 	- Door Clearance - Platform Exit Clearance - Platform Openings - High Bay Modification To New Integration Facility
Mobile Launch Platform (MLP) 	- Exhaust Holes - SRB Holddown Posts - Over Pressure Plumbing
Pad 	- Propellant Loading/Storage - LRB Access - Umbilicals

Figure 4.3-1 Launch Facility Modifications

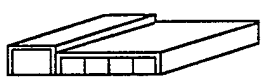
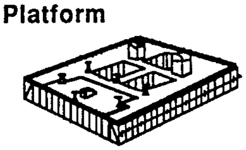
FACILITY	DESCRIPTION	REQUIREMENT
LRB Processing Facility 	• Horizontal Parallel Processing For Two LRBs Accommodated • Horizontal Storage For Two Set Of LRBs (Four Total) Accommodated • Facility Equiped With Engine, Avionics, Logistics, and Admin Areas • Similar To External Tank Facility At Vandenberg Air Force Base, CA • Synergistic With Factory Operations	• Provide Area For LRB Processing • Horizontal Processing Reduces Handling Operations (Only One Rotation To Vertical In VAB Transfer Aisle) • Tiered Platforms Provide Access To All LRB Areas
External Tank Checkout Facility 	• Horizontal Processing And Storage Of External Tanks • Facility Equiped With Logistics, and Administration Areas • Storage For Four External Tanks Accommodated • Similar to External Tank Facility At Vandenberg Air Force Base, CA • Synergistic With Factory Operations	• Conversion Of VAB High Bay 2 Or 4 Requires Relocation Of External Tank Operations • New External Tank Facility Cheaper Than Entirely New Integration Facility • Horizontal Processing Reduces Handling Operations • Tiered Platforms Provide Access To All ET Areas
Mobile Launch Platform 	• Will Provide Rise Off Type Umbilicals For RP-1 And LO2 Loading • Duplicates Features of Modified MLP	• Required Pre-IOC To Meet Launch Rate

Figure 4.3-2 New Launch Facility Requirements

5.0 PROGRAMMATICS

5.1 LCC SUMMARY

The cost estimates are based on the groundrules and assumptions that were developed for this study. The major groundrules and assumptions are listed in Table 5.1-1. The estimates are divided into two sections. Baseline pump and pressure LRB cost estimates are summarized in Section 5.1.1 and the technology pressure-fed LRB estimates are summarized in Section 5.1.2.

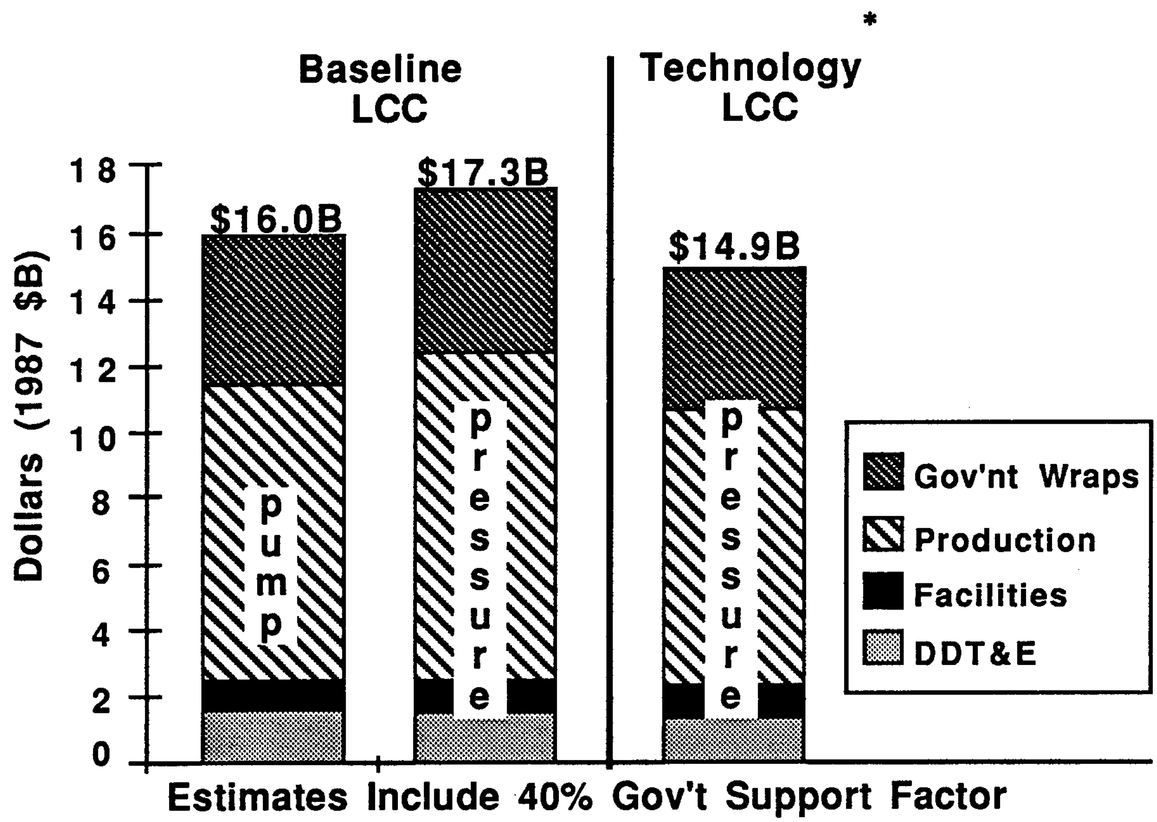
Program Phase	Groundrules and Assumptions
General	All costs are in Fiscal Year 1987 dollars Government factors separately identified as follows - Government Support 5% - Management Reserve 25% - Contractor Fee 10% No discounting used No SRB transition cost impacts included No SRB flights delayed or cancelled
DDT&E	Ground test hardware includes GVTA, STA, MPTA, SETA, and Shock and Acoustic Test Articles Orbiter mass simulated for GVTA Engines mass simulated for Shock & Acoustic Tests
Production	Capability sized for steady state of 14 per year Separate learning curves identified for specific hardware items Production spares: Engines, 10%; Other subsystems, 6%
Operations	10-Year operational program Ramp rate 4, 8, 12, 14 launches; then 14 per year 122 flights total; (244 Boosters) KSC and JSC operations excluded
Facilities	Sized for steady state of 14 flights per year Booster manufacturing facilities reflect MAF shared facility costs MPTA, SETA, and engine component tests at Stennis STA, GVTA, and Modal, Shock, and Acoustic tests at MSFC KSC facilities are included

Table 5.1-1 Programmatic Cost Groundrules and Assumptions

The baseline vehicles were defined under groundrules that minimized new technology approaches. The intent was to first demonstrate that liquid boosters were a viable alternative to the current solid rocket boosters and only then to incorporate near term technologies to reduce program costs. This approach benefited the pump-fed booster system since no enabling technologies were identified and pump-fed technology is better understood. In order to incorporate minimal technology requirements into the pressure-fed booster, the manufacturing processes were held to well known technologies. An optimum pressure-fed system, however, would incorporate near term technology improvements (such as Electron Beam Welding) to reduce costs. While the baseline LCC estimates do not incorporate these benefits, a separate pressure-fed technology LCC estimate that shows such benefits is provided.

5.1.1 Baseline LCC Summary

Figure 5.1.1-1 identifies the life cycle cost estimates for both of the baseline vehicles (pump-fed and pressure-fed), and a technology (pressure-fed) vehicle.



* Includes MFG And CSTI Technology Improvement Benefits

Figure 5.1.1-1 - LRB Life Cycle Cost Estimates

The cost analyses performed during this study show an eight percent smaller LCC for the baseline pump-fed LRB than for the baseline pressure-fed LRB excluding government wraps ($11.4B - pump; $12.4B - pressure). The DDT&E, facilities, and Research and Technology (R&T) cost estimates for either booster are virtually the same. The Production/ Operations estimates for the baseline boosters account for nearly all of the LCC difference. The 40% program wrap factors are excluded from the numbers in the following discussion.

The DDT&E cost estimates represent approximately fifteen percent of the entire life cycle costs ($1.6B - pump; $1.5B - pressure); Production/ Operations accounts for roughly eighty percent ($8.8B - pump; $9.8B - pressure); and Facilities a little over five percent of the total LCC ($0.8B - pump; $0.9B - pressure). The R&T estimates account for less than one percent of the LCC ($0.010B - pump; $0.022B - pressure).

The cost drivers are the same, but order of magnitude different for the pump and pressure-fed booster programs. The engine subsystem is the pump-fed booster program's primary cost driver at $3.6B (production only), whereas the engine subsystem for the pressure-fed booster is the primary cost driver at $2.4B (production only).

5.1.1.1 Research And Technology

The cost estimates for the Research and Technology phase of the baseline program are less than one percent of LCC. The baseline pump-fed booster requires no enabling technology breakthroughs. The baseline pressure-fed booster is constrained by enabling technologies.

Total R&T estimates for the baseline pump-fed booster are $10M. R&T estimates for the baseline pressure-fed booster are $58M. The pump-fed booster estimate is based on the enhancing development of Weldalite™049. The pressure-fed booster estimate is based on the enabling technologies associated with the development of: Weldalite™049 material, a pressurization system, and an ablative TCA. It is important to note that there is sufficient time available to develop these technologies such that there will be no impact on the initial launch date. The scheduled first launch date is driven by the DDT&E phase and not the R&T phase.

5.1.1.2 Design, Development, Test And Engineering

The DDT&E cost estimates represent approximately fifteen percent of the entire LCC. The estimates (see Figure 5.1.1.2-1) are close for both the pump and pressure-fed systems ($1.6B - pump; $1.5B - pressure), but the cost drivers are different. The engine design and test requirements drive the estimate for the pump-fed boosters' DDT&E phase. The pressure-fed booster program is driven by the structures, pressurization system, and MPS design and test requirements (including hardware.)

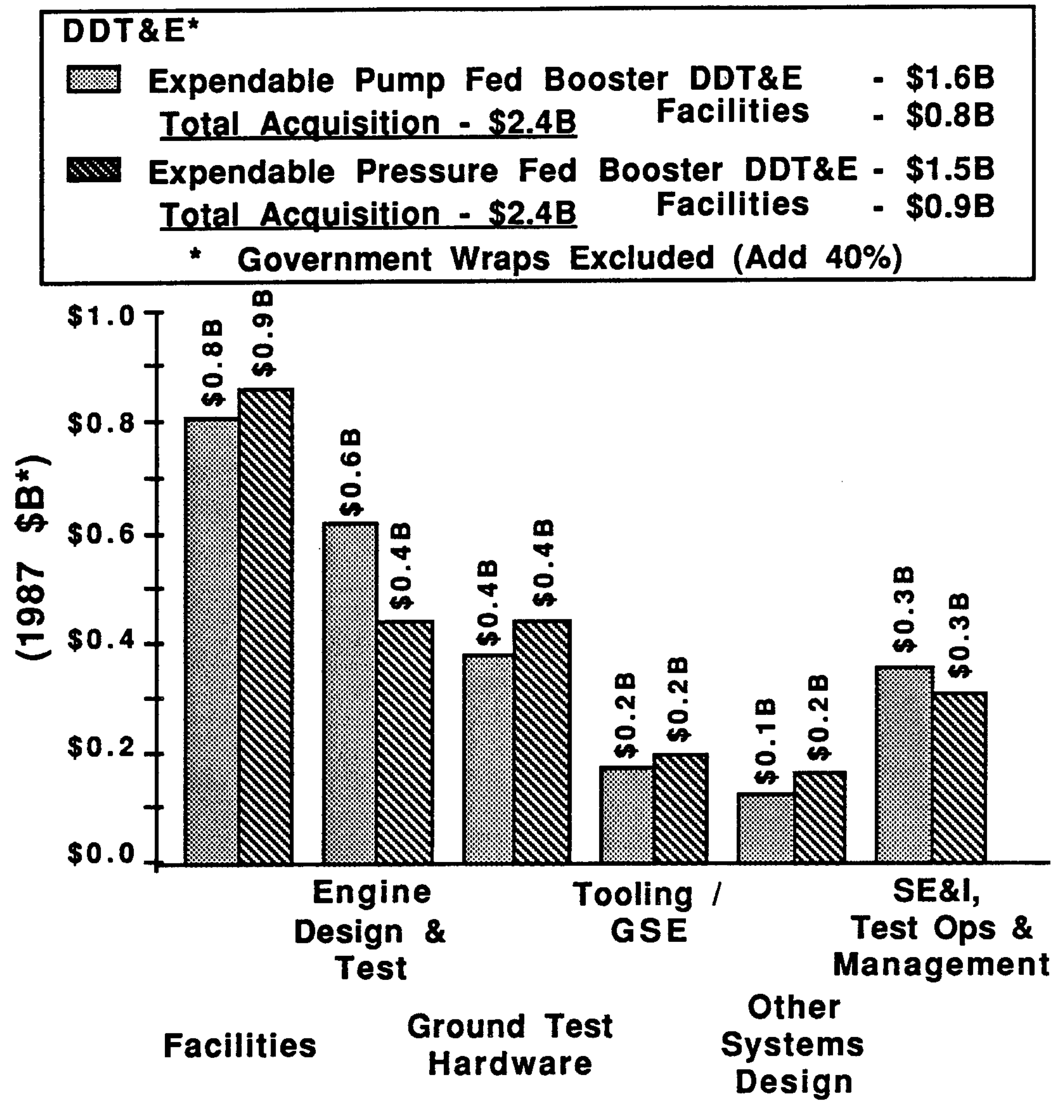


Figure 5.1.1.2-1 - LRB DDT&E Cost Estimates By System

The pressure-fed engine DDT&E costs are significantly lower than for the pump-fed engine, but the engine savings are offset by increased DDT&E requirements for the structures, pressurization, and main propulsion systems. The result is roughly comparable DDT&E costs for pump-fed and pressure-fed programs. Facilities costs are not included in the DDT&E estimates since they are addressed in the Facilities phase. They are included in Figure 5.1.1.2-1 to provide an overview of the initial investment cost required for the LRB program.

5.1.1.3 Facilities Phase

The Facilities phase cost estimate accounts for almost five percent of the total life cycle cost. There is little difference in the facilities cost estimates for the pump and pressure-fed boosters ($0.8B - pump; $0.9B - pressure).

5.1.1.4 Production/Operations Phase

The Production and Operations phases of this program are combined into one phase for estimating purposes. Figure 5.1.1.4-1 identifies the Production/ Operations cost estimates.

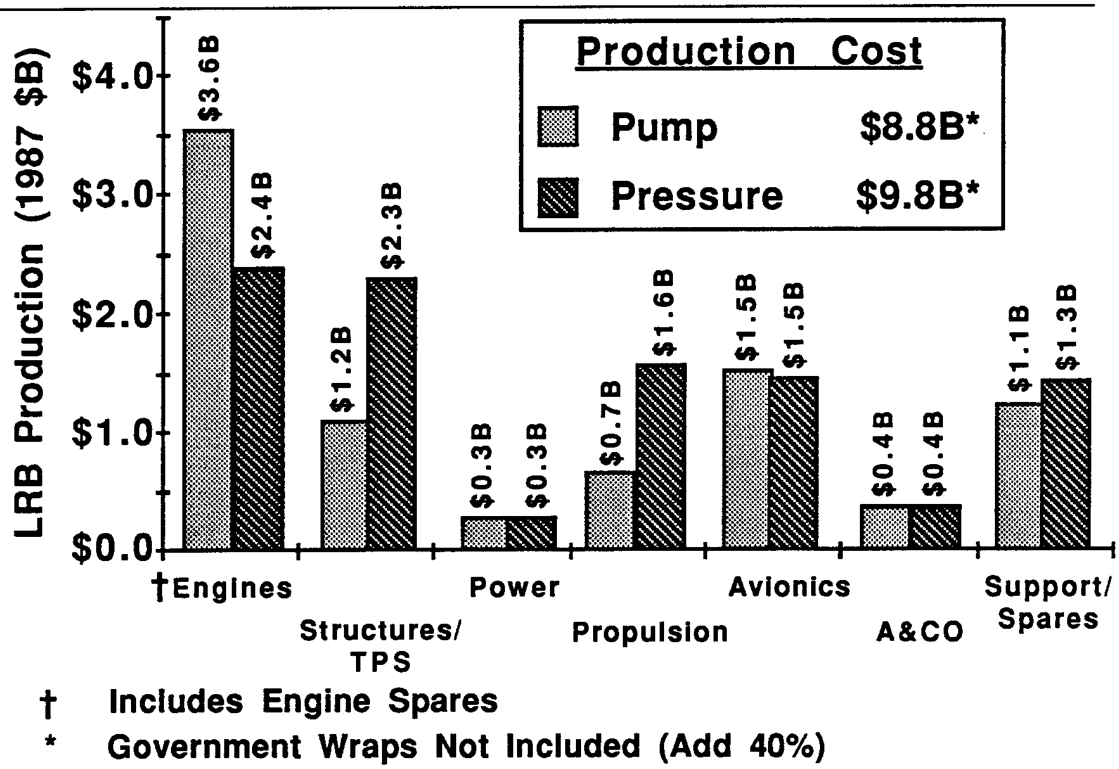


Figure 5.1.1.4-1 - LRB Production LCC By System

The Production/ Operations phase of this program accounts for roughly eighty percent of the LCC ($8.8B - pump; $9.8B - pressure). The major LCC discriminator between pump and pressure-fed boosters can be found in this phase. The production costs for the 244 baseline pressure-fed boosters is $1.0B greater than for the baseline pump-fed booster.

The production/ operations costs for the pump and pressure-fed boosters are significantly different due to the following three subsystem interactions: engines, structures and propulsion. The engine subsystem provides the pressure-fed booster with a distinct production cost advantage over the pump-fed engines ($2.4B v.s. $3.6B). However, the pressures introduced in order to accommodate the pressure-fed engine push the cost of the structures and propulsion subsystems past those of the pump-fed system . These cost increases drive the overall Production/ Operations costs of the pressure-fed system higher than the pump-fed system. It should be noted that the pressure-fed structures costs are being driven by current welding technologies and significant cost reductions in this area are achievable (see manufacturing technology estimate).

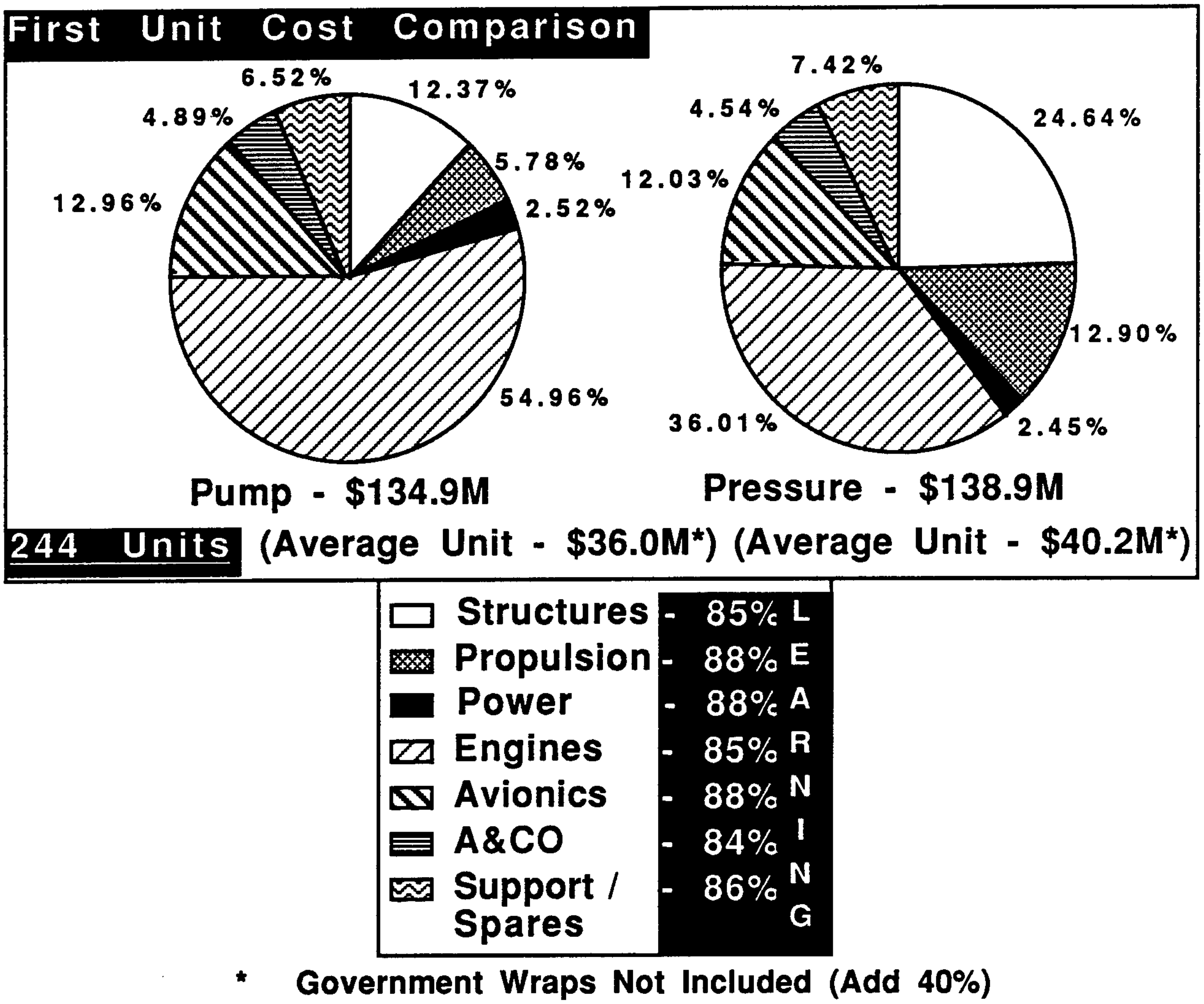


Figure 5.1.1.4-2 - LRB First Unit Costs

As noted earlier, ground and mission operations are not included in the Production/ Operations estimates. The Production/ Operations cost estimates detailed here include only the delivery of the LRB flight hardware to the launch site. A separate NASA study addresses cost estimates from receipt of the LRB hardware to receipt of the next ship set (i.e., Orbiter/ET, vehicle integration, mission operations, etc.) The first unit costs and the average unit costs of the pump and pressure-fed boosters are shown in Figure 5.1.1.4-2.

5.1.2 Technology LCC Summary

5.1.2.1 Technology Approach

The baseline pressure-fed vehicle was defined under groundrules that minimized new technology approaches. The intent was to first demonstrate that the pressure-fed booster was a viable alternative to the pump-fed system and only then to incorporate near term technologies to reduce program costs. The technology pressure-fed estimate incorporates these near term enhancing technologies into the pressure-fed system. The technology pressure-fed estimate also includes anticipated benefits developed from a CSTI technology test bed. The cost reductions come from a combination of reduced hardware requirements and an improved database that will reduce the contingencies carried for previously unavailable engineering data.

The benefit of such technologies is a reduction in program costs for relatively little investment cost. The technology estimate incorporates improvements on the baseline pressure-fed vehicle in the three system cost drivers: structures, propulsion, and engines. These enabling and enhancing technologies offer potential benefits to the pressure-fed booster that can offset some of the significant cost penalties for this type of booster (due to the structures and pressurization systems) and allow the low cost pressure-fed engine advantage to be realized.

5.1.2.2 Enabling Technologies

The large subscale test demonstration of the pressurization system and TCA is paramount to proceeding with the development of the pressure-fed LRB. Although pressurization systems based on similar thermodynamic principles have been built before, none of these systems have approached the size and mass requirements of the LRB. A pressure-fed test bed can improve on the pressure-fed technology base. Additionally, the demonstration of these systems outside of an intensive full scale development program may identify a more cost efficient design of the eventual flight systems. Two systems in particular can benefit from such a test program: the pressurization system, and the pressure-fed engine (Thrust Chamber Assembly). A Civilian Space Technology Initiative (CSTI) "technology" test bed has been proposed to test these systems.

In addition to demonstrating the enabling technology concepts feasibility, a major benefit of a test program is the development of a pressure-fed technology database that will allow better designs, improved manufacturability, and a resulting reduction in program costs. Baseline costs assume full scale production as currently designed. CSTI technology estimates include potential reductions in the amount of and/or the complexity of the hardware required for these subsystems in addition to improvements upon the current manufacturing processes as a result of the analysis.

The technology benefits identified for the pressurization system are due to a potential reduction in the complexity of the currently proposed flight system. The benefits to the pressurization system from the technology test bed is a cost reduction of 20%. The TCA demonstration program, another part of the CSTI test bed, will allow the investigation of injector simplification to improve manufacturability. Improvements to the TCA subsystems can provide a 15% reduction in engine system costs (10% from ablative chambers and 5% from injector simplifications.)

5.1.2.3 Enhancing Technologies

The enhancing technologies are not required for the introduction of the pressure-fed LRB to the STS, but if developed and incorporated contribute to a reduction in program costs. This is different than the enabling technologies because the enabling technologies are required in order to be able to develop a pressure-fed LRB for the STS.

5.1.2.3.1 Electron Beam Welding

Our initial assessment of highly pressurized structures included a welding technique adopted from our External Tank experience. Although these techniques (Plasma/Arc and GMA) have proven effective on lightweight, low pressure tankage, the weld land thickness of our 1000 psia tankage makes this process extremely labor intensive and thus not cost effective. Our advanced technology department has identified Electron Beam welding as a very achievable near term alternative to the baseline approach. Electron beam welding has the potential to reduce the structures costs by 30%.

5.1.2.3.2 LRB Recovery/Reusability Assessment

An analysis of the technical and economic feasibility of LRB recovery and reuse was performed at the trade study level during the course of this study. The booster recovery/reuse operational approach was similar to the current SRB water recovery, launch site disassembly and depot refurbishment cycle.

Although the cost analysis results demonstrated that recovery and reuse of certain booster subsystems could provide LCC savings of as much as 7 to 10% over expendable boosters, uncertainty in noncost variables including complexity, safety, maintainability, and risk overruled the cost results in favor of expendable boosters. Additional issues contributing to the choice of an expendable baseline included: the relatively small magnitude of reusable booster cost savings; and the relative uncertainty in key reusable booster assumptions such as refurbishment requirements, booster service life, attrition, and which systems had potential reuse after salt water impact and intrusion. A large part of the uncertainty in our reusable booster assumptions was due the lack of or inability to obtain a sound historical data base from which the assumptions could be substantiated.

Further recovery analyses should include a detailed analysis of refurbishment requirements and an assessment of the minimum cost achievable for expendable systems, especially engines (i.e., as engine costs grow reusability is more attractive.) From a hardware perspective, the concept of reusable systems makes more sense than the singular use of high cost spacecraft hardware. But, without a thorough analysis and understanding of "real" refurbishment requirements, reusability also has many more inherent risks that could ultimately cause significantly increased LCC.

5.1.2.4 Life Cycle Cost Comparison of Pressure-Fed Technology Benefits

The LCC estimate summary bar chart (Figure 5.1.2.4-1) illustrates the relative conservatism of the baseline pressure-fed booster estimate with respect to the baseline pump-fed LCC estimate. Many of the uncertainties are due to immature technology definition for the pressure-fed structures manufacturing and propulsion system definition. The technology cost benefits shown include the application of Electron Beam welding to the pressurized structures and MPS improvements ($1.6B); and expected configurational savings in the pressurization system and pressure-fed engine resulting from the CSTI technology program ($0.8B).

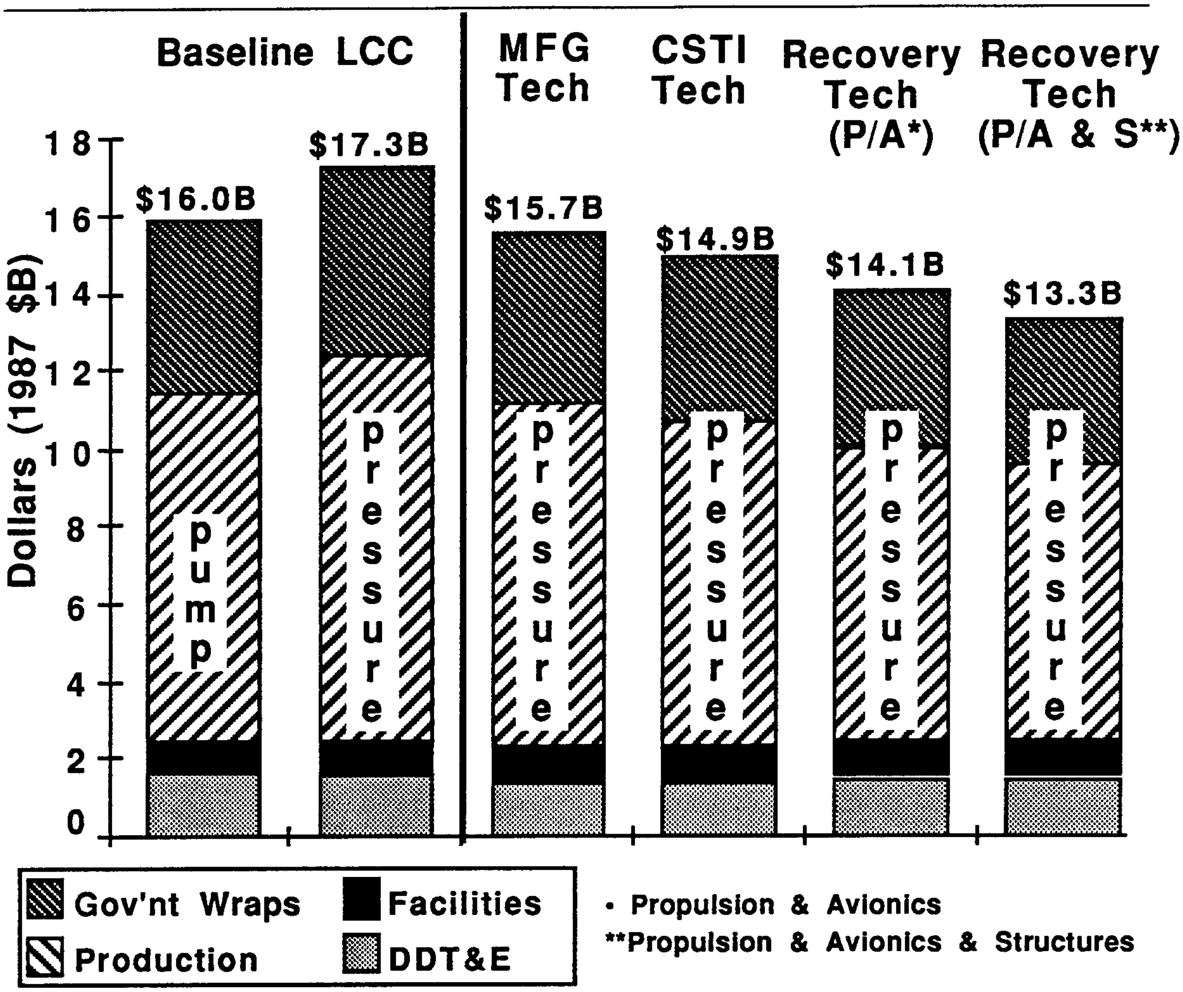


Figure 5.1.2.4-1 - Technology LRB Life Cycle Cost Estimates

5.1.2.5 Technology Average Unit Cost Comparison

The average unit cost by subsystem (Figure 5.1.2.5-1) highlights the expected LCC reductions of the major subsystems with the application of the technologies identified. The baseline average unit cost estimates for the pump-fed and pressure-fed booster are $36M and $40.2M respectively. The technology programs identified include the structures manufacturing, pressurization system and TCA. The net benefit in unit cost reductions provides a revised unit cost estimate of $33.6M for the pressure-fed booster. The reductions are due to the decrease in manufacturing weld labor (structures and propulsion) and potential configurational changes in the pressurization system and engine. These savings are provided directly as a result of the expected data base and manufacturing techniques developed under the two technology programs.

Cost By Subsystem

	Baseline Pump	Baseline Pressure	MFG Technology Pressure	MFG/ CSTI Technology Pressure
Structures	$4.7M	$9.5M	$6.1M	$6.1M
Propulsion	$2.8M	$6.4M	$5.7M	$5.2M
Power	$1.2M	$1.2M	$1.2M	$1.2M
Engines	$14.9M	$10.0M	$10.0M	$8.5M
Avionics	$6.3M	$6.1M	$6.1M	$6.1M
A&CO	$1.6M	$1.6M	$1.5M	$1.4M
Support	$4.5M	$5.4M	$5.1M	$5.1M
TOTALS	$36.0M	$40.2M	$35.7M	$33.6M

Figure 5.1.2.5-1 - Technology LRB Average Unit Costs

5.1.3 Shared NSTS/ALS LCC

The groundrules and assumptions for the ALS analysis are identified in Table 5.1.3-1. The groundrules set-up the basis for the analysis. One important point to note is that the ALS core costs are not included in the LCC estimates with the exception of the engines. The three ALS options have the same core vehicle so it is not a discriminator between configurations. The primary emphasis of the trade study was to determine the attractiveness of common ALS booster/core engines and of the cost benefits for the NSTS/ALS programs sharing a common booster.

Program Phase	Groundrules and Assumptions
General	1987 constant year dollars Government factors separately identified as follows - Government Support 5% - Management Reserve 25% - Contractor Fee 10% No SRB transition costs impacts included No SRB flights delayed or cancelled Operations: NSTS 10 years; ALS 15 years NSTS flight rate 14/year after Ramp from 4, 8, 12: (244 Boosters) ALS Mission Model 25/year: (750 Boosters) KSC and JSC operations excluded IOC: STS LRB 1996; ALS 1998 Manufacturing facilities sized for steady state of 39 flights per year Excludes ET and Orbiter impacts Core cost estimates are excluded except for engine subsystem

Table 5.1.3-1 - Shared NSTS/ALS Programmatic Groundrules And Assumptions

The shared NSTS/ALS LRB cost analysis considered three possible ALS/NSTS LRB Alternatives. The options were evaluated to determine the best alternatives from a cost perspective. The cost analysis indicates that there are two of the three configurations that should be considered further: namely, option one (RP-1 booster/LH2 Core) and option three (LH2 booster/LH2 Core - common engines) . Option Two (LH2 booster/LH2 Core - different engines) does not offer any potential cost savings over options one and three due to the development of two separate engines and the vehicle growth inherent in selecting LH2 fueled boosters.

From a non-recurring cost standpoint, option three is the clear winner between the three options due to the single engine development program requirement. Options one and two require dedicated engines for the booster and the core which helps push the non-recurring cost estimates between $1.2B and $1.4B more than option three.

From a recurring cost standpoint (see Figure 5.1.3-1), option one has the lowest costs due to the smaller structures. The structures are 3 feet smaller in diameter and several feet shorter than the nearest other option. The average unit cost of option one is lower than any other option. In comparison to the recurring costs for option one, recurring costs for option three placed second (+$1.8B) and the recurring costs for option two finished last (+$2.3B).

	AVERAGE UNIT COSTS			
	NSTS	NSTS/ALS		
Booster Subsystem	Baseline Pump	Option 1 LO2/RP-1 LO2/LH2	Option 2 LO2/LH2 LO2/LH2	Option 3 LO2/LH2* LO2/LH2*
Structures	$4.4 M	$3.2 M	$3.8 M	$3.9 M
Propulsion	$2.8 M	$2.2 M	$2.3 M	$2.3 M
Power	$1.2 M	$1.0 M	$1.0 M	$1.0 M
Avionics	$6.3 M	$4.9 M	$4.9 M	$5.5 M
Booster Engines	$14.8 M	$10.6 M	$10.9 M	$10.1 M
TPS	$0.3 M	$0.2 M	$0.5 M	$0.5 M
Asemble & Ck out	$1.6 M	$1.2 M	$1.2 M	$1.2 M
Sustaining Tooling	$0.5 M	$1.3 M	$1.4 M	$1.5 M
Initial Spares	$0.9 M	$0.8 M	$0.8 M	$0.8 M
Sustaining Engr.	$1.7 M	$1.4 M	$1.5 M	$1.5 M
Program Mgmt.	$1.4 M	$1.2 M	$1.2 M	$1.2 M
TOTAL	$36.0 M	$28.0 M (4 Engs)	$29.5 M (4 Engs)	$29.5 M (5 Engs)
Core ALS Engines		$13.7 M (4 Engs)	$13.7 M (4 Engs)	$12.1 M (6 Engs)
Average Unit Cost (2-LRBs / Core Engines Only)		$69.7M	$72.7M	$71.1M

* Common Engines

Figure 5.1.3-1 - Shared NSTS/ALS Average Unit Costs

The cost analysis found that the common booster/core engine approach does minimize the engine life cycle cost estimates, but penalizes the booster subsystems and maximizes the NSTS integration impacts. LCC estimates for options one and three were within 1% of each other. The program costs for option two were 5% greater than the other options. The additional NSTS integration cost impacts due to larger diameters and longer lengths will tend to increase the costs for options two and three. The analysis suggests that option one would have the smallest life cycle costs when all impacts are considered. Options one and three warrant further consideration since the cursory LCC analysis found little cost discrimination between the two options.

5.2 PROGRAM SCHEDULE

The summary schedule was condensed from the detailed LRB pump and pressure-fed schedules contained in the preliminary Program Implementation Plan (DR-9).

Detailed schedules show that the pump and pressure-fed programs have only minimal differences in their plan. The summary schedule shown in Figure 5.2-1 is applicable to both concepts.

6.0 CONCLUSIONS

The results of the Liquid Rocket Booster for the Space Transportation System System Study clearly demonstrated that the LRB is a promising option to the solid rocket booster. The inclusion of LRBs in the National Space Transportation System would significantly improve mission safety and reliability while providing increased performance.

Both pump-fed and pressure-fed liquid boosters are viable. The pump-fed LRB requires no enabling technology. However, the development of technology leading to a low cost pump-fed engine is assumed in the study

The pressure-fed LRB does require technology development to demonstrate large scale pressure-fed propulsion system capabilities. These technology acquisitions, combined with reduced manufacturing cost techniques for large high pressure propellant tanks, make the pressure-fed option attractive.

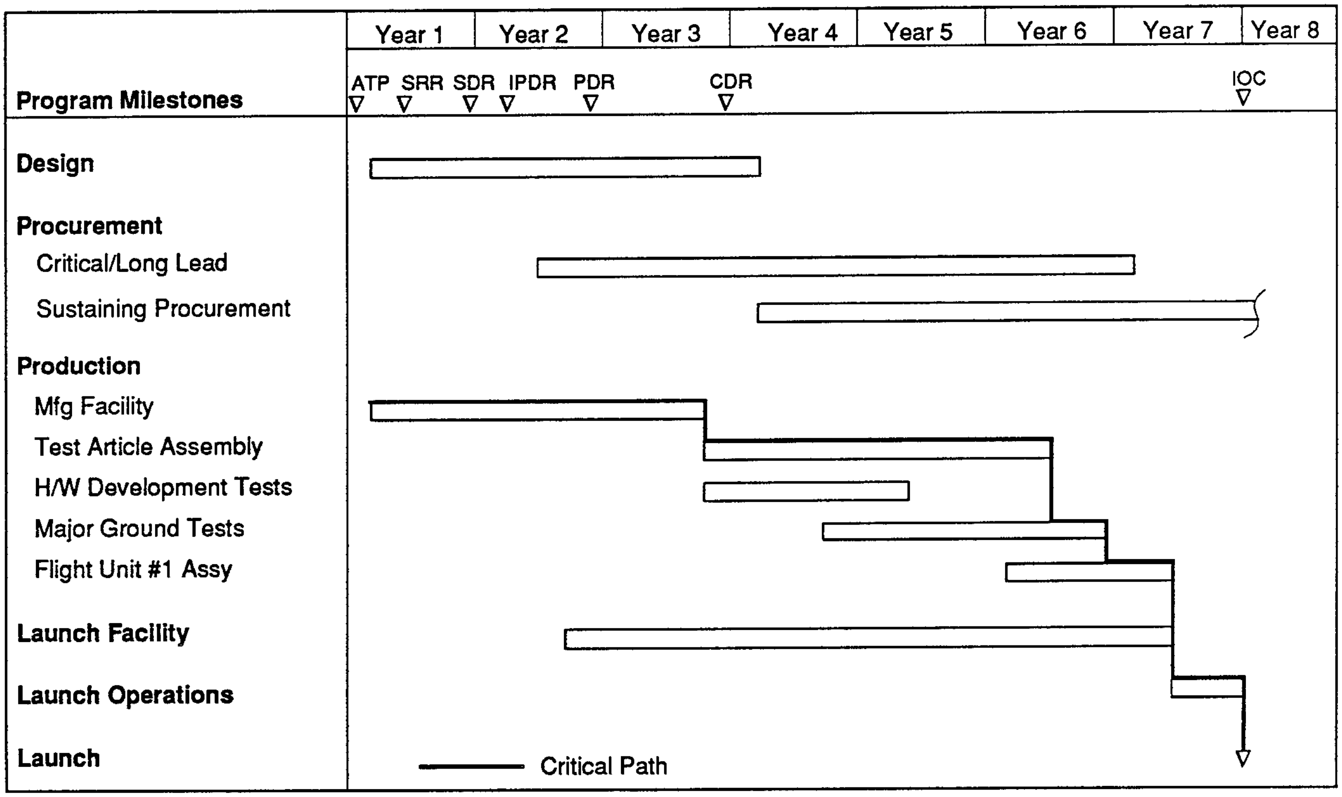


Figure 5.2-1 LRB Program Schedule