CONTRACT NO. NAS8-37137

VOLUME II
APPENDIX 9
LRB ALTERNATE APPLICATIONS AND EVOLUTIONARY GROWTH

(NASA-CR-183604) LIQUID ROCKET BOOSTER STUDY. VOLUME 2, BOOK 5, APPENDIX 9: LRB ALTERNATE APPLICATIONS AND EVOLUTIONARY GROWTH Final Report, Aug. 1988 - Jan. 1989 (General Dynamics Corp.) 83 p CSCL 21H G3/20

N90-10134

Unclas 0204301

LIQUID ROCKET BOOSTER STUDY FINAL REPORT

GENERAL DYNAMICS
Space Systems Division

LIQUID ROCKET BOOSTER STUDY

VOLUME II
APPENDIX 9
BOOK 5

LRB ALTERNATE APPLICATIONS AND EVOLUTIONARY GROWTH

February 1989

Prepared for
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

Prepared Under
CONTRACT NAS8-37137

Prepared By
GENERAL DYNAMICS SPACE SYSTEMS DIVISION
P.O. Box 85990
San Diego, California 92138

FOREWORD

This LRB study report appendix was prepared by General Dynamics Space Systems Division (GDSS) for the National Aeronautics and Space Administration Marshall Space Flight Center (NASA/MSFC) in accordance with Contract NAS8-37137. The results were developed primarily from August 1988 to January 1989.

This volume describes the analyses performed in assessing the merit of the LRB concept for use in alternate applications such as for Shuttle "C", for Standalone Expendable Launch Vehicles (ELVs), and possibly for use with the Air Force's Advanced Launch System (ALS). This volume also contains a comparison of the three LRB candidate designs, namely, 1) the LO2/LH2 pump fed, 2) the LO2/RP-1 pump fed, and 3) the LO2/RP-1 pressure fed propellant systems in teams of evolution and growth; both design and cost factors, and other qualitative considerations are presented. It also contains a further description of the recommended LRB standalone, core-to-orbit launch vehicle concept.

The GDSS personnel primarily responsible for the work are listed as follows:

John Maloney	Task Leader, Concept Evaluation
Paul Brennan	Concept Development
Joe Szedula	Performance/Trajectories
John Olds	Performance/Trajectories
Dave Hays	Concept Design
Dave Locke	Cost Analysis

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACS	- ATTITUDE CONTROL SYSTEM
ALS	- ADVANCED LAUNCH SYSTEM
AUC	- AVERAGE UNIT COST
BIT	- BUILT IN TEST
BLOW	- BOOSTER LIFT-OFF WEIGHT
BRM	- BOOSTER RECOVERY MODULE
BSM	- BOOSTER SEPARATION MOTORS
DDT&E	- DESIGN, DEVELOPMENT, TEST AND EVALUATION COSTS
ELV	- EXPENDABLE LAUNCH VEHICLE
EPL	- EMERGENCY POWER LEVEL
ERM	- ENGINE RECOVERY MODULE
ET	- EXTERNAL TANK
ETR	- EASTERN TEST RANGE
FASTPASS	- FLEXIBLE ANALYSIS FOR SYNTHESIS, TRAJECTORY, AND PERFORMANCE FOR ADVANCED SPACE SYSTEMS
GDSS	- GENERAL DYNAMICS SPACE SYSTEMS DIVISION
GG	- GAS GENERATOR
GLOW	- GROSS LIFT-OFF WEIGHT
GN&C	- GUIDANCE, NAVIGATION, AND CONTROL
GO2	- GASEOUS OXYGEN
GTO	- GEO TRANSFER ORBIT
INU	- INERTIAL NAVIGATION UNIT
IOC	- INITIAL OPERATING CAPABILITY
IUS	- INERTIAL UPPER STAGE
KSC	- LIFE CYCLE COST
L/D	- LENGTH / DIAMETER
LEO	- LOW EARTH ORBIT
LH2	- LIQUID HYDROGEN
LO2	- LIQUID OXYGEN
LRB	- LIQUID ROCKET BOOSTER (FOR THE SPACE SHUTTLE)
MAX G	- MAXIMUM AXIAL ACCELERATION
MAX Q	- MAXIMUM DYNAMIC PRESSURE
MAX Qα	- MAXIMUM PRODUCT OF DYNAMIC PRESSURE AND ANGLE OF ATTACK
MAX QV	- MAXIMUM PRODUCT OF DYNAMIC PRESSURE AND VELOCITY
MECO	- MAIN ENGINE CUT OFF
MLP	- MOBILE LAUNCH PLATFORM
MSFC	- MARSHALL SPACE FLIGHT CENTER
NASA	- NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NPL	- NORMAL POWER LEVEL
P/L	- PAYLOAD
PM	- PROGRAM MANAGER
RF	- RADIO FREQUENCY
RGA	- RATE GYRO ASSEMBLY
RPL	- RATED POWER LEVEL
SE	- SYSTEMS ENGINEERING

LIST OF ACRONYMS (CON'T)

SRB	- SOLID ROCKET BOOSTER
SRM	- SOLID ROCKET MOTOR
SSME	- SPACE SHUTTLE MAIN ENGINE
STAS	- SPACE TRANSPORTATION ARCHITECTURE STUDY
STME	- SPACE TRANSPORTATION MAIN ENGINE STUDY
STS	- SPACE TRANSPORTATION SYSTEM
TBD	- TO BE DETERMINED
TPS	- THERMAL PROTECTION SYSTEM
TVC	- THRUST VECTOR CONTROL
T/W	- THRUST / WEIGHT
USAF	- UNITED STATES AIR FORCE
VAB	- VERTICAL ASSEMBLY BUILDING

SUMMARY

The objectives of the LRB alternate applications study were to identify future or alternate applications for LRBs, and to examine potential cost benefits to the LRB program due to cost sharing and increased rates of production resulting from alternate uses of LRBs. Three alternate applications were primarily investigated: 1) STS LRBs for the Air Force's Advanced Launch System (ALS), 2) A possible LRB Standalone ELV, and 3) Evolution for use on the NASA Shuttle-C launch vehicle.

Three candidate LRBs were analyzed to meet these applications, namely the LO2/LH2 pump fed, the LO2/RP-1 pump fed, and the LO2/RP-1 pressure fed concepts.

The study provided technical and programmatic data that was utilized to help select the recommended LRB concept. The recommended LRB concept is the LO2/LH2 pump fed design, which is described in Section 5.0 of the LRB final report, Volume II.

This study has established that the LRB concept can be used successfully in many alternate applications. This flexibility provides additional benefits to the basic STS-LRB program, such as potential LRB development cost savings due to DDT&E cost sharing with other programs, and by reductions in production unit cost because of increased rates of production to support multiple applications.

Major conclusions of the alternate applications study are listed below:

LRB APPLICATIONS TO ALS:

- The LO2/LH2 LRB is best suited for ALS because of common propellants.
- The LO2/LH2 LRB has very similar engines to the ALS, thus a common engine development is possible.
- A family of vehicles with payload capabilities ranging from 50-200k lbs can be derived by varying the number of LRBs used, and the number of engines used per LRB.
- Use of LRBs for ALS can reduce NASA's LRB DDT&E and recurring production costs (i.e., shared program with USAF).

LRB APPLICATION TO STANDALONE EXPENDABLE LAUNCH VEHICLES:

- LRB standalone expendable launch vehicles can be used as an initial building block for ALS in the lower payload range.
- New LRB standalone launch vehicles provide an additional measure of assured access to space.
- The LO2/LH2 LRB has the best performance of candidate LRB designs for standalone launch vehicle applications.
- The recommended LRB standalone launch vehicle is a core-to-orbit concept which use 1 or 2 LRB boosters in a modular approach to deliver 25-80 Klbs of payload to LEO (see Section 6.2).

LRB APPLICATION TO SHUTTLE-C:

- LRBs provide approximately 20k lbs greater payload capability than SRBs for Shuttle-C.
- Use of LRB engines as SSME replacements may lower Shuttle-C costs per flight.
- Applicability of LRBs and LRB engines to Shuttle-C provides NASA with an additional measure of assured access to space.
- The LRB provides many of the same benefits to the Shuttle "C" that it provides the shuttle, such as improved reliability (i.e., engine out capability) and safer operations (i.e., hazardous propellants are removed from the VAB).

These results are displayed in Figure 1-1 below.

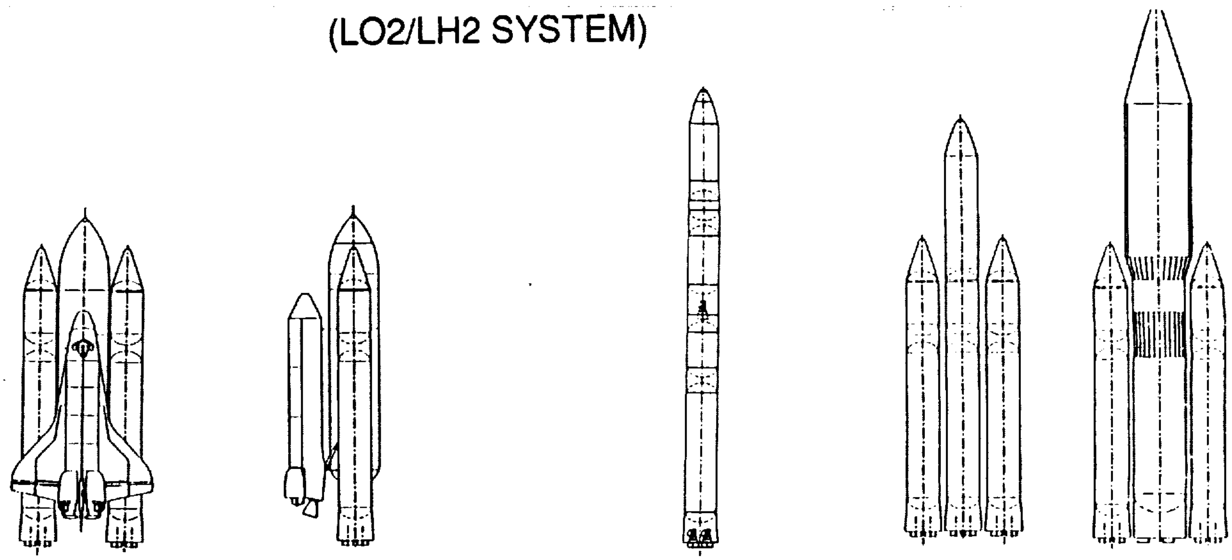


Figure 1-1. LRB Evolution and Growth Results

SECTION 1
INTRODUCTION

A major consideration in the selection of a recommended LRB design is its capability to evolve and grow into other applications. Three LRB concepts were analyzed for this task, namely the LO2/LH2 pump fed, LO2/RP-1 pump fed, and LO2/RP-1 pressure fed boosters; however, the LO2/LH2 configuration was studied to a greater extent. These concepts were analyzed by comparing design and cost factors, and by noting qualitative considerations. This data was fed into the basic study task to help in the selection of the recommended STS concept.

1.1 APPROACH

The study approach (shown in Figure 1.1-1) was established to meet the objectives of the alternate application study, which were to:

- Identify future applications and efficient growth paths for LRB concepts.
- Examine cost benefits to the LRB program due to cost sharing and increased rates of production.
- Establish spin-off benefits like a better evolution of the space shuttle and a more flexible national space launch system.

The study approach was broken down into five major tasks. The first task involved a top level consideration of alternate and growth uses for the LRB. Emphasis was placed on identifying applications which required minimal modification to the LRBs as designed for the Shuttle.

Requirements analysis was performed for task two. This involved identifying top level system requirements and flowing down these requirements to the LRB element. Requirements were obtained by consulting with our in house studies for Shuttle C and ALS and supplemented by consultation with NASA.

The third task consisted of analyses and comparisons of options within the categories of LRB application to ALS, standalone ELVs, and Shuttle C. This task was the longest in duration, and included such items as comparing various LRB standalone launch vehicle

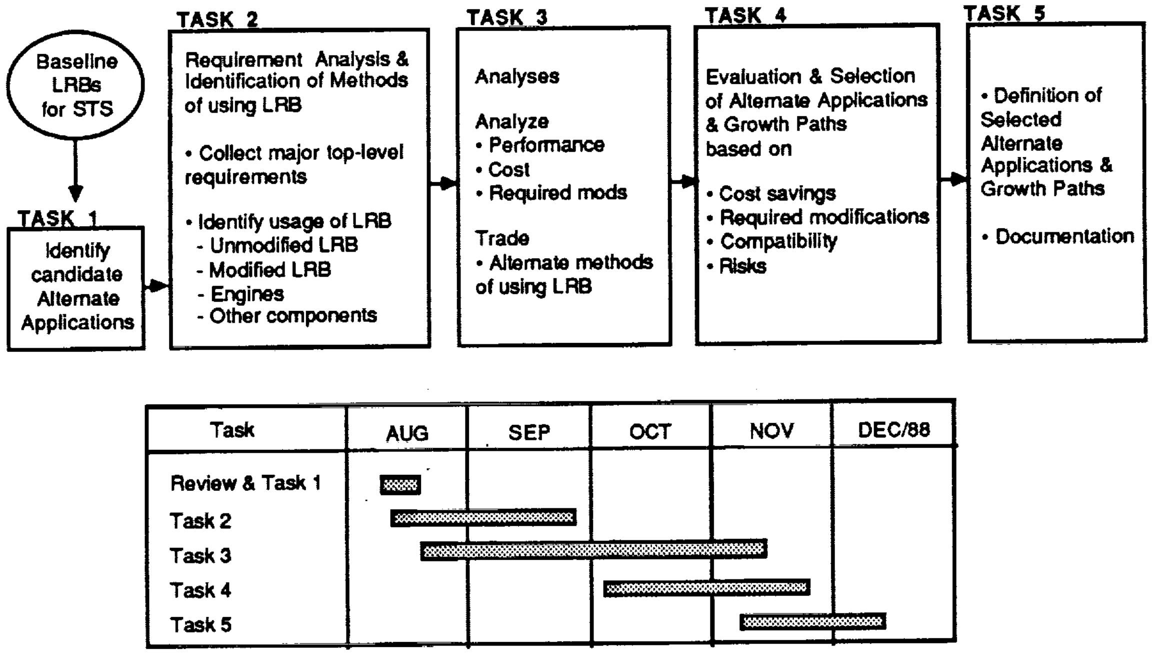


Figure 1.1-1. Approach/Tasks for Study of Alternate LRB Applications

designs, and evaluating the use of the LRB engines vs. SSMEs on the Shuttle C cargo carrier. The analyses conducted focused mainly on performance (and costs to a more limited extent), although additional qualitative examinations were performed to identify required booster modifications for use of LRBs with other launch vehicle systems.

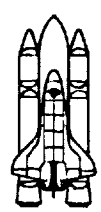
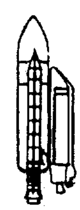
Task four produced results which were incorporated into the downselection of the final LRB concept. Evaluations and selections conducted for this task included determining the preferred standalone LRB ELV concept, and on a larger scale, assessing the evolution and growth potential of the different LRB designs. Selection processes were based on performance capabilities, costs and qualitative considerations.

The fifth, and last task, was concerned with providing additional definition to downselected alternate applications, and documenting results. As a preferential ALS application method was not decided upon (largely because ALS is in initial phases of design), and as all Shuttle C applications are similar, only the recommended standalone launch vehicle application was further defined.

1.2 REQUIREMENTS

Table 1.2-1 indicates the most promising potential applications for LRBs, and associated top level requirements for these applications. Performance (total impulse) values quoted for each application were derived by examining the capabilities for the overall systems. As the ALS and Shuttle C designs mature these values are likely to change. Each LRB delivers nominally 270 million Lb•sec of impulse, and thus to fulfill impulse requirements, LRBs must be used in multiples in many instances. Unlike the shuttle, the alternate applications identified generally do not require man-rating, although man-rating cost implications will be examined as part of the ALS phase II study. Requirements definition for LRB standalone ELVs, in many instances, is contingent upon further study. Additional requirements for Shuttle C and for ALS applications are found in sections 3.0 and 5.0 respectively.

Table 1.2-1. LRB Applications – Top Level Requirements

APPLICATION / REQUIREMENT	 STS LRB	 ALS	 SHUTTLE "C"	 STANDALONE
PAYLOAD (K LBS)	70.5 (160nm,28.5°)	80 – 120 (80x150nm,28.5°)	100-150 (220nm,28.5°)	TBD (150nm,28.5°)
PERFORMANCE (TOTAL BOOSTER IMPULSE)	540 M LBSEC	640 M LBSEC	500 M LBSEC	250+ M LBSEC
MAN - RATED	YES	NO	NO	NO
FLIGHT RATE/YEAR	14	10 Flts/yr (Capability to 20 Flts/Yr)	2-3	TBD
ENGINE - OUT CAPABILITY	YES	YES	YES	TBD
BOOSTER REUSABILITY	NO	Engines Only	TBD	NO
IOC	1995	2000	1993	1995 -1996

SECTION 2
CANDIDATE AND BASELINE LRB CONCEPTS

This section presents an overview of the basic LRB design study effort, and presents additional information on the LRB concepts which were examined in terms of evolution and growth.

Our LRB for STS design study approach was to start with a "clean sheet of paper", perform basic trades (such as propellant selection) from which concepts would be sized, and then select the best configuration in terms of costs, safety, STS integration and evolutionary potential. Basic study ground rules are listed below:

- Each concept is sized for a 70.5 KLB payload capability to a 150nmi due east orbit from KSC
- Safe abort with one LRB engine (or 1 SSME) out
- GD Goal: Full payload Abort-To-Orbit (105 nmi) with 1 engine out
- Virtually no hardware changes to Orbiter
- Use STS trajectory constraints on Max Q, Max G, etc.
- Minimize changes to ET
- Reasonable changes to KCS facilities and GSE (may need new MLP)
- IOC depends on concept but 1995 is an approximate target

We first evaluated engines and propellants on the basis of safety, performance, and STS compatibility. Concepts were then refined and evaluated by a number of trades and analyses, as shown in Figure 2-1.

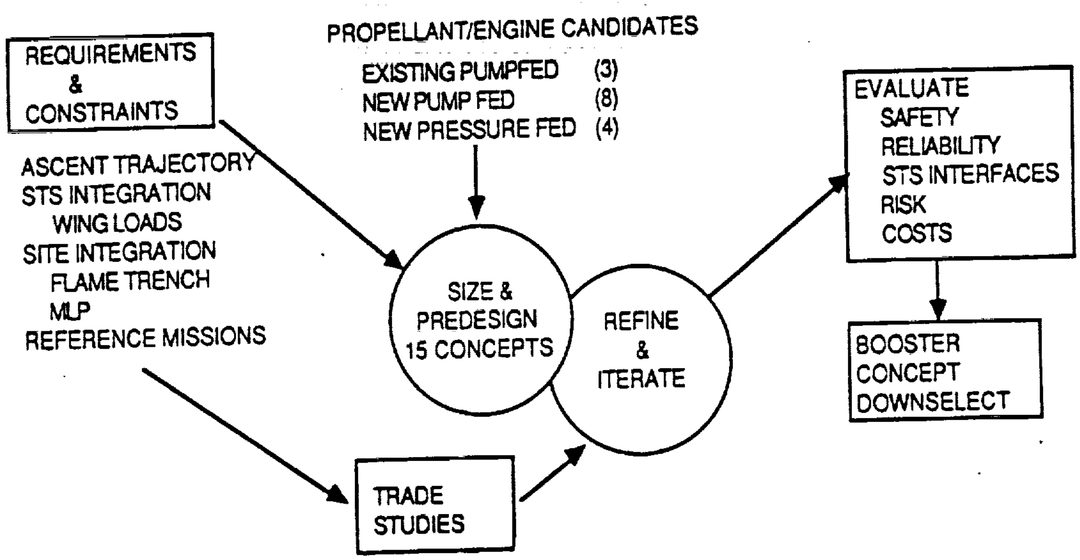


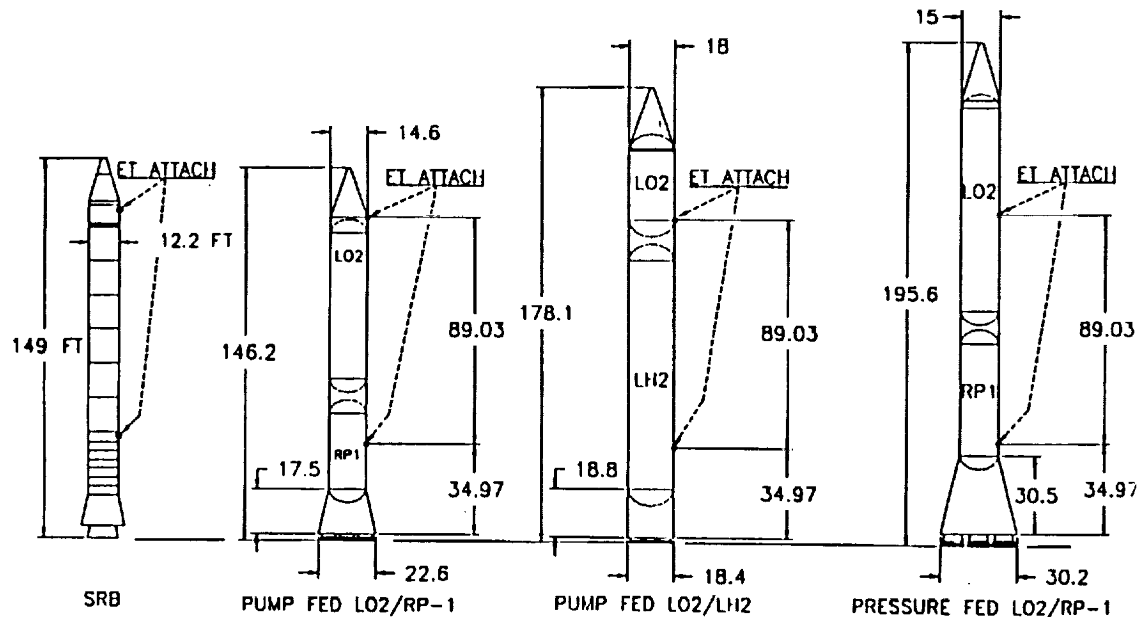
Figure 2-1. Approach to LRB concept selection

2.1 CONCEPT DESCRIPTIONS

The three candidate LRB concepts considered for alternate applications were the:

- LO2/RP-1 PUMP-FED
- LO2/LH2 PUMP-FED
- LO2/RP-1 PRESSURE-FED

The dimensions, and a quantitative comparison of these three boosters is shown in Figure 2.1-1. Costs are compared for these vehicles in Tables 2.1-1 and 2.1-2. It should be noted that the average LRB recurring cost is about $30M for any booster (less contractor fee, government support and contingency), and that the average Life-Cycle-Cost is about $11,000M 1987 dollars. It will be shown in section 3.0 (LRB Application to ALS) that these costs can be significantly reduced if LRBs and/or LRB engines can be used for both programs.



DATA (ONE BOOSTER)	SOLID ROCKET BOOSTER	LO2/RP-1 PUMP FED	LO2/LH2 PUMP FED	LO2/RP-1 PRESSURE FED
DRY WEIGHT (Klbs)	146	116	122	237
LRB GLOW (Klbs)	1,250	1,092	821	1,598
THRUST (sea level)(Klbs) (nominal)	2,912	565 (2260)	515 (2060)	841 (3364)
INITIAL T/W	1.5	1.37	1.46	1.53

Figure 2.1-1. Candidate LRB Concepts

Table 2.1-1. DDT&E/Production Cost for Selected Vehicles (1987 $M)
Expendables @ 14 STS Flights Per Year (244 LRBs)

Cost Element \ Concept	Pump-fed New LH2/LO2	Pump-fed New RP1/LO2	Press-fed New RP1/LO2
DDT&E			
Structures /TPS	231	206	248
Separation system	23	23	30
Propulsion system	146	169	388
Main engines	1007	878	435
Avionics/Electrical Power	70	70	70
Tooling/Test Ops/GSE/ S/W	462	424	433
Systems Engr/Program Mgmt	218	204	188
TOTAL	2157	1974	1792
Average Unit Cost			
Structures /TPS	8	7	9
Separation system	1	1	1
Propulsion system	3	4	10
Main engines	13	9	5
Avionics/Electrical Power	3	3	3
Sustaining Tooling/Final Assy	3	2	4
Systems Engr/Program Mgmt	2	2	2
TOTAL	33	28	34

* EXCLUDES CONTRACTOR FEE, GOVERNMENT SUPPORT AND CONTINGENCY.

Table 2.1-2. LCC for Selected Vehicles (1987 $M)
Expendables @ 14 STS Flights Per Year (244 LRBs)

Cost Element \ Concept	Pump-fed New LH2/LO2	Pump-fed New RP1/LO2	Press-fed New RP1/LO2
Nonrecurring			
Vehicle DDT&E	2157	1974	1792
Orbiter modifications	229	229	229
ET modifications	20	20	20
Facilities	413	357	372
STS SE&I	105	105	105
TOTAL NONRECURRING	2924	2685	2518
Recurring			
Vehicle production	8001	6873	8362
Launch operations	830	818	830
TOTAL RECURRING	8831	7691	9192
TOTAL LCC	11755	10376	11710

* EXCLUDES CONTRACTOR FEE, GOVERNMENT SUPPORT AND CONTINGENCY.

LO2/RP-1 PUMP-FED. This system uses a gas-generator (GG) cycle and the technology and reliability that has been demonstrated through such vehicles as the Saturn V with F-1, the Atlas with MA-5, and the Delta with RS-27 engines. For the considered applications, the LRB with an expendable LO2/RP-1 GG engine concept offers several major advantages: (1) low development and schedule risks, (2) low risk for STS integration due to the smaller LRB size, (3) high operational flexibility and low hardware/software complexity on both ground and vehicle systems, and (4) low overall system cost. This vehicle is described in detail in Section 4.0 of the LRB Final Report (Vol. II).

LO2/LH2 PUMP-FED. The selection of this concept was based on low technical risk, minimal environmental concerns, propellant's commonality with current shuttle ET, and engine commonality with STME and ALS programs. The LO2/LH2 LRB costs are higher than the other selected pump-fed concept. However, the commonality with the STME and ALS engines may bring its actual costs down due to the rate effect, thus making it more competitive with other LRB concepts. This vehicle is described in detail in Section 5.0 of the LRB Final Report (Vol.II).

RP-1 PRESSURE-FED. This LRB concept uses a familiar fuel and a simple design, but would require the use of an unmatured technology. Further development would be required to address the issues of combustion stability, injecting, cooling and throttling. In spite of this young technology, however, the overall DDT&E for this vehicle would be the least of all candidates, giving it a Life Cycle Cost equal to that of the LO2/LH2 concept. The fact that the tanks would require extra reinforcement to handle the higher pressures would give it added capability to survive potential water recovery. It is the biggest and heaviest of the three choices, and is described in detail in Section 7.0 of the LRB Final Report (Vol.II).

FINAL SELECTION. The final selected LRB concept was the LO2/LH2 configuration. This vehicle involves the least technical risk of the three candidates, and its light weight and comparatively low thrust provide for simplified trajectory design. The dangers of extra high pressures and hazardous exhaust gases are avoided by using the LO2/LH2 LRB, and it is considered the easiest to integrate into the KSC operations, where these propellants are already in use. The primary basis for this selection, however, stems from the commonality of this configuration with the USAF's ALS vehicle. Such commonality creates the potential for significant cost reduction by cost sharing with the ALS program. A more detailed discussion of the final downselection process can be found in Section 3.13 the LRB Final Report (Vol.II.).

[Note that in some instances, quoted values for LO2/LH2 vehicle parameters, (i.e., dry weight, thrust, etc.) differ. This is because early evolution and growth analyses were based on a vehicle concept which was subsequently revised. However, the changes in vehicle characteristics were generally small, making trends based on analysis with earlier designs still valid.]

SECTION 3

LRB APPLICATIONS TO ALS

This section describes the potential applications of LRBs to ALS. As the current GDSS ALS baseline uses liquid boosters, the use of STS LRBs is a logical consideration as well. The USAF's Advanced Launch System, as conceptualized by GDSS, is not merely a vehicle design, but a complete launch system, addressing design, manufacturing, payload integration, transfer and launch to provide low cost, flexibility and growth. The program emphasizes low cost access to space by using a modular family of vehicles, use of technology demonstration programs to reduce cost risks, and through the combination of high reliability and limited reusability. Figure 3-1 displays the GDSS ALS approach.

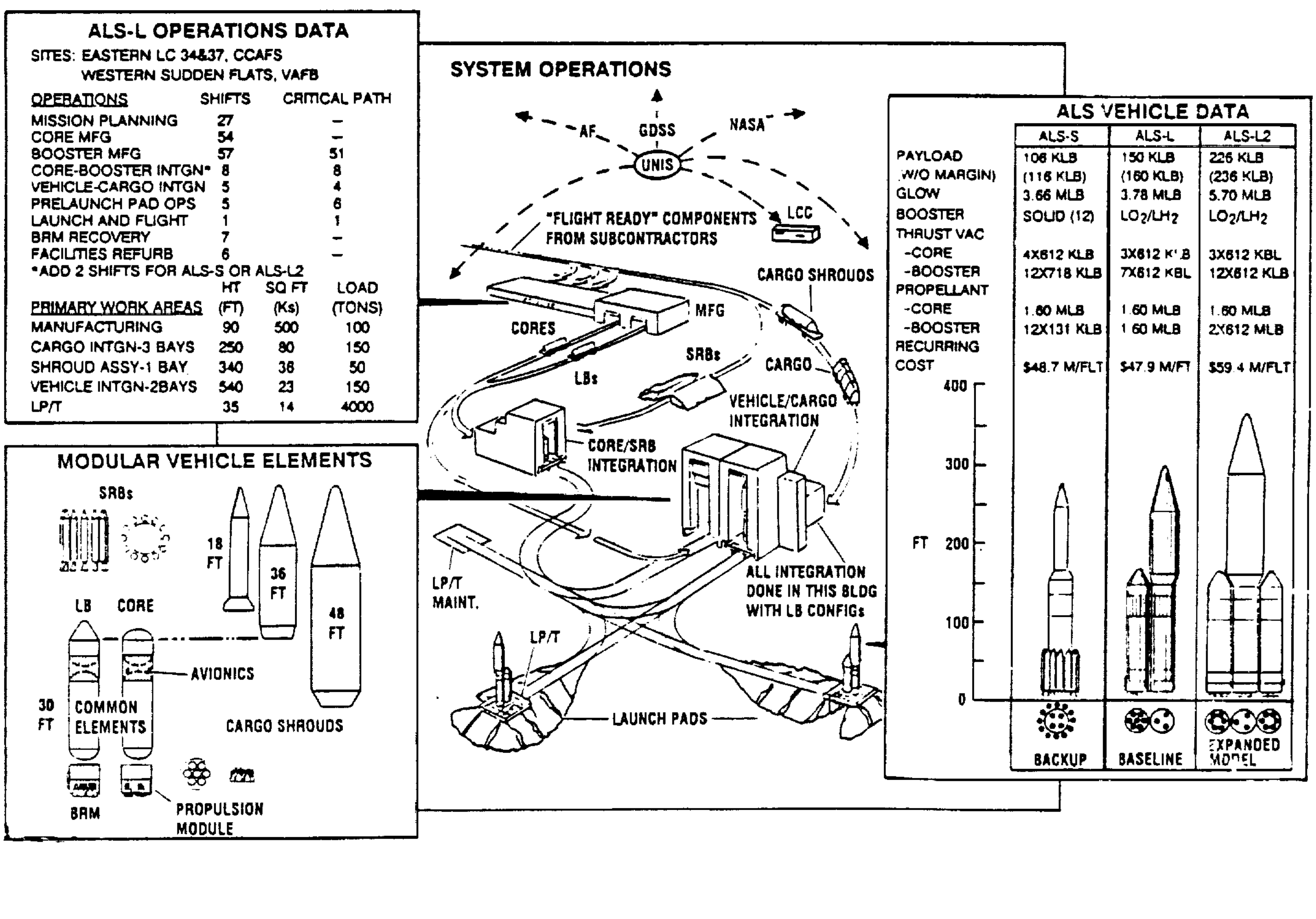
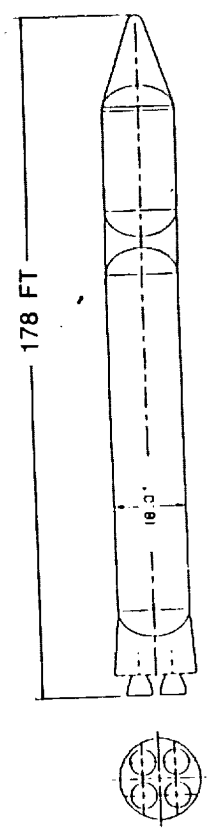


Figure 3-1. GD ALS Approach

The examination of possible LRB-to-ALS applications has produced results which suggest that there is a synergistic potential of joining the two programs via a common engine development, or possibly a common booster. Figure 3-2 compares the LRB and ALS booster systems, and shows that there are a number of similarities, including Isp range, vacuum thrust, mixture ratio, and fuel; leading to the possibility of a common engine for both ALS and LRB.

Section 3.0 further presents ALS/LRB requirements, ALS/LRB cost considerations, ALS/LRB performance capabilities, and a discussion of modifications necessary to integrate LRBs with the GDSS phase II proposal ALS configuration

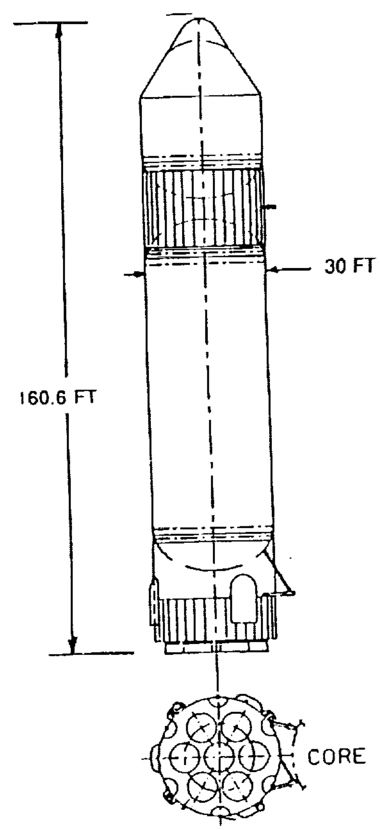


LO2/LH2 LRB

	LRB	ALS Booster
Propellants	LO2/LH2	LO2/LH2
Dry Weight (klb)	129	186
No. of Engines	4	7 *
Engine-out Capability**	1	1
Engine		
Thrust, vac NPL (sec)	558	612
Isp, vac NPL (sec)	411.4	429.4
Pc NPL (psia)	2250	2000
Mixture Ratio	6.0	6.0
Area Ratio	20:1	38.8
Throttleability	100% or 75%	None
Reliability (90% Confid.)	0.99	0.99

* common engine for Core & Booster

** with mission complete capability



ALS BOOSTER

Figure 3-2. LRB/ALS Booster Comparison

3.1 APPROACH

The basic approach used to investigate the applicability of LRBs to ALS is similar to the overall LRB alternate applications study approach.

The study began with the identification of the various feasible ways of using a LRB or LRB engine with the ALS. Initial focus was placed on using LO2/LH2 LRBs because all ALS contractors have selected this propellant combination; however the applicability of the other RP-1 fueled LRBs was investigated to a limited extent, and results developed for these boosters appear in Section 6.0. The option tree of Figure 3.1-1 shows the many approaches that were considered. These options include the use of the complete LRB or just portions, such as engines or avionics. At this point it is possible to optimize the ALS core for the LRBs, or perhaps the LRB can be somewhat modified to best suit a favored ALS design, (i.e., making the LRBs partially recoverable). Also, variations in the number of LRBs used is possible as well.

After feasible options were identified, ALS requirements were assimilated. These requirements were obtained by reviewing ALS phase I results. Requirements were then analyzed on a top level to determine those which should be applied to the LRB.

Using the list of available LRB/ALS application options, analyses were then conducted to determine which option(s) provided the best synergism.

Upon completion of the comparisons and analyses, overall results were evaluated and conclusions formulated. Since the ALS program is still in a state of development, it was difficult to select a preferred method or approach to using LRBs for the ALS.

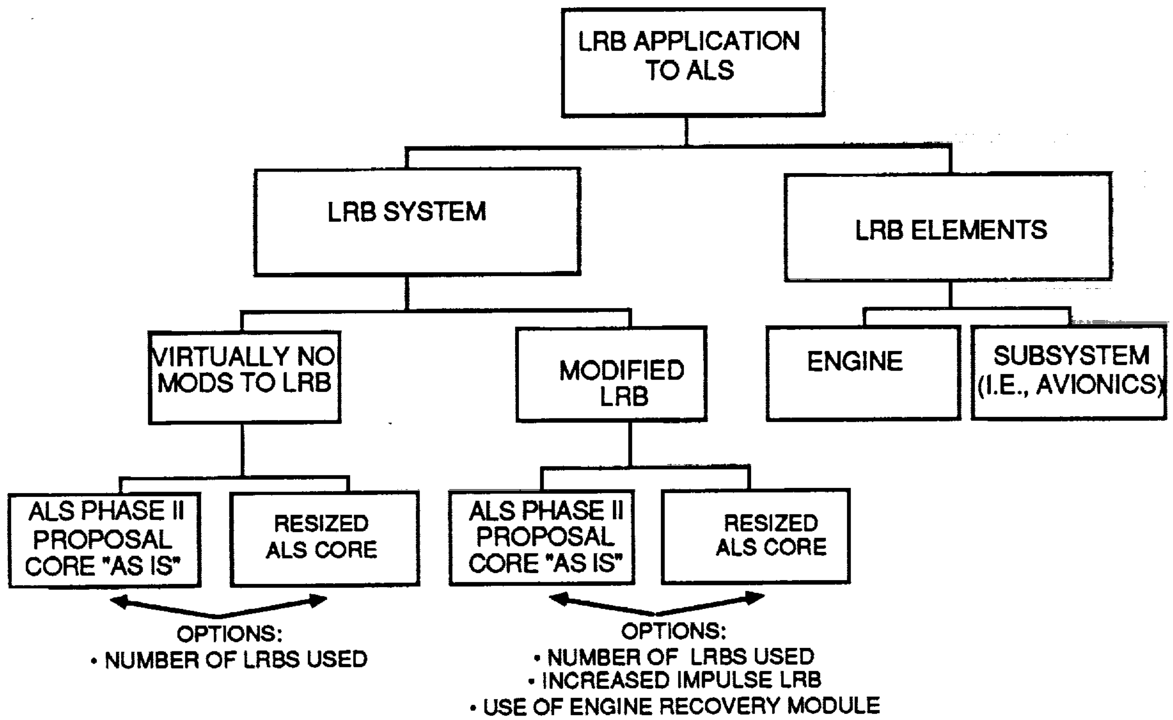


Figure 3.1-1. LRB Application to ALS Options Tree

3.2 REQUIREMENTS

As the ALS program is entering Phase II study, several key Phase I requirements have evolved. However, requirements which reflect the underlying principal of the ALS philosophy to minimize costs such as "simplification and standardization of payload interfaces" have not.[1] [2] Table 3.2-1 highlights the key ALS requirements. It should be noted for Phase II that ALS is to cover a wide range of payloads (80-120 Klbs to LEO due east, with 1-50 Klbs to be examined as a special study). This wide payload range suggests a vehicle of modular approach; i.e., a core which can utilize varying numbers of boosters to meet different orbital payload requirements. In this sense, the use LRBs offers such modular capabilities.

Table 3.2-1. ALS Requirements Summary

Requirement Category	During Phase I	Update for Phase II
Payload		
- Normal	100 - 150 Klbs Due East	80 - 120 Klbs (Due East) (Special Study for 1 - 50 Klbs)
- Expanded	At least 160 Klbs Polar	Same
Rate Capability		
- Normal	20 - 30 Flts/Yr	10 Flts/yr (Capability to 20 Flts/Yr)
- Expanded	40 - 50 Flts/Yr (Max)	As Necessary To Deliver 5 Mlbs/Yr
Operability		
- Availability	At Least .9	Same
- Resiliency	At Least 35% of Surge	Same
Payload Interfaces	Minimum Services Simplification & Standardization	Same
Operating Cost	$300/LB at 25 Flts/Yr	$300/LB at 10 Flts/Yr
Cargo Shroud		
- Nominal	33 ft dia x 80 ft long	Same
- Expanded	43 ft dia x 125 ft long	Same
Ascent Reliability	.98 Probability After Launch	Same (.99 Design Statistical Reliability)
Physical Security	Appropriate For Payload Classification And Threat	Same

As the LRBs have been primarily designed to meet STS requirements, many of which are constraining (i.e., a maximum diameter of 18 feet), it has not entirely possible to adopt the overall ALS design philosophy. The challenge to the LRB program for Phase B is to reconsider and incorporate many of the ALS design approaches, as highlighted below:

- Optimize system for low cost and high reliability
- Operations/production drive vehicle design
- Trade weight for improvement in cost and reliability
- Modular approach for flexibility, robustness, cost reduction and technology insertion
- Focus technology demonstrations on high-payoff areas
- Simplify design to allow multiple sourcing/low labor rates

A requirements analysis was performed to identify trajectory/sizing constraints for performance analyses; these are listed in Table 3.2-2. The ALS orbit of 80 by 150 nmi, 28.5 degree inclination was used. The assumed LRB engine out criteria which was used to meet the ALS engine out requirements appears at the bottom of Table 3.2-2.

Table 3.2-2. ALS with LRBs, Trajectory Sizing Constraints

#	Item	Value	Rationale
1)	T/W @ Liftoff	(Not Constrained)	
2)	T/W @ Separation	(Not Constrained)	
3)	Max g's During Flight	(Not Constrained)	
4)	Max Q (PSF)	850	Aero Loads (To Be Verified)
5)	Max Qα, Qβ (PSF•DEG)	±1600	Aero Loads (To Be Verified)
6)	Max Qv (PSF•FT/SEC)		
	i. After Fairing Sep	±58	Avoid Excessive Payload Heating
7)	Orbit Parameters		
	i. Perigee (n.mi)	80	
	ii. Apogee (n.mi)	150	LEO
	iii. Inclination (deg)	28.5 (90)	Due East Launch (Polar Launch)
8)	Booster/Stage Disposal		
	i. Entry Point	(TBD)	
	ii. Sep Altitude	(TBD)	
	iii. Sep Dwn Range	(TBD)	
9)	Max L/D		N/A
10)	NPL, EPL, Isp & Throttle Range	(Engine Specific)	
11)	Payload Weight	(Variable/Situation Specific)	
12)	Configuration Compatibility	"Attachment Of Boosters/Stages Must Make Sense Structurally"	
13)	Payload Fairing Size(s)		
	i. Nominal Model (ALS-L)	33 ft dia x 80 ft long	
	ii. Expaned Model (ALS-L2)	43 ft dia x 125 ft long	
14)	No. Engines-out @ L/O (And Still Make Mission)		
	i. If 1 or 2 LRBs Used	1 Only (Core Or Booster)	
	ii. If > 2 LRBs Used	2 Total (1 each for 2 LRBs, or 1 LRB + 1 Core)	

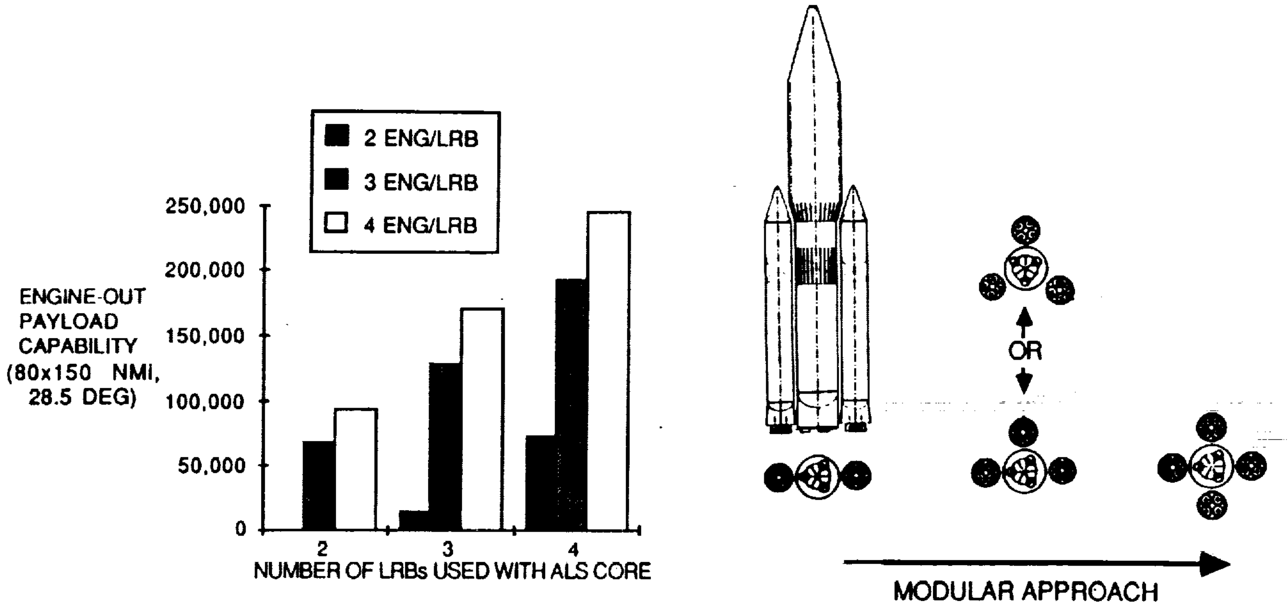
3.3 ANALYSES

The Task 3 portion of the LRB/ALS study consisted of analyses and comparisons of the many possible ways to apply a LRB to the Advanced Launch System. These comparisons and analyses included evaluating system performance vs. number of LRB "boosters" used, examining the possibility of resizing the ALS core for use with LRBs and assessing LRB cost effects due to increased rates of production.

3.3.1 LRB'S WITH THE BASELINE GDSS PHASE II PROPOSAL ALS CORE

To examine the attractiveness of using LRBs with minimum modification to the ALS concept (as proposed by GD for Phase II study), performance analyses were conducted and necessary modifications for LRB/ALS integration were identified. Cognizant of ALS requirements to provide varying payload capability and recognizing the ALS philosophy of modular design, the payload capabilities of the ALS core with varying numbers of LO2/LH2 LRBs (2 to 4) were determined (Figure 3.3-1); the capabilities fall in the range of 50K to 250K lbs to LEO with engine out. Also, varying the number of LRB engines was considered. By using 3 LRBs with 2 engines each it is possible to reach the lower payload requirements of 1-50 Klbs to LEO. These performance analyses were conducted with the program FASTPASS, which is a program used to analyze trajectories and optimize payloads within a set of given constraints. (Refer to Section 8.1.3 of the LRB Final Report (Vol.II.) for further definition of FASTPASS).

In terms of LRB/ALS integration, some minor modifications are required. For instance, new structural attachments are required for attachment in the LRB aft skirt area, and for the forward attachments in the LRB intertank area. At present, the ALS design uses separation impulse developed by the pyrotechnic attachment struts, thus the LRB separation motors are not necessary. Some aerodynamic interference problems may also exist between the ALS fairing and the LRB nose cone, prompting the possibility of slight ALS core resize to 28ft in diameter (a smaller diameter lengthens the core thereby increasing booster clearances); refer to Figure 3.3-2.



Engine-out Criteria Assumed:

- For 2 LRBs Used -- 1 Engine Out (Core Or LRB)
- For 3 & 4 LRBs Used -- 2 Engines Out Total (Core + 1 LRB Engine, Or 1 LRB Engine-out On 2 Different LRBs)
- Further Refinement Of Engine-out Requirements Required

Figure 3.3-1 ALS Core with LRBs (LEO Performance)

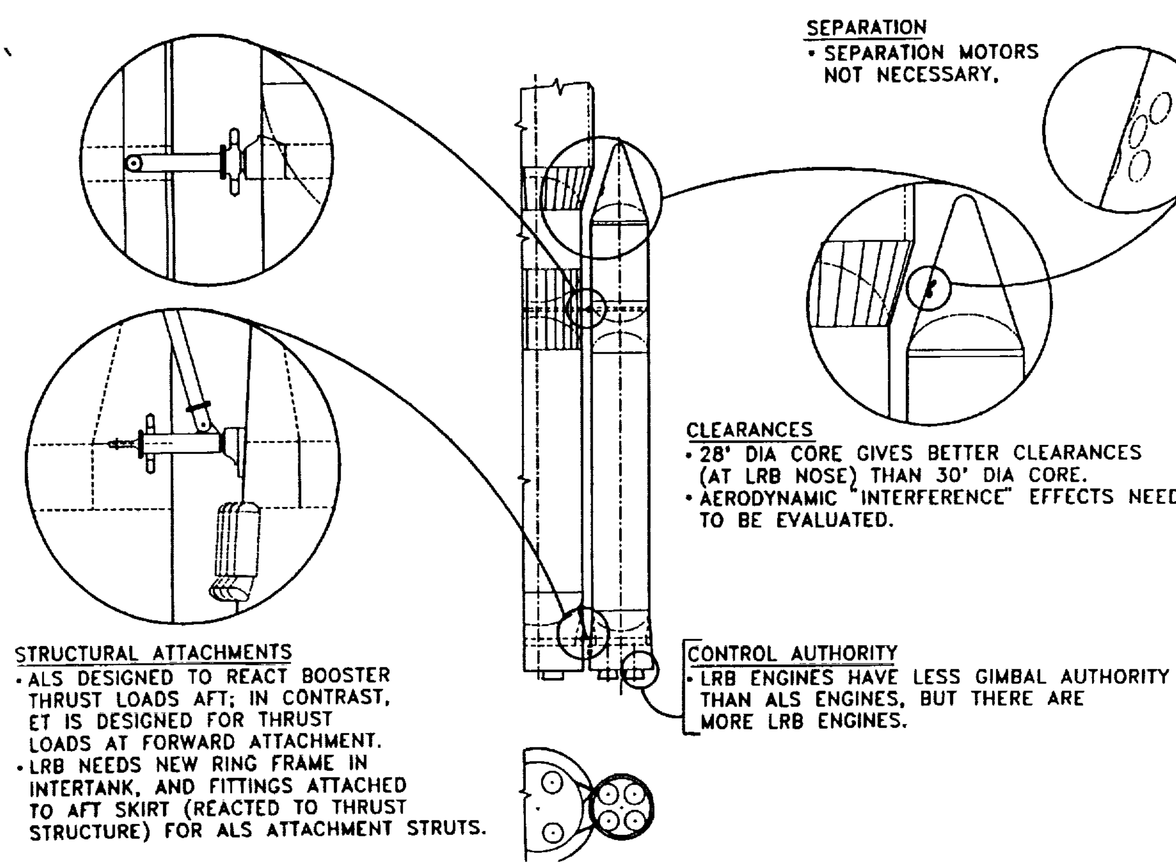
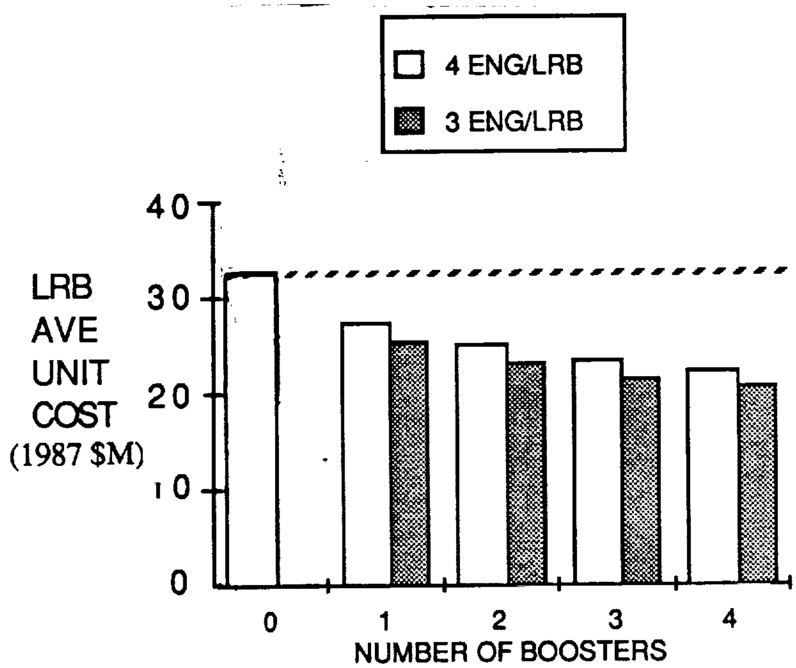


Figure 3.3-2. LRB Integration with ALS

Cost analyses were performed using the LRB cost model with consideration given to higher production rates which result from building LRBs in different quantities on the ALS program at the same time with the normal production run for STS. Average unit cost (AUC) reductions for the LO2/LH2 LRB when used as a booster for ALS are shown in Figure 3.3-3. It should be noted that the Phase I ALS nominal mission model was used for costing purposes, however the cost reduction trends computed (which are as much as 30% when 4 LRBs are used) are indicative of benefits gained by using LRBs on multiple programs.

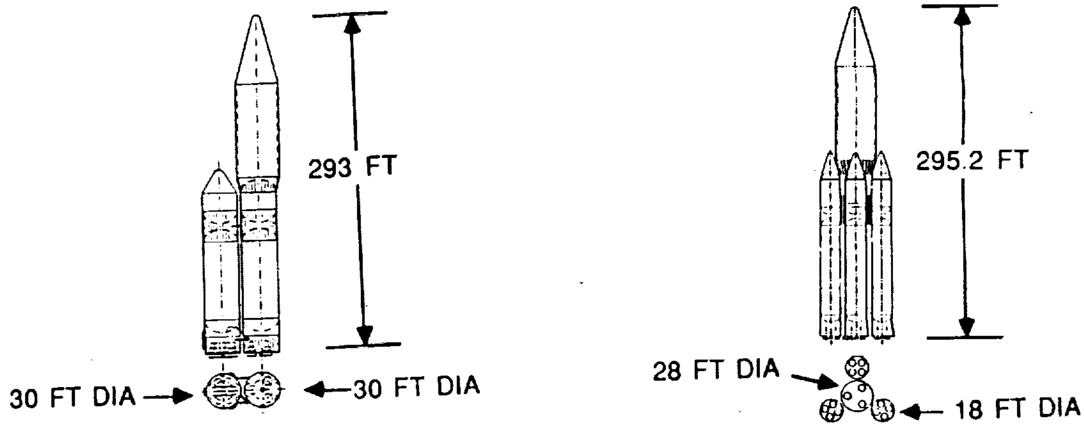


* Excludes Contractor Fee, Government Support And Contingency

Figure 3.3-3. LRB/ALS Cost Sharing Benefits

3.3.2 LRB'S WITH A RESIZED ALS CORE

Consideration was given to resizing the ALS core [3] to meet its design goal of 160 Klbs (of which 10Klbs is unallocated margin) to a 80 x 150 nmi orbit, using LO2/LH2 STS LRBs and LRB engines on the core. Three engines were used on the core vehicle and it was determined that 3 LRB 's most efficiently (i.e., smallest changes to the core) deliver the required payload (see Figure 3.3-4). For better LRB clearances, the core diameter was decreased to 28ft, otherwise many system elements (i.e., the fairing) were not modified. Of interest is the fact that the core resizing required is minor; the vehicle grows in length by 3ft, but has an inert weight reduction of 1,000 lbs. Because the LRBs considered here were fully expendable, engines used on the boosters were not recovered for reuse on the core.



	REFERENCE (ALS ϕII PROPOSAL)	WITH LRBs*(LRB ENGINES ON CORE)
LEO PAYLOAD (80x150 nml,28.5°)	150 K Lbs (160 K Lbs W/O MARGIN)	150 K Lbs (16O K Lb W/O MARGIN)
TOTAL GLOW	3.86 M Lb	4.179 M Lb
BLOW	1.87 M Lb	3 x 766 K Lb
INERT WEIGHT:		
CORE	177 K Lb	176 K Lb
BOOSTER	210 K Lb	3 x 108 K Lb
THRUST (VAC):		
CORE	3 x 612 K Lb	3 x 508 K Lb
PER BOOSTER	7 x 612 K Lb	4 x 508 K Lb
ENGINE-OUT CAPABILITY	CORE AND/OR BOOSTER	CORE + 1 BOOSTER, AND/OR 1 ENGINE ON EACH OF 2 BOOSTERS

* Not the final LO2/LH2 LRB configuration

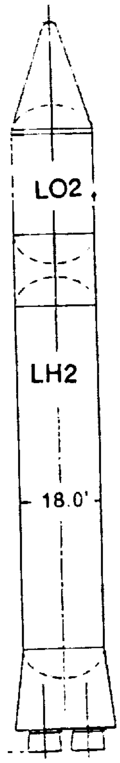
Figure 3.3-4. LRB with a Modified ALS Core

3.3-3 LRB SIZED USING A THROTTLEABLE MODIFIED ALS ENGINE

Understanding that an LRB might possibly be developed for the shuttle which would use ALS engines, a quick sizing of such an LRB for STS was undertaken. The engine parameters used are shown on Figure 3.3-5. The primary scar required to the ALS engine for use with STS LRB would be to add step throttling. Our results tend to indicate that the LRB using ALS engines would be only slightly larger than a LRB using a more STS optimized engine. This sizing was based on now outdated constraints, but the trend is still considered valid. Most likely, the ALS and LRB programs can use a common engine (possibly the STME currently being studied) which can be designed to reach a compromise between the similar engine needs of the two programs.

3.3-4 LRB (FOR STS AND ALS) WITH ENGINE RECOVERY MODULE

Because the current GDSS ALS design approach utilizes a booster recovery module and limited engine reuse,[4] consideration was given to developing a LRB design which would incorporate this approach as well.



		DELTA FROM LRB USING ENGINES SIZED TO STS REQUIREMENTS
DRY WEIGHT		+ 3%
BLOW		- 3%
NO. ENGINES		SAME
ENGINE-OUT CAPABILITY		SAME
ALS ENGINE PARAMETERS:		
THRUST VAC	612K	
Isp (VAC)	429.4	
Pc	2000 PSIA	
Ar	38.8	
STEP THROTTLE		
MAX	100%	
MIN	75%	

Figure 3.3-5. 18' Diameter LO2/LH2 LRB Using Modified ALS Engine

The ALS limited engine reuse and booster recovery approach is shown in Figure 3.3-6, which illustrates a typical ALS mission. The limited engine reuse is based on the inherent life of an expendable engine. In order to demonstrate that an engine meets all design requirements, qualification testing usually exceeds 3000 seconds for the engine. This time duration represents 4 of 5 flights. The ALS approach is to utilize this feature, and recover the booster engines after each flight using a booster recovery module and splash down in the ocean. Recovered engines are cleaned and refurbished after recovery, then reflown on the booster or core. Total reflights are limited to 4, with the 4th flight occurring on the expendable core. This approach greatly reduces the quantity of engines purchased.

A typical STS flight profile using LRBs which employ a booster recovery module is shown in Figure 3.3-7. A booster recovery module developed for this mission is shown in Figure 3.3-8. Key features of this recovery module are: 1) simple separation mechanisms (quick disconnects and linear shaped charges to cut the aft skirt); 2) parachutes and attenuation bags to absorb the water impact loads; and 3) additional LRB avionics for performing the functions of sensing altitude, sequencing events, and providing a signal beacon. The LRB recovery module is retrieved from the ocean after splash down at about 20 ft/s, then the engines are readied for reuse.

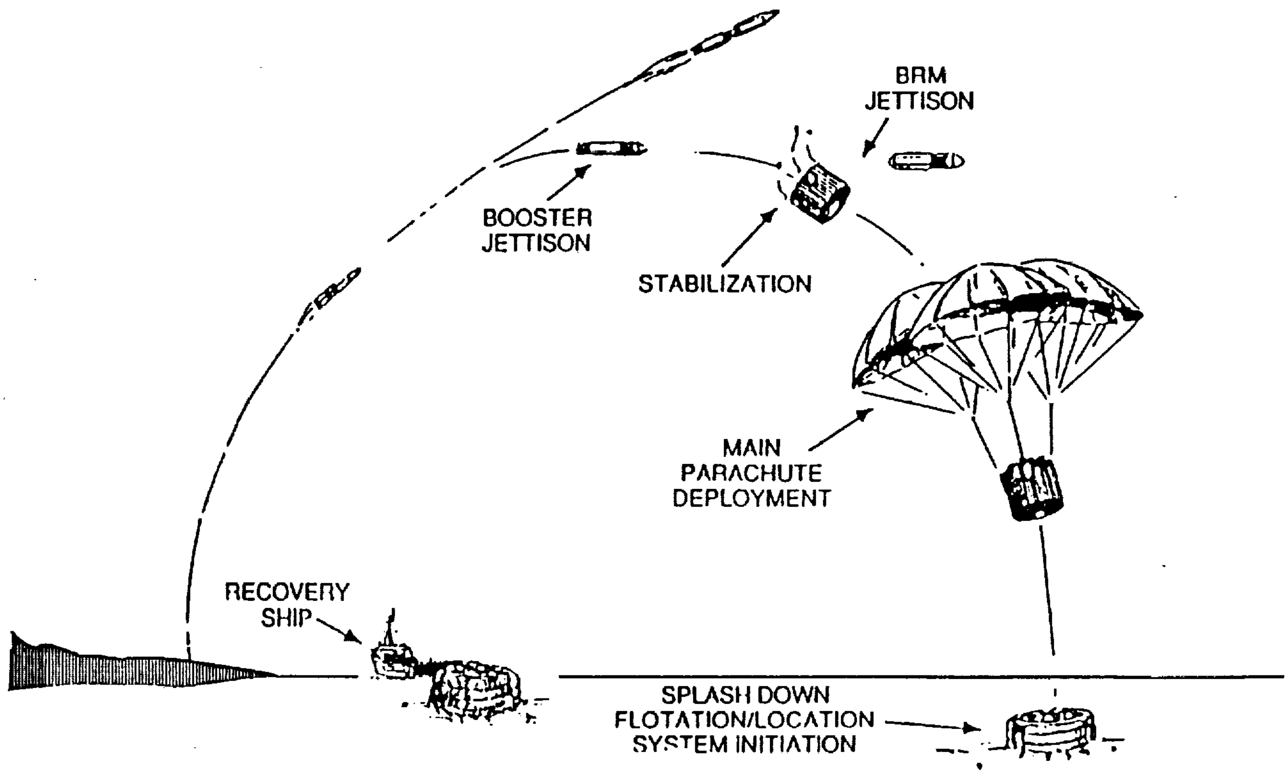


Figure 3.3-6. GDSS ALS Booster Recovery Concept

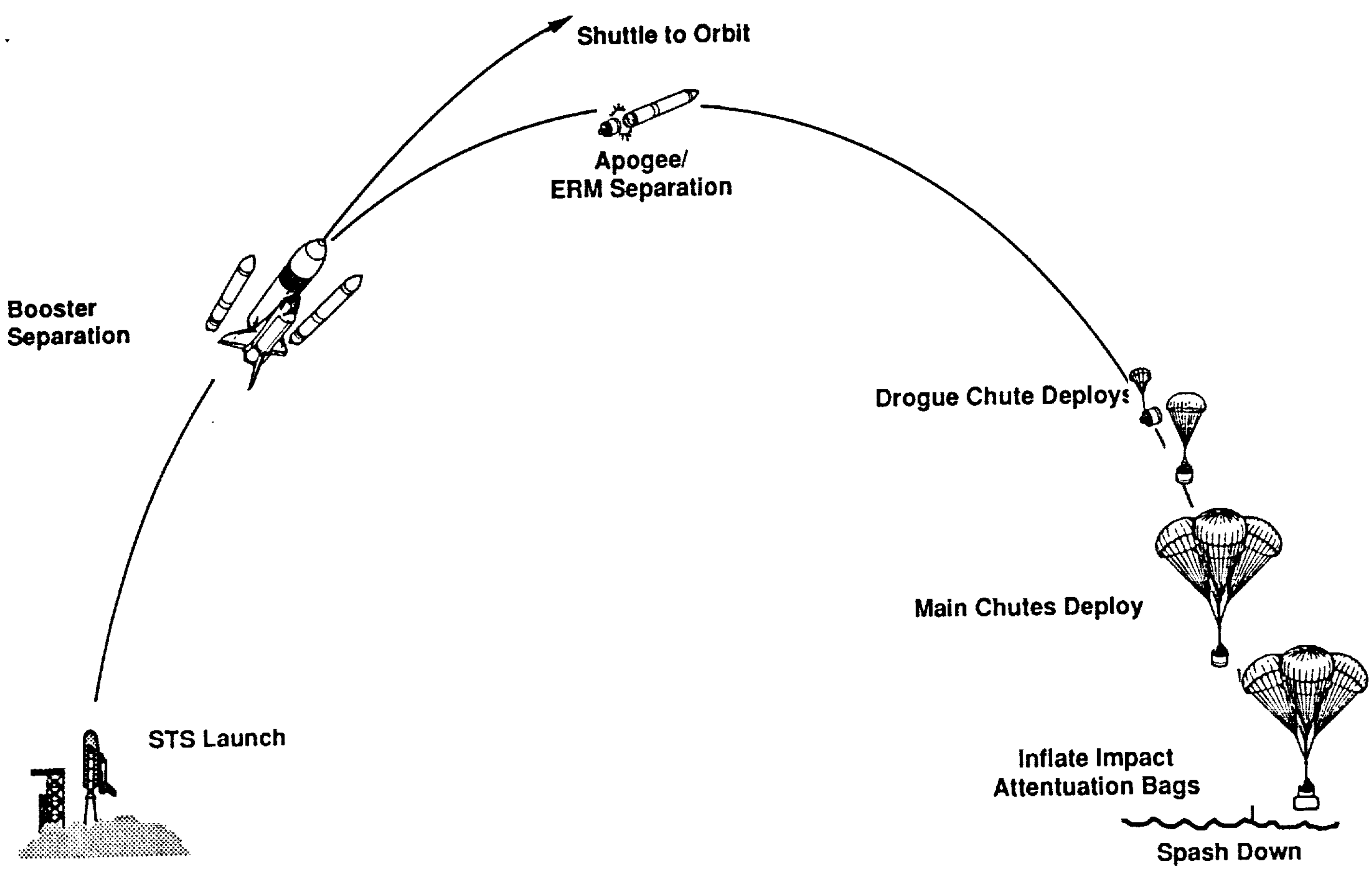


Figure 3.3-7. STS Booster Engine Recovery Module Flight Sequence

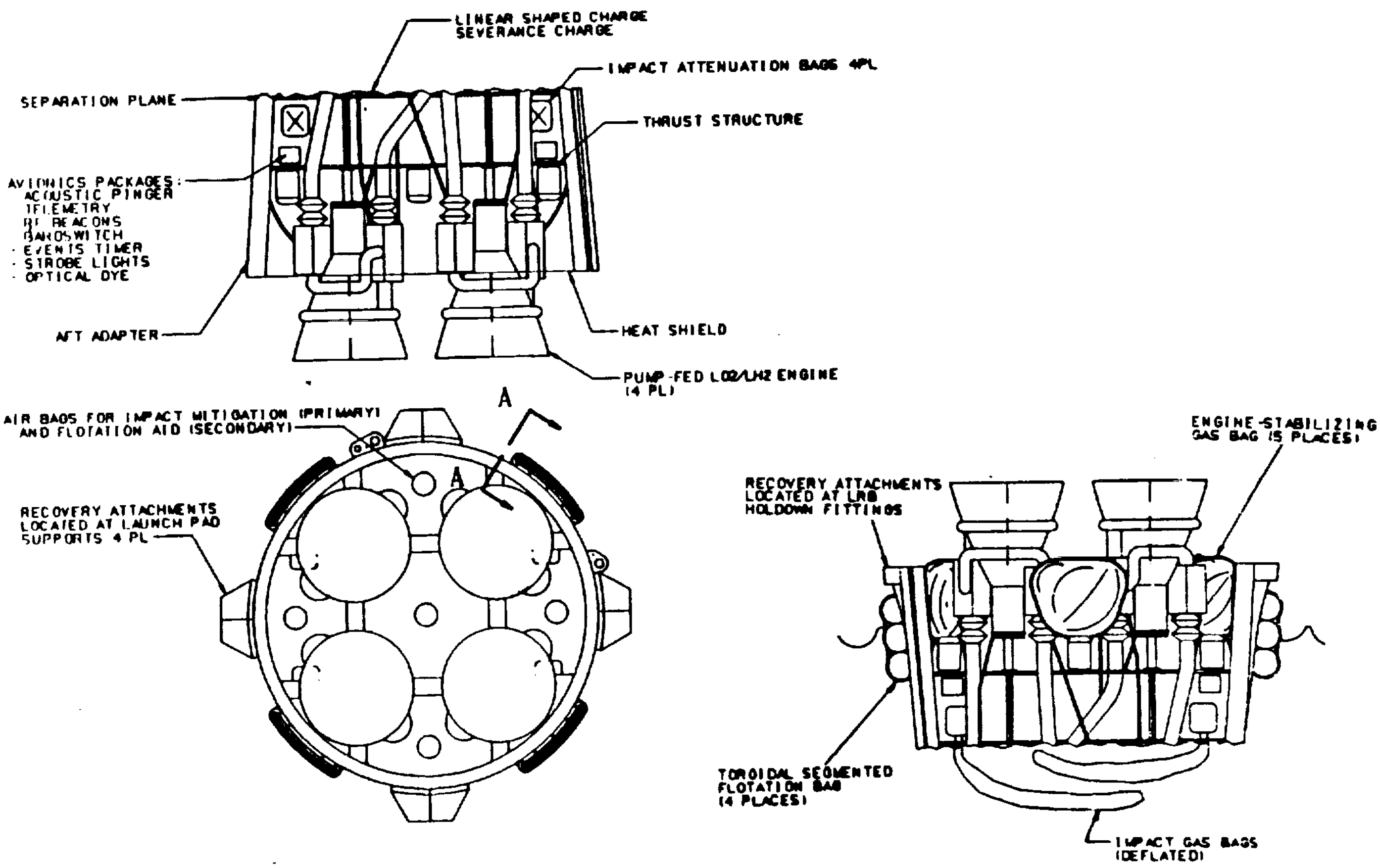
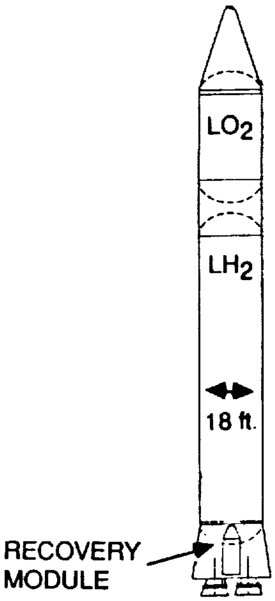


Figure 3.3-8. LRB Engine Recovery Module Configuration

An LRB has been resized using this module, and is displayed in Figure 3.3-9. The resizing of the LRB is not excessive as the additional LRB recovery system weight is on the order of 6,000 lbs. The booster inert weight increases by approximately 9%. This sizing was based on now outdated constraints, but the trend is still considered valid. After having defined a engine recovery module for STS LRBs, performance analyses were performed to examine feasibility of using such an LRB for ALS. In general, the previous results shown in Figure 3.3-1 are applicable for using fully expendable, or recovery module LRBs as the total impulse (derived from shuttle requirements) are the same for each type of STS booster. In addition, the resizing of the ALS core needed to meet the 160 Klbs ALS baseline (phase I) requirement using LO2/LH2 LRBs with engine recovery modules is minor (i.e., the core inert weight grows 3Klbs and the length increases about 2.3ft); see Figure 3.3-10.

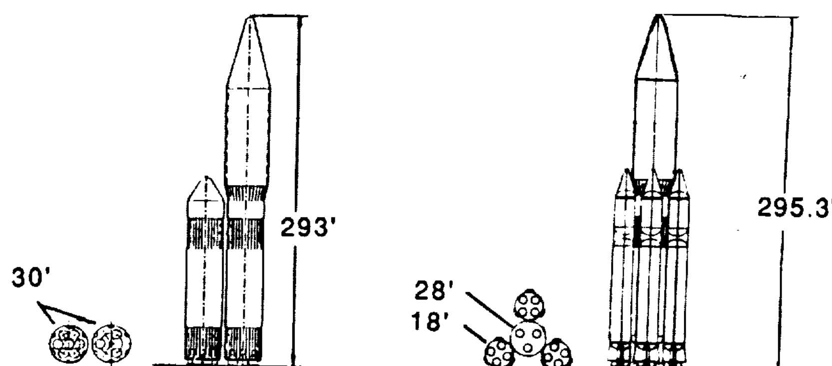


BOOSTER:	DELTA FROM FULLY EXPENDABLE LRB
DRY WEIGHT	+ 9%
BLOW	+ 3%
RECOVERY SYSTEM WEIGHT	N/A
NO. ENGINES	SAME
ENGINE-OUT CAPABILITY	SAME
ENGINE PARAMETERS (NPL)	
THRUST (VAC)	+ 1 %
Isp (VAC)	SAME
THROTTLE RANGE	SAME
TVC CAPABILITY	SAME
TANK MATERIAL	SAME
TANK CONSTRUCTION	SAME

RECOVERY SYSTEM:

- ENGINES HAVE LIMITED REUSE (4 FLTS)
- SHAPED CHARGES USED TO SEVERE FEEDLINES, STRUCTURE
- IMPACT IN ATLANTIC OCEAN AT ~ 20 FT/SEC USING IMPACT ATTENUATION BAGS AND PARACHUTES
- RECOVERY SYSTEM INCLUDES:
  - PARACHUTES (DROUGE & MAIN)
  - FLOATATION EQUIPMENT
  - RECOVER AVIONICS (RF BEACON, BAROSWITCH, ETC.)
  - SEPARATION CHARGES AND EQUIPMENT
  - ATTENUATION BAGS

Figure 3.3-9. LRB with Engine Recovery Module



	REFERENCE (ALS PROPOSAL)	LRB* ENGINES ON CORE
LEO PAYLOAD (80x150 nmi, 28.5 Deg)	150 KLb 160 KLb (W/O MARGIN)	150 KLb 160 KLb (W/O MARGIN)
TOTAL GLOW	3.86 M Lb	4.25 M Lb
BLOW	1.87 M Lb	3 x 791 K Lb
INERT WEIGHT:		
CORE	177 K Lb	180 K Lb
BOOSTER	210 K Lb	3 x 118 K Lb
THRUST (VAC):		
CORE	3 x 612 K Lb	3 x 515 K Lb
BOOSTER (NPL)	7 x 612 K Lb	4 x 515 K Lb
ENGINE-OUT CAPABILITY	CORE AND/OR BOOSTER	CORE + 1 BOOSTER, AND/OR 1 ENGINE ON EACH OF 2 BOOSTERS

*Not the final LO2/LH2 LRB configuration

Figure 3.3-10. Resized ALS Core with ERM LRBs

In terms of evaluating the economics of using LRBs that employ limited engine reuse and recovery modules, analyses were conducted using the LRB cost model (described in Vol. III of the LRB Final Report) with consideration given to additional DDT&E expenditures on:

- Engine modifications, such as special platings for salt water immersion
- The recovery system
- Recovery facilities

Additional production expenditures for the recovery system, structural separation systems, and engine additions (ie., platings) were also included. The cost results were normalized to a "utilization rate". The utilization rate is defined as the flight rate (using 2 LRBs each flight) for a given 10 year mission model with a ramp-up to full production rate in 3 years. Because the LRB engines are such large contributors to the overall LO2/LH2 LRB costs (see Figure 3.3-11), substantial savings (as shown in Figure 3.3-12) can be incurred by using the limited engine reuse approach. For example, if the combined launches of the Shuttle and ALS require a utilization rate of 26 engine recovery module version LRBs (14 STS flts/yr, plus 12 ALS flts/yr) the reduction in LRB average unit cost from a fully expendable LRB for STS only is on the order of 30%.

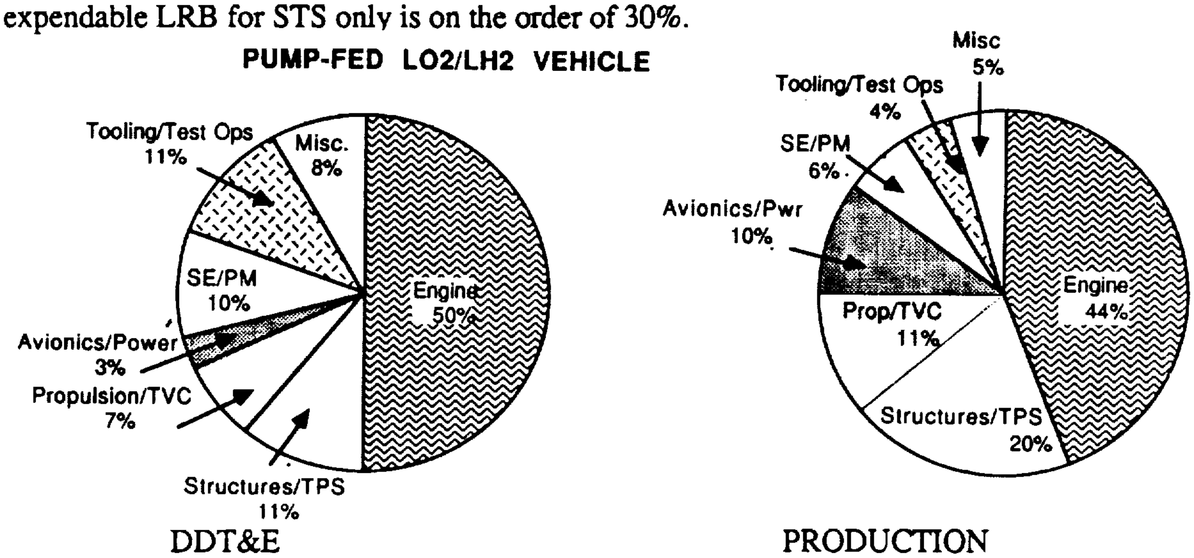


Figure 3.3-11. Engines are a Major Cost Contributor

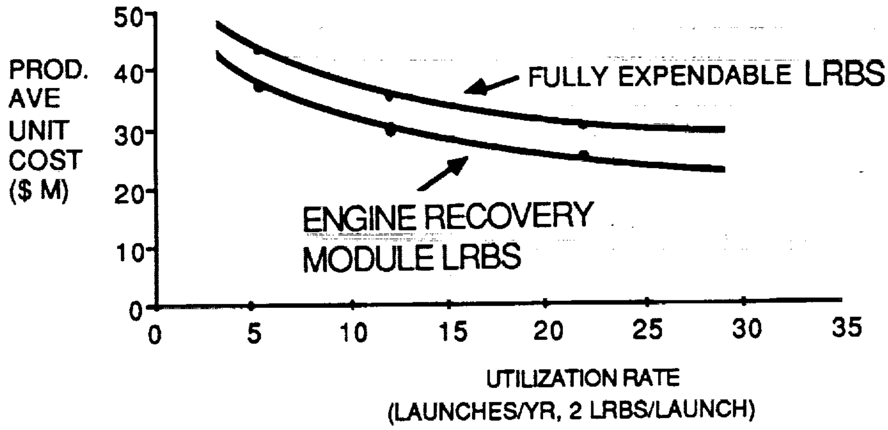


Figure 3.3-12. Potential Savings of Limited Engine reuse Approach

3.4 LRB DEVELOPMENT FUNDING CONSIDERATIONS

If the ALS and LRB programs are linked via a common engine or a common booster, then funding responsibilities become an issue. There are several approaches which might be adopted to fund the LRB development; see Figure 3.4-1. The amount of funding NASA needs to expend can be significantly reduced. For example, if the Air Force (under ALS auspices) develops the LRB 0.5 Mlb thrust LO2/LH2 engine, and NASA builds the rest of the LRB, NASA LRB DDT&E costs are reduced by about one billion dollars.

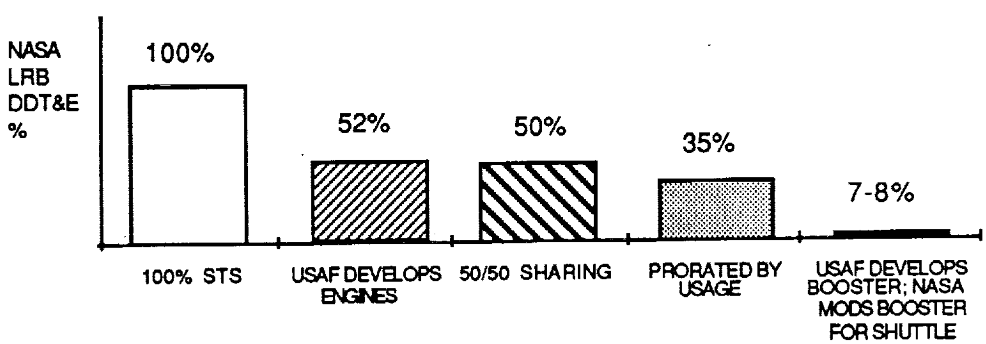


Figure 3.4-1. Review of Possible Cost Sharing Scenarios

3.5 EVALUATION OF RESULTS

This discussion is part of Section 6.0.

SECTION 4
LRB APPLICATION TO STANDALONE EXPENDABLE LAUNCH VEHICLES

This section describes the potential application of LRBs as either multi-stage or single stage standalone expendable launch vehicles. Initially the LO2/LH2 configuration was the only LRB concept used in this analysis but the RP-1 fuel boosters were later examined as well. Results for these RP-1 configurations are presented in Section 6.0.

4.1 APPROACH

The basic approach used to investigate the applicability of LRBs to standalone Expendable Launch Vehicles (ELVs) is similar to the overall LRB alternate applications study approach. Numerous options (approximately 15) were considered, and the material which follows provides performance/sizing data and qualitative analyses. LRB standalone ELV costs are discussed in Section 6.0.

The study began with the identification of the various feasible ways to form expendable launch vehicles using LRBs. Figure 4.1-1 shows the many options that were considered. These options are shown classified into payload ranges in Figure 4.1-2. They include using multiple or single stage standalone ELVs, or core-to-orbit vehicles. New upper stages were considered which used either existing or new engines, and for the core-to-orbit vehicles, various types of solid and liquid boosters were examined.

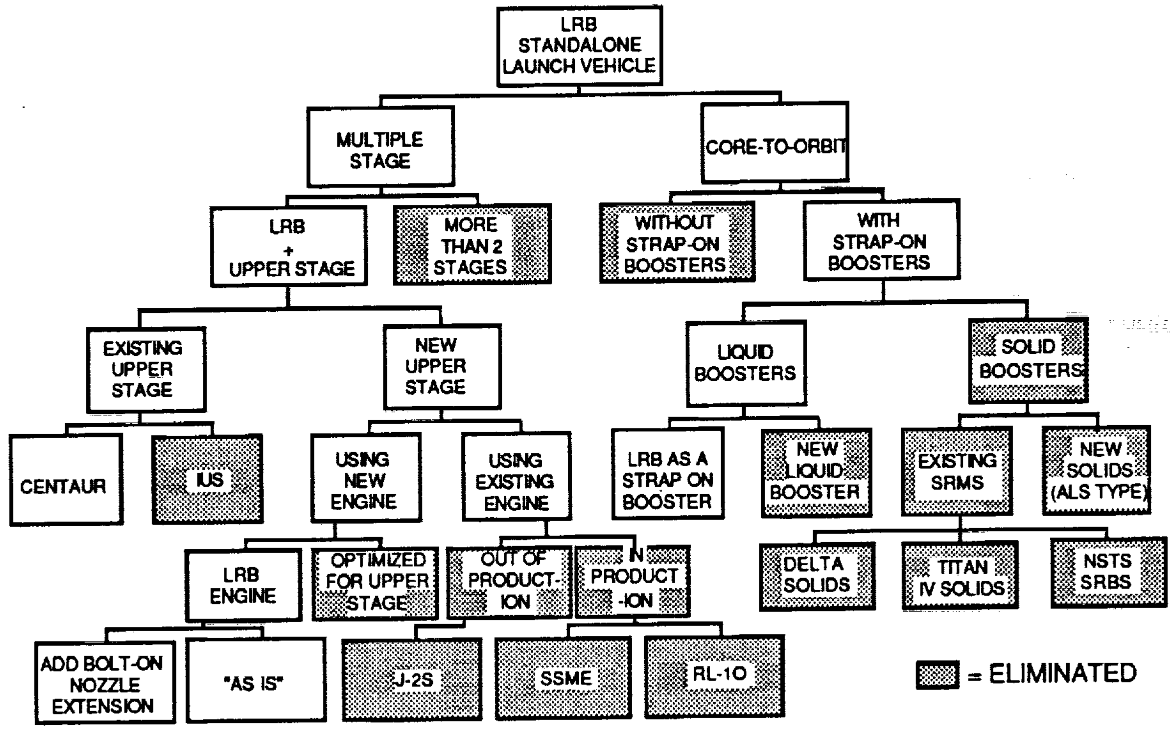
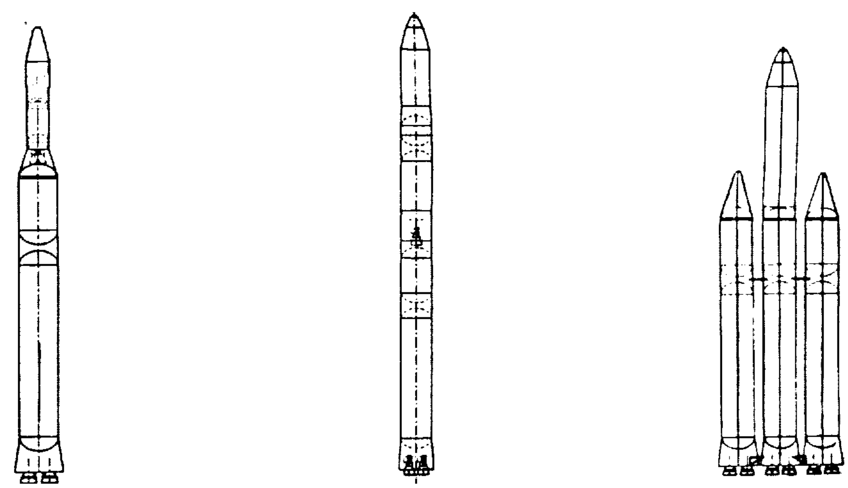


Figure 4.1-1. LRB Standalone Launch Vehicle Trade Study Tree



	ATLAS II CLASS	TITAN IV CLASS	HEAVY LIFT
PERFORMANCE:	10 - 30 K LBS (LEO) 5 - 15 K LBS (GTO)	40 - 50 K LBS (LEO)	40 - 100 K LBS (LEO)
VARIABLES:	• NUMBER OF ENGINES • VEHICLE LENGTH	• UPPER STAGE • NUMBER OF ENGINES • VEHICLE LENGTH • AUXILIARY PROPULSION	• NUMBER OF BOOSTERS

Figure 4.1-2. LRB Standalone Concepts Classified by Payload Range

After feasible options were identified, standalone ELV requirements were examined; however, at this point, requirements definition is largely incomplete.

Comparisons and analyses were then conducted to determine the attractiveness and economic benefits of various standalone launch vehicles utilizing LRBs. Analyses included determining vehicle performance capabilities as well as identifying necessary system modifications. Typical comparisons included solid vs. liquid boosters, new vs. existing engines, and new vs. existing upper stages.

Upon completion of the trades and analyses, overall results were evaluated and conclusions formulated. The preferred standalone launch vehicle was a core-to-orbit launch vehicle using a modified LRB core, and LRB "boosters". This vehicle is further defined in section 6.2. In general, existing engines and upper stages were favored over new designs to reduce DDT&E costs.

4.2 REQUIREMENTS

One of the most significant standalone LRB ELV requirements is the payload capability. As shown in Figure 4.2-1,[5] planned payload missions generally break out into two distinct weight classifications: 5-20 Klbs and 40-60 Klbs. This is representative of the current capabilities of launch vehicles today. We have selected the 40-60 Klb category as our requirement, as we anticipate less market competition in this range. However, a full architecture level analysis is needed to find the optimum payload range. Lower level requirements, such as engine-out are contingent upon further analyses. Table 4-1 lists the Trajectory/Sizing Constraints used for our standalone ELV designs. It should be noted that many of the values in the table (i.e. Max Q, Max G, etc.) were chosen to provide "realistic" scenarios and launch ascent loads. A reference orbit of 80 by 150 n.mi. due east (from KSC) was chosen as the LEO destination.

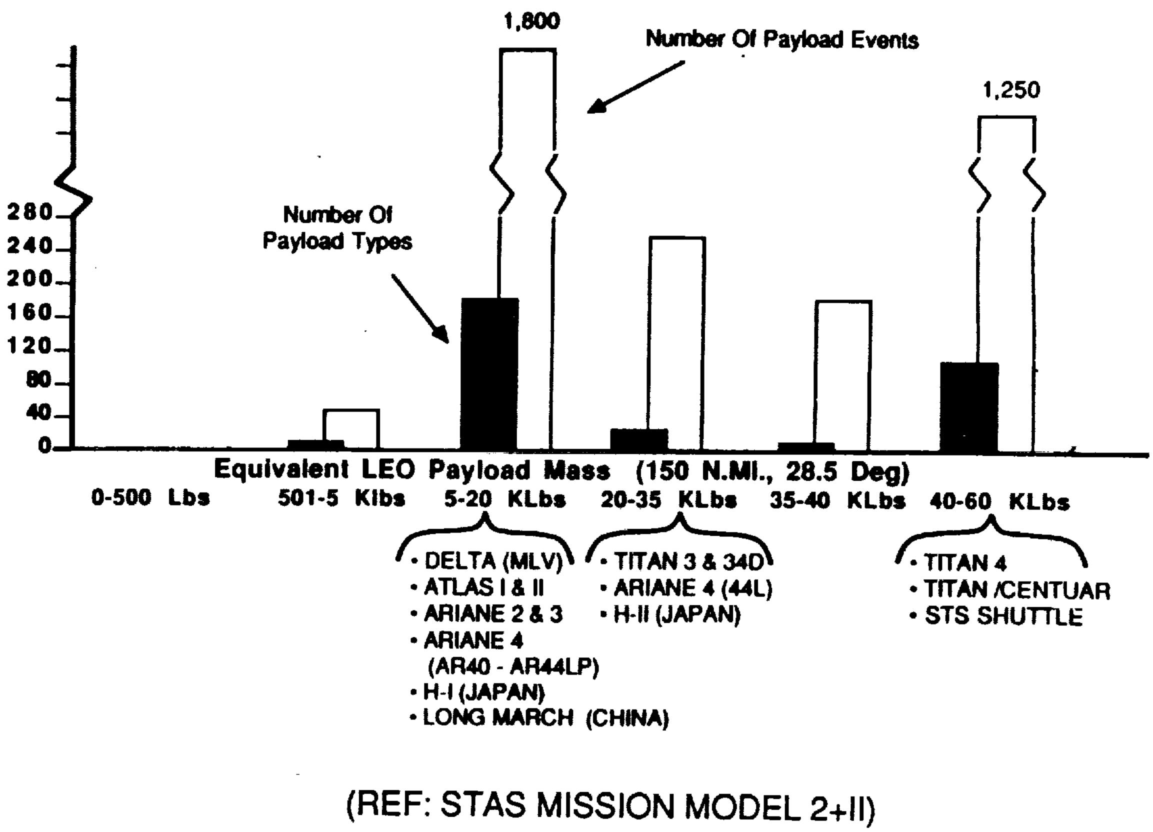


Figure 4.2-1. Nominal Mission Model Payload Breakout

Table 4.2-1. LRB Standalone ELV Trajectory/Sizing Constraints

#	Item	Value	Rationale
1)	T/W @ Liftoff	1.6	Lift-off Loads (To Be Verified)
2)	T/W @ Separation	(Not Constrained)	
3)	Max g's During Flight	5.5	Accomodate Payloads
4)	Max Q (PSF)	850	Aero Loads (To Be Verified)
5)	Max α (Deg)		
	i. High Q (No Winds)	0.0	Aero Loads (To Be Verified)
6)	Max Qv (PSF•FT/SEC)		
	i. After Fairing Sep	±58	Payload Heating (To Be Verified)
7)	Orbit Parameters		
	i. Perigee (n.mi)	80	
	ii. Apogee (n.mi)	150	LEO
	iii. Inclination (deg)	28.5	Due East Launch
8)	Booster/Stage Disposal		
	i. Entry Point	(TBD)	
	ii. Sep Altitude	(TBD)	
	iii. Sep Dwn Range	(TBD)	
9)	Max L/D	16:1	Loads, Controllability (To BeVerified)
10)	NPL, EPL, Isp & Throttle Range	(Engine Specific)	
11)	Payload Weight	(Variable/Situation Specific)	
12)	Configuration Compatibility	"Attachment Of Boosters/Stages Must Make Sense Structurally"	
13)	Payload Fairing Sizes	a) Titan IV b) Generic "Medium" (3.3 M Fairing) c) 36'x80'	

4.3 ANALYSES

Following are the major comparisons and analyses that were conducted to examine the applicability of LRBs as standalone ELVs. They include examining LRBs with existing upper stages, with new upper stages, and as core-to-orbit launch vehicles.

4.3.1 LRBS WITH EXISTING UPPER STAGES

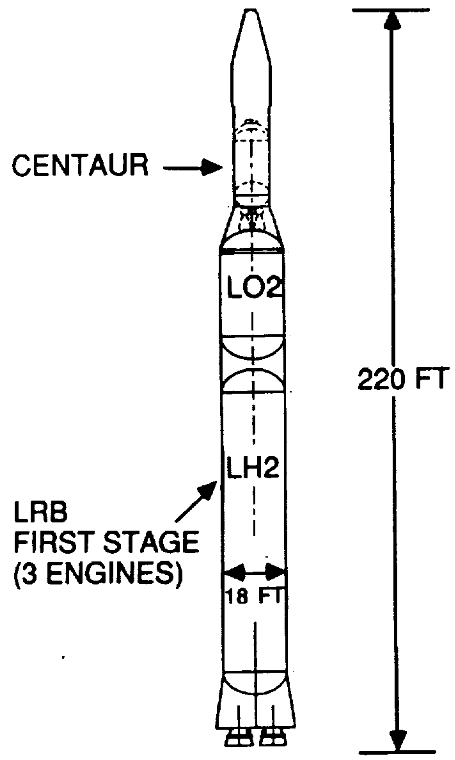
Because, the mass fraction of LRBs is relatively low (~.87), they cannot deliver any appreciable payload without using an additional upper stage. It was decided not to investigate the use of two or more upper stages in series on top of a LRB because DDT&E costs become exorbitant if more than one upper stage is employed.

Of the existing upper stages, options were rapidly screened to Centaur (Titan and Atlas versions) and the IUS. Other existing upper stages were not considered due to integration problems or low performance capabilities. The IUS was subsequently dropped in favor of the better performing Centaur configurations.

The major characteristics of a LRB/Centaur (Atlas Version Centaur) Launch Vehicle are shown in Figure 4.3-1. Of particular note is the payload capability, and the LRB modifications required.

The rationale behind removing an engine is as follows. Removing an engine allows a 27% increase in payload capability over the use of 4 engines, and a 15% increase over the use of 2 engines (in other words, three engines produces the best Δ velocity split); refer to Figure 4.3-2. To use three engines on the LRB requires some modification to the thrust structure and the booster propulsion system. Presently, it is planned to add additional thrust beams as shown in Figure 4.3-3. Some modification to engine feed lines is required to route the propellant to only three engines. The LRB/Centaur (Atlas version) performance to GTO is approximately twice the current Atlas/Centaur capability and represents a substantial payload increase (Note, the LEO performance value provided is a reference value only and does not represent the structural capability of the Centaur).

(LO2/LH2 LRB CONFIGURATION)



PAYLOAD:

• GTO (2 BURN)	12,100 LBS
• LEO (80 x 150 NMI, 28.5 DEG)	32,640 LBS *

VEHICLE:

• GLOW	844,500 LBS

TRAJECTORY:

• MAX Q	850 PSF
• MAX G	5.5 g'S
• STAGGING VELOCITY	17,000 FT/SEC
• TOTAL DETLA VELOCITY (LEO)	29,010 FT/SEC

MAJOR LRB MODIFICATIONS:
- REMOVE 1 ENGINE AND ATTENDANT TVC
- MODIFY THRUST STRUCTURE
- CHANGE FLIGHT SOFTWARE
- REMOVE NOSE CONE AND ADD INTERSTAGE ADAPTER

* PERFORMANCE REFERENCE VALUE ONLY. CURRENT CENTAUR IIA STRUCTURAL LIMIT IS ABOUT 10,000 LBS

Figure 4.3-1. LRB with Centaur IIA Upper Stage

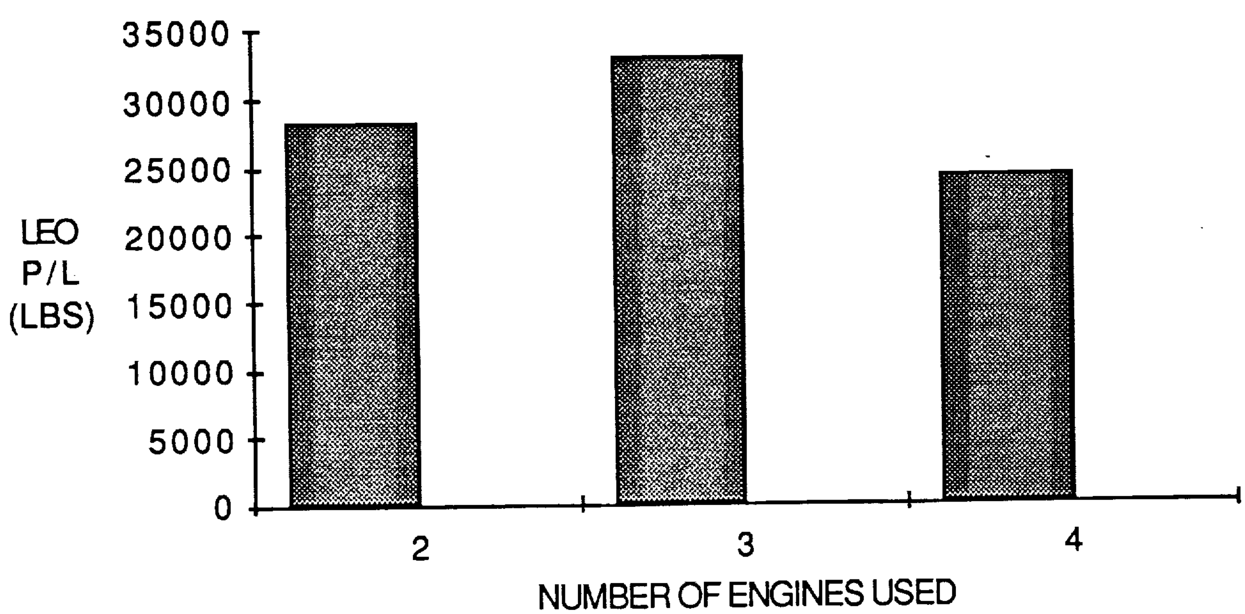


Figure 4.3-2. LRB Centaur IIA Payload Capabilities vs. Number of LRB Engines Used

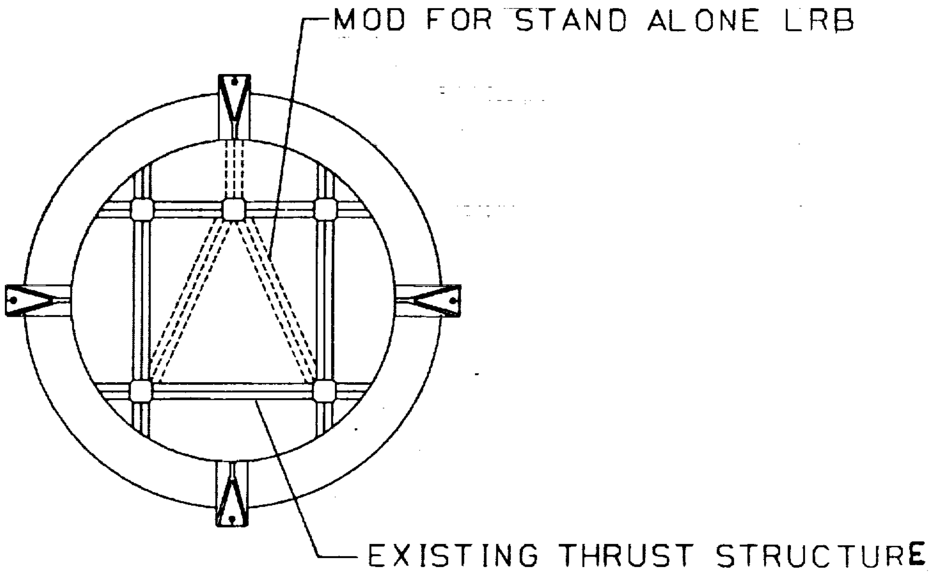
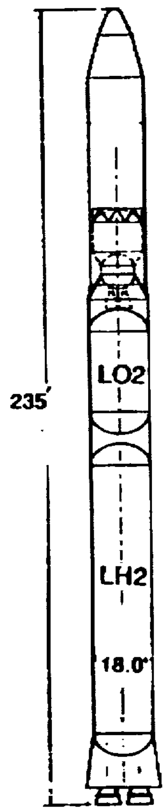


Figure 4.3-3. Adapting Thrust Structure to Hold 3 Instead of 4 Engines

A Centaur (Titan version) upper stage can also be used with LRBs to form a launch vehicle, as described in Figure 4.3-4. The performance for this launch vehicle is not as great as the LRB/Centaur IIA vehicle described previously, however, the payload volume is much greater. For our analyses it was decided that the Titan/IV payload fairing should be used with the Centaur (Titan version) LRB upperstage rather than a new fairing because: 1) many interfaces exist with this fairing, 2) a new fairing DDT&E cost would be considerable, and 3) it is unlikely that the Centaur (Titan version) could be used without a protective fairing around it during ascent. Because the Titan IV fairing[6] (Figure 4.3-5) is on the order of 14000 Lbs (rather than 4,500 lbs for the Atlas/Centaur fairing), the equivalent GTO payload capability of the LRB/Centaur (Titan version Centaur) is on the order of 8,000 lbs rather than 12,000 lbs for the LRB/Centaur (Atlas version), even though its propellant loading is 10,000 lbs more. Also, the Centaur (Titan version) is a more expensive upper stage than the Centaur (Atlas version) vehicle.



PERFORMANCE:
- GEOSTATIONARY ORBIT (3 BURN) 4,325 LB
- GTO (2 BURN) ~8,000 LBs

VEHICLE:
- GLOW 702,100 LBS

TRAJECTORY PARAMETERS:
- MAX Q 836 PSF
- MAX G 5.5 g's

MODIFICATIONS TO LRB:
- REMOVE 1 ENGINE AND ATTENDANT TVC
- MODIFY THRUST STRUCTURE
- CHANGE FLIGHT SOFTWARE
- REMOVE NOSE CONE AND ADD PAYLOAD FAIRING ADAPTER
- ADD INTERSTAGE ADAPTER
- REMOVE SEPARATION ROCKETS

Figure 4.3-4. LRB/Centaur (Titan Version Centaur)

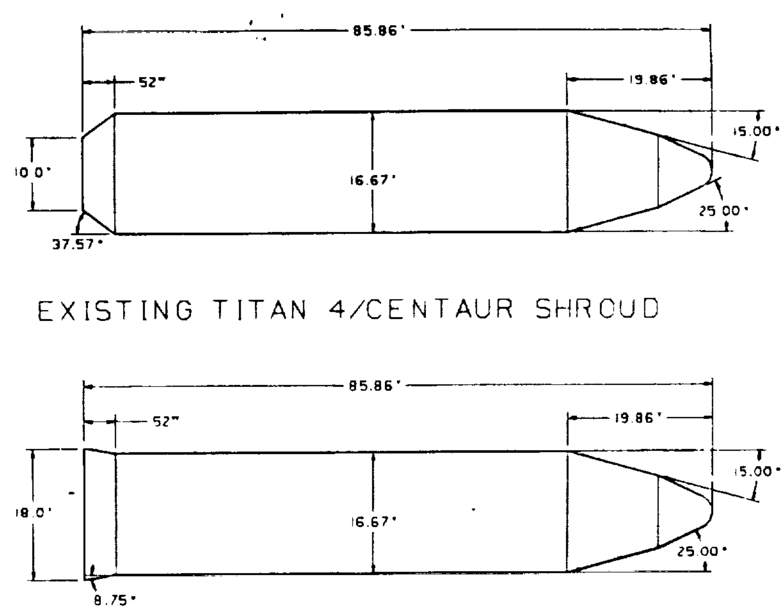


Figure 4.3-5. Modification for Titan IV/Centaur Shroud

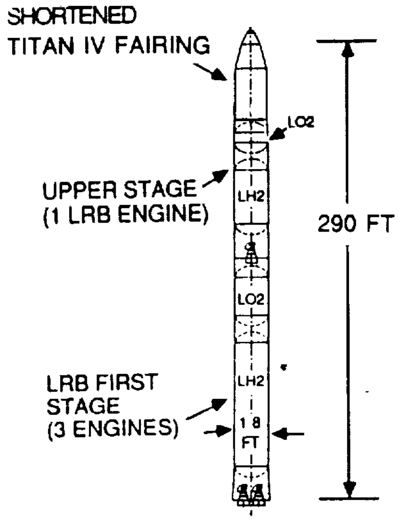
4.3.2 LRBs WITH NEW UPPER STAGES

In terms of creating a LRB launch vehicle with a new upper stage, several options exist. The primary option has to do with the upper stage engine and propellants used. LO2/LH2 is probably the only viable propellant for the upper stage because of the high Isp needed. New LO2/LH2 engines can be developed or existing engines applied. Existing engines include out of production and currently in production engines. The J2 is an example of an out of production existing engine, and it was felt that the costs associated with restarting production lines for the J2 would not offset the benefits gained by using an "existing" engine. The other "existing" engines, the SSME and RL10 were likewise dropped. The SSME was eliminated due to cost considerations and the RL10 was dropped due to the fact that 5 or 6 were needed to meet the 40-60 klbs payload range. This resulted in the choice of a new upper stage engine. A fully optimized upper stage engine was not selected due to high DDT&E costs, and thus it was decided to use an LRB engine for the upper stage. At this point, it has not been decided whether or not to add a bolt-on nozzle extension to the LRB engine to increase its area ratio, and therefore improve vacuum performance.

Further upper stage definition should center on optimizing the vehicle structure because LRB skin gauges and design approaches were used (this was done under the initial assumption that LRB tooling and tank fixtures could be used for the upper stage as well).

Using an LRB engine, a new upper stage can be added to an LRB to make a Titan IV class launch vehicle, as described in Figure 4.3-6. This vehicle uses a shortened Titan IV fairing, and delivers 40Klbs to LEO (80 x 150 n.mi, 28.5 deg inclination). Required modifications include removing one engine and adding additional GN&C avionics. The shortened fairing was used to keep the L/D ratio about 16:1 to avoid vehicle structural dynamics problems. Note that the guidance, navigation and control avionics for the upper stage are used for the entire vehicle.

(LO2/LH2 LRB CONFIGURATION)



PAYLOAD:
- LEO (80 x 150 NMI, 28.5 DEG) — 40,000 LBS

VEHICLE:
- GLOW — 1,260,370 LBS
- INERT WT

  UPPER STAGE — 53,051 LBS

TRAJECTORY:
- MAX Q — 413 PSF
- MAX G — 5.5 g'S
- STAGING VELOCITY — 4,903 FT/SEC
- TOTAL DETLA VELOCITY — 32,408 FT/SEC

MAJOR LRB MODIFICATIONS:
- REMOVE 1 ENGINE AND ATTENDANT TVC
- MODIFY THRUST STRUCTURE
- CHANGE FLIGHT SOFTWARE
- REMOVE NOSE CONE AND ADD INTERSTAGE ADAPTER

UPPER STAGE FEATURES:
- SINGLE LRB BOOSTER ENGINE
  (CONSIDERING USING NOZZLE EXTENTION FOR HIGHER AR)
- PROVIDES ENTIRE VEHICLE GN&C

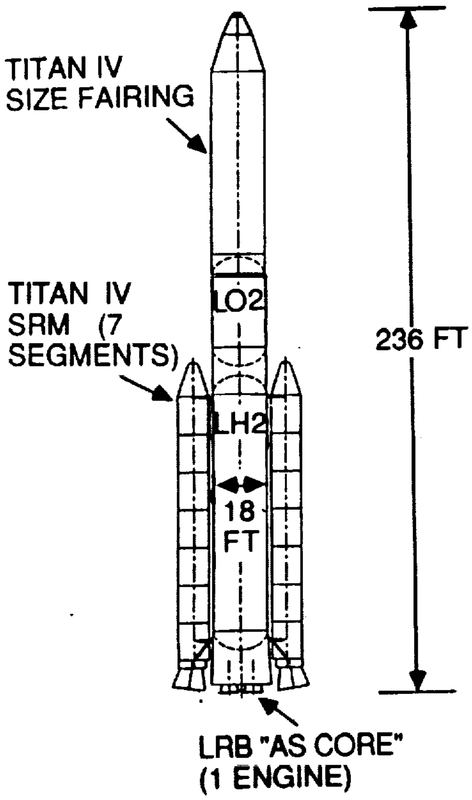
Figure 4.3-6. LRB with New Upper Stage

4.4 LRB CORE-TO-ORBIT LAUNCH VEHICLES

In terms of LRB core-to-orbit launch vehicles, at a minimum strap-on boosters are required to deliver any appreciable payload. Liquid or solid boosters can be used. New solid boosters (possibly monolythic) were rejected based on high DDT&E costs. Of the existing solid boosters possible, the Delta SRMs and Shuttle SRBs were dropped in favor of the Titan IV seven segment solids.

Figure 4.3-7 shows a core-to-orbit vehicle using two Titan IV seven segment solids. Only a single LRB engine is used. It was found that a using a single ground started engine for the LRB core gives the maximum performance, even when compared to using two air started engines. Interestingly, the payload capability of this vehicle is not nearly as much as the Titan IV. This can be explained by the fact that the Titan IV vehicle employes multiple stages which is much more efficient than using a single core-to-orbit approach. [7]

(LO2/LH2 LRB CONFIGURATION)



PAYLOAD:
- LEO (80x150 NMI,28.5 DEG) 15,000 LBS

VEHICLE:
- GLOW 2.173 M LBS

TRAJECTORY:
- MAX Q 818 PSF
- MAX G 4.47 g'S
- STAGGING VELOCITY 6,564 FT/SEC
- TOTAL DELTA VELOCITY 30,092 FT/SEC

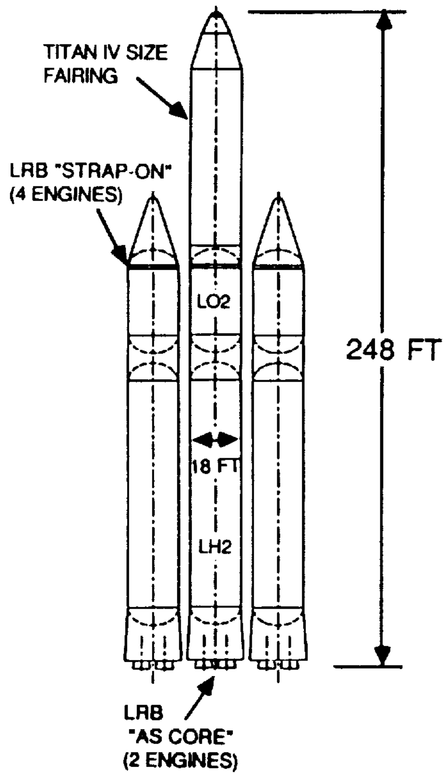
MAJOR MODIFICATIONS TO LRB (FOR USE AS CORE):
- REMOVE 3 ENGINES AND ATTENDANT TVC
- MODIFY THRUST STRUCTURE
- ADD GN&C, AND TELEMETRY AVIONICS
- ADD NEW FLIGHT SOFTWARE
- REMOVE NOSE CONE AND ADD PAYLOAD FAIRING ADAPTER
- ADD BOOSTER STRUCTURAL ATTACHMENTS
- ADD AN ACS SYSTEM AND DEORBIT MOTOR

Figure 4.3-7. LRB Core-To-Orbit Launch Vehicle Using Titan IV SRMs

The core to orbit vehicle presented in Figure 4.3-7, utilizes a modified Titan IV fairing as is shown in Figure 4.3-5 so as to accommodate shuttle sized payloads. The total vehicle length is on the order of 250 feet, and the GLOW is about 2.2 Mlbs.

In contrast, Figure 4.3-8 depicts a core-to-orbit vehicle using two liquid boosters; this vehicle approach was ultimately chosen as the preferred LRB ELV. This vehicle easily provides the greatest payload capability of the options considered -- over 80 Klbs to LEO. The Titan IV size fairing on the core LRB allows the vehicle to carry Shuttle size payloads. Adapting STS LRBs to this configuration would require only a few modifications. For the core vehicle, modifications include the removal of 2 engines (the thrust structure needs little changes and fluid lines can be capped off), new GN&C avionics and software, and adding a payload fairing adapter to replace the nose cone. The LRB "boosters" would require only minor structural modifications to accommodate attachment hardware. Further definition of this vehicle is presented in Section 6.2.

(LO2/LH2 LRB CONFIGURATION)



PAYLOAD:

• LEO (80x150 NMI,28.5 DEG)	80,000 LBS

VEHICLE:

• GLOW	2.54 M LBS
• INERT WT	
LRB (AS CORE)	115,890 LBS
LRB (AS STRAP-ON BOOSTER)	130,600 LBS

TRAJECTORY:

• MAX Q	850 PSF
• MAX G	5.5 g'S
• STAGGING VELOCITY	11,633 FT/SEC
• TOTAL DELTA VELOCITY	28,857 FT/SEC

MAJOR MODIFICATIONS TO LRB (FOR USE AS CORE):

- REMOVE 2 ENGINES AND ATTENDANT TVC
- MODIFY THRUST STRUCTURE
- ADD GN&C, AND TELEMETRY AVIONICS
- ADD NEW FLIGHT SOFTWARE
- REMOVE NOSE CONE AND ADD PAYLOAD FAIRING ADAPTER
- ADD BOOSTER STRUCTURAL ATTACHMENTS
- ADD AN ACS SYSTEM AND DEORBIT MOTOR

Figure 4.3-8. LRB Core with 2 Strap-on LRBs

4.5 EVALUATION OF RESULTS

This discussion is part of Section 6.0.

SECTION 5
LRB APPLICATIONS TO SHUTTLE -C

This section describes the potential applications of LRBs to the proposed STS Shuttle-C Launch Vehicle. The study included examinations using LRBs with Shuttle-C in conjunction with either SSMEs or possibly LRB engines on the expendable cargo carrier. The application of LRBs to Shuttle-C is a straightforward growth path for the LRB program. Many of the benefits that the LRB provide the Shuttle are also applicable to Shuttle C such as more flexible trajectory design (i.e., throttling) and reduced hazardous operations associated with solid propellants.

5.1 APPROACH

The basic approach used to investigate the applicability of LRBs to Shuttle C is similar to the overall LRB alternate applications study approach. Numerous options were considered, and the material which follows provides performance data and qualitative analyses.

The study began with the identification of the various feasible ways to utilize LRBs with Shuttle C. Initially the LO2/LH2 configuration was the only LRB concept used in this analysis, but the RP-1 fueled boosters were later examined as well. Results for these configurations are presented in Section 6.0. Figure 5.1-1 shows the many options that were identified for using LRBs on Shuttle C. These options are shown classified into 2 basic groups, options based on using SSMEs on the cargo carrier and another group based on using LRB engines on the cargo carrier. In both cases, modified or unmodified LRBs can be used. Possible modifications might be to make the LRBs partially or fully recoverable, or to increase the propellant loading of the LRBs which in turn increases the Shuttle "C" performance capabilities. It should be noted that the cargo carrier has no wings and thus LRB diameters are limited only by facility considerations.

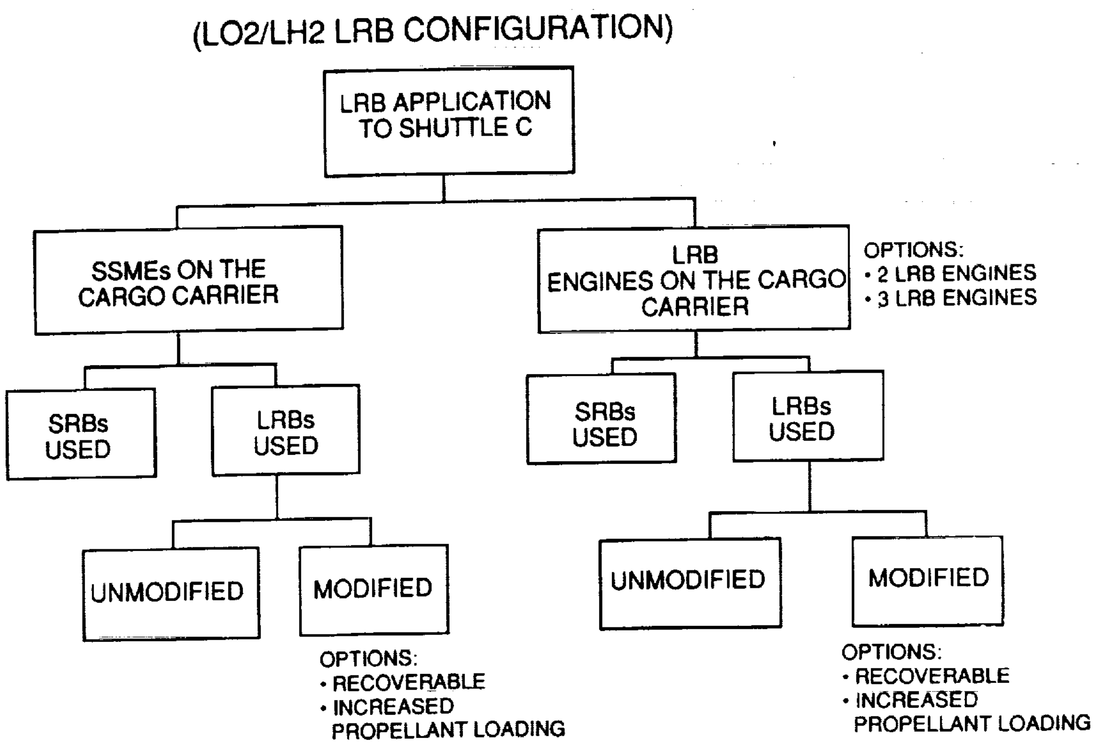


Figure 5.1-1. LRB Application to Shuttle C Trade Study Tree

After feasible options were identified, Shuttle C system level requirements, such as payload capability and interfaces, and launch and flight constraints, were examined.

Comparisons and analyses were then conducted to determine the attractiveness of various approaches. Analyses focused primarily on performance calculations and trajectory simulations. Typical comparisons included LRB engines vs SSMEs on the cargo carrier, 2 cargo carrier engines vs 3 , and modified vs unmodified LRBs.

Upon completion of the trades and analyses, overall results were evaluated and conclusions formulated. The preferred Shuttle C/LRB configuration was difficult to determine at this time as most approaches are similar. In general, the application of LRBs to Shutlle C is a straightforward application.

5.2 REQUIREMENTS

Table 5.2-1. lists the major requirements applied to the Shuttle-C system.[8] These requirements are classified into payload, launch, flight, and communications categories. One of the principal requirements is to use existing shuttle hardware components to the greatest extent, which includes using ETs, SSMEs, and possibly Shuttle based avionics. Because the LRBs are designed for minimum impact to these elements, they should readily fulfill lower level requirements, such as avionics interfaces, structural attachments and loads. In addition, the KSC facilities which are planned for LRBs for the Shuttle, will support LRBs for the Shuttle C as well. Table 5.2-2 lists the Trajectory/Sizing Constraints used for analyzing Shuttle C/LRB performance capabilities. It should be noted that the Shuttle "C" ascent trajectory is constrained much less than the current Shuttle ascent trajectory.

Table 5.2-1. Top Level Shuttle C Requirements

STS Synergism	
- Commonality	"The Shuttle-C Vehicle Configuration And Supporting Elements Shall Use Developed/Proven NSTS Or Other Existing Hardware, Software, and Operational Proceedures To The Fullest Extent Practical To Ensure Safety, Reliability, And Early Launch Capability"
Payload	
- Capacity	A Minimum Of 100,000 Lbs To A 220 N.Mi, 28.5 Degree Circular Orbit
- Interface	Minimum Envelope Shall Be 15' Dia x 60' Long
- Reference Missions	Shall Be Capable Of Meeting DRM-1 (Space Station Assembly), DRM-2 (Space Station Logistics), And DRM-3 (Centaur Planetary)
Launch	
- Capability	1993-1 Flight, 1994-2 Flights, 1994 thru 2002- 3 Flts/Yr
- Period	10 Days
- Probability	95%
Flight	
- Duration	Minimum Of 12 hr. On-orbit Stay Time
- Power level	100% SSME RPL
- Traj Constraints	(Sec Table 5.2-2)
Communication	
	• Continuous Telemetry Com Link For All Mission Phases • Verify Proper Receipt Of Command Data • Subsystems Monitoring

Table 5.2-2 Shuttle C and LRBs Trajectory/Sizing Constraints [9]

#	Item	Value
1)	Max g's During Flight	3.0
2)	Max Q (PSF)	819
3)	α (Deg)	0.0 (Thru Max Q - Gravity Turn)
4)	Max Qv (PSF•FT/SEC) After Fairing Sep	TBD (But Altitude ≥ 400 Kft Suggested To Limit P/L Heating)
5)	Reference Orbit	
	Altitude	220 n.mi.
	Inclination	28.5 deg (from KSC)
	Insertion	Direct
6)	MECO Target	
	Radius	67.5 n.mi.
	Flight Path Angle	1.04 deg
	Velocity	25904.2 ft/sec
	Inclination	28.45 deg
7)	Booster Stagging	Q ≤ 75 PSF
8)	NPL, EPL, Isp & Throttle Range	100% (SSME's) (Full Range For LRBs)
9)	Winds	July

5.3 ANALYSES

Following are the major comparisons and analyses that were conducted to examine the applicability of LRBs to Shuttle C. They include examining cargo carriers with SSMEs or LRB engines, and the use of 2 or 3 LRBs or SSMEs on the cargo carrier. The reference configuration used is shown in Figure 5.3-1. This figure displays a Shuttle C configured with the current ET and SRBs and lists the weights of the major components. For this Shuttle C configuration, the boattail is the same as for the current Shuttle. Note the SRB are the only reusable elements. In fact the expensive $15-$25M SSMEs are expended. Shown in Figure 5.3-2 is a comparable Shuttle C design using LRBs. Note all elements are the same, except for the boosters themselves. The LRBs at present are expendable, and thus recovery operations considered for the Shuttle C SRBs would not be necessary.

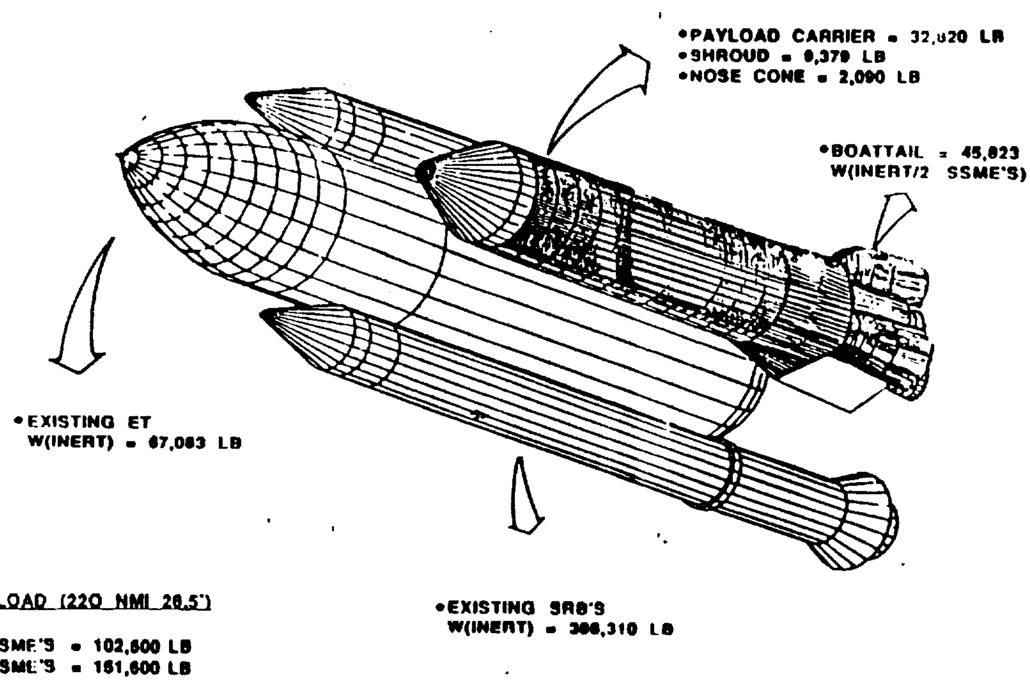


Figure 5.3-1. Shuttle C with SRBs Reference Configuration [10]

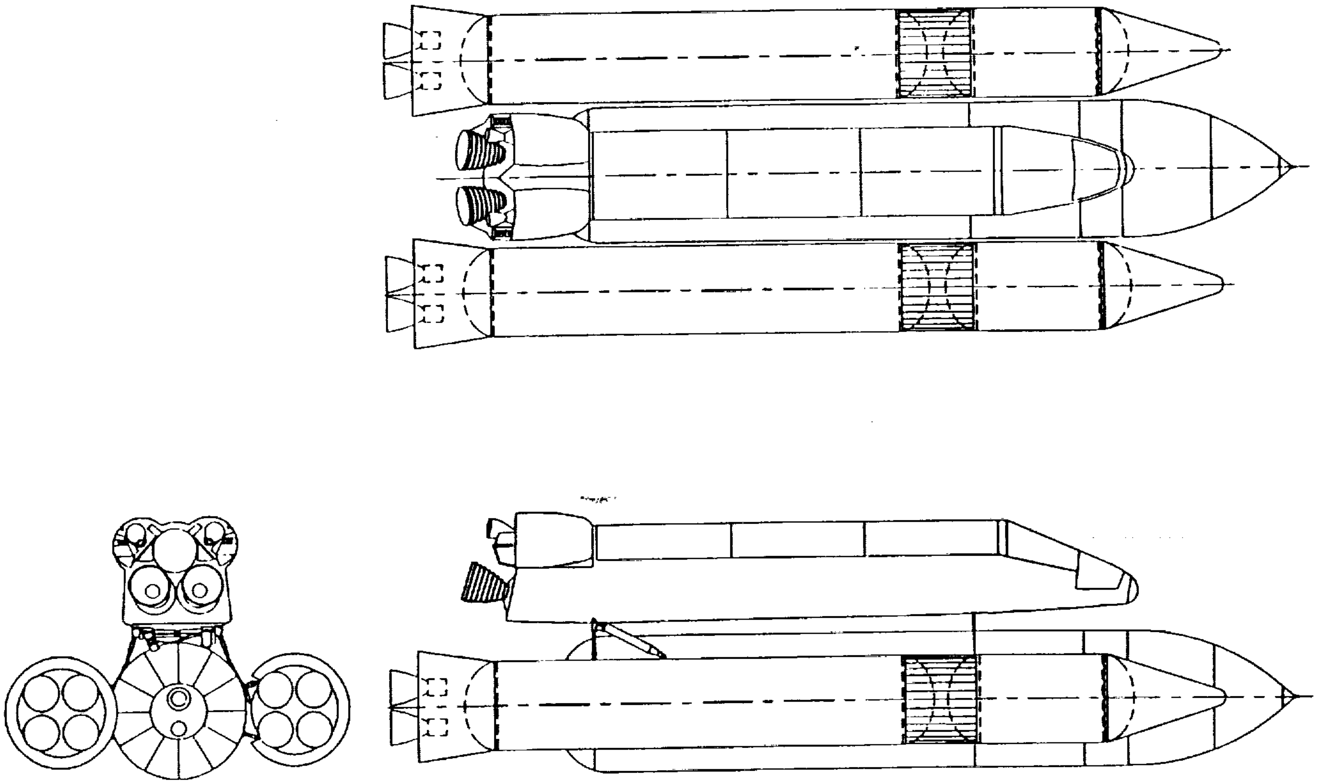
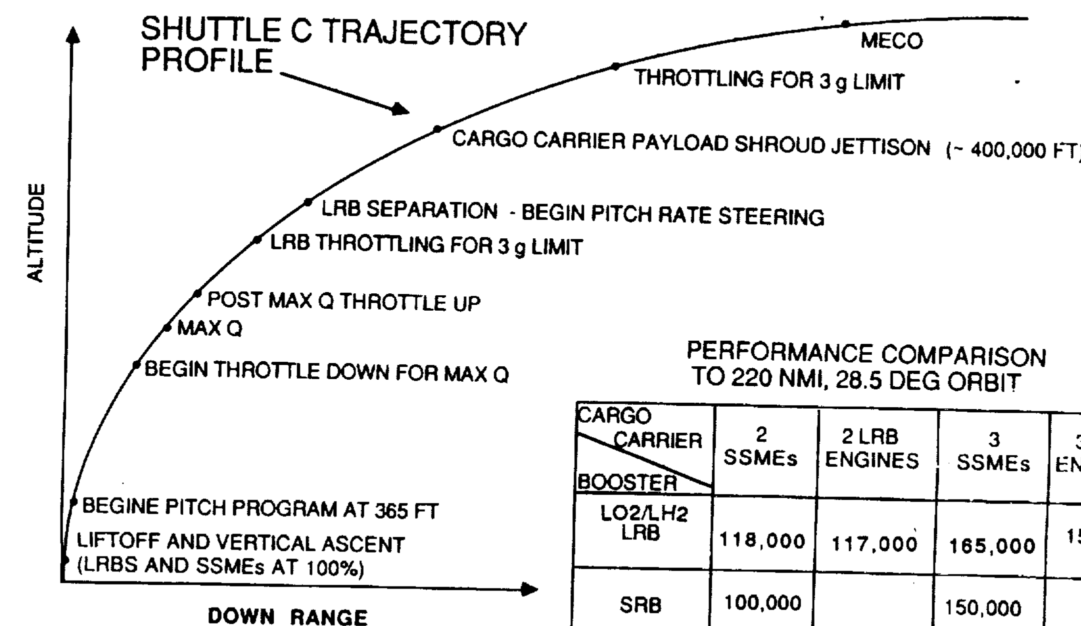


Figure 5.3-2. Shuttle C with LRBs Reference Configuration

Figure 5.3-3 shows the Shuttle C Trajectory profile with significant trajectory events highlighted. In terms of performance results, in almost all cases the LO2/LH2 LRB provides approximately 20 Klbs more payload capability. It is interesting to note that for the case with two engines on the cargo carrier, using LRB engines produces the same results as using SSMEs. This is due to two offsetting trends. The SSME engines, which are more high performance (greater Isp) than the LRB engines, nevertheless have lower thrust than the LRB engines. The higher Isp tends to give the SSME Shuttle C configuration more performance capability than the lower performance LRB engines. However, this is offset by the fact that when 2 engines are used on the cargo carrier, the propellant loading possible after separation is reduced because there is less available thrust than with the normal three Orbiter engines. Thus, the 2 higher thrust LRB engines allow the ET to have a greater propellant loading at lift-off (~ 180,000 lbs of LO2 and LH2), which offsets the Isp difference. This is not the case for the 3 engine cargo carrier because the ET is full whether LRB engines or SSMEs are used; thus, the Isp difference prevails and the SSME cargo carrier configuration performs better.

Thus, in comparing the use of LRB engines or SSMEs for Shuttle C, the choice is dependant on the number of engines to be used. If two engines are to be used on the cargo carrier, less expensive LRB engines should be used. However, if three engines are to be used on the cargo carrier, and performance is at a premium, higher performing SSME engines should be used. In any event, it is likely that LRB and SSME engines are nearly interchangeable for Shuttle C.



PERFORMANCE COMPARISON
TO 220 NMI, 28.5 DEG ORBIT

CARGO CARRIER / BOOSTER	2 SSMEs	2 LRB ENGINES	3 SSMEs	3 LRB ENGINES
LO2/LH2 LRB	118,000	117,000	165,000	152,000
SRB	100,000		150,000	

Figure 5.3-3. Shuttle C Trajectory Profile

In terms of qualitative considerations for using LRBs instead of SRBs for Shuttle C, the following items are important. LRBs offer Shuttle C:

- Improved performance-approximately 20 Klb greater payload

- Enhanced reliability
  - -Engine health verified on pad prior to launch
  - -Ability to throttle or shut down engines in the event of a failure
  - -Mission can be accomplished with engine-out

- Streamlined operations
  - -Shorter booster processing timeline[11]
  - -Removal of hazardous operations from the VAB
  - -Increased flexibility in mission trajectory design

- Improved effects to the environment
  - -Elimination of near field acid pollution

- LRB engines are possible replacements for the SSME, and should cost considerably less per engine.

5.4 EVALUATION OF RESULTS

This discussion is presented in Section 6.0.

SECTION 6

EVALUATION OF LRB ALTERNATE APPLICATIONS

A comparison of the three candidate LRB concepts for evolution and growth applications is discussed in this section, and an evaluation of ALS/LRB, LRB standalone ELV, and Shuttle "C"/LRB results is presented as well. The conclusions of the evolution and growth application study were incorporated into the final concept selection process for the basic LRB. Technical and qualitative data supplied included risk, STS cost, and evolution and growth factors.

This section also presents further definition of the selected standalone-core-to-orbit launch vehicle (refer to section 6.2).

6.1 EVALUATIONS

The following evolution and growth evaluations include analyses for the three favored LRB concepts, namely, the LO2/LH2 pump-fed, LO2/RP-1 pump-fed, and LO2/RP-1 pressure-fed designs.

6.1.1 SHUTTLE "C"/LRB

Table 6.1-1 presents a comparison of the three LRBs for the Shuttle "C" (SRB data is also provided as a reference). The table shows the performance capability using two boosters, and also the performance using the LO2/LH2 LRB engines on the cargo carrier. All the LRB concepts provide the Shuttle "C" vehicle with about the same payload capability. Because all three different LRBs concepts have been designed to use the same ET structural and electrical interfaces, and because Shuttle wing loading considerations are not applicable, each LRB design should integrate with the Shuttle "C" vehicle equally as well. All three LRB designs offer benefits to the Shuttle "C" system when compared to using SRBs. The main benefits are:

- Safer Operations - Hazardous Propellants Are Removed From The VAB
- Shorter Prelaunch Operations - Time Consuming Stacking Of SRBs Is Not Required
- Improved Trajectory Design - Because of throttling
- Higher Reliability - Engine Out Capability Exists With The LRBs

The primary discriminator between the LO2/LH2 pump-fed, LO2/RP-1 pump-fed, and LO2/RP-1 pressure-fed boosters is the notion that LO2/LH2 LRB booster engines might serve as replacements or alternatives to the SSMEs baselined for Shuttle "C".

Table 6.1-1. Shuttle C with LRBs – Performance/Compatibility

FEATURE \ BOOSTER	SRB (REF.)	LO2/LH2	LO2/RP-1 (PUMP)	LO2/RP-1 (PRESSURE)
PAYLOAD TO LEO (220 N.Mi, 28.5 DEG)				
NUMBER OF ENGINES ON CARGO CARRIER:				
- 2 SSME	~100	118	116	120
- 3 SSME	~150	165	164	173
-2 LO2/LH2 LRB ENGINES		117		
-3 LO2/LH2 LRB ENGINES		152		
COMPATIBLITY	• MINIMAL MODS TO STS SYSTEM	• CAN USE LRB ENGINES ON THE CARGO CARRIER • SAME PRO-PELLANTS AS ET		

On a new unit price basis, the LO2/LH2 LRB expendable engines are much less expensive than the reusable, high performance SSMEs. Currently, it is planned to use SSMEs on Shuttle "C" which have almost reached the end of their qualified life for the Shuttle (i.e., the SSMEs fly their last flight on Shuttle "C" after several flights on the Shuttle). However, LO2/LH2 LRB engines should be considered for Shuttle "C" in the event that new SSMEs must be purchased; this might occur if a higher Shuttle "C" flight rate is desired (say 10 flights/yr instead of the planned 3 flts/yr) to support an accelerated space station construction schedule. If a higher Shuttle "C" flight rate is desired, the amount of SSMEs per year which reach the end of their qualified life for the Shuttle may not be sufficient. Therefore, Shuttle "C" designers should examine the possibility of designing the cargo carrier boat tail to use either SSMEs or LO2/LH2 LRB engines.

6.1.2 LRB STANDALONE LAUNCH VEHICLES

Table 6.1-2 presents a comparison of the three LRB boosters for use as standalone Expendable Launch Vehicles (ELVs). The table shows performance capabilities, cost data, and qualitative comments on applicability.

Table 6.1-2. LRB Standalone Launch Vehicle Comparison

	LRB/CENTAUR			LRB WITH NEW UPPER STAGE	LRB CORE-TO-ORBIT		
FEATURE \ VEHICLE	LH2/LO2 PUMP FED	LO2/RP-1 PUMP FED	LO2/RP-1 PRESS. FED	LH2/LO2 PUMP FED	LH2/LO2 PUMP FED	LO2/RP-1 PUMP FED	LO2/RP-1 PRESS. FED
PAYLOAD (LBS): LEO	33,000 *	30,100 *	18,400 *	40,000	80,000	44,600	-
GTO	12,500	11,500	5,900				
DDT&E	$178 M	$159 M	$137 M	$1009 M	$327 M	$300 M	
AVE. COST/FLT (10 FLT/YR)	$70.2 M	$64.8 M	$71.0 M	$ 56.5 M	$93.5 M	$76.9 M	
$/LB: TO LEO	$2,130	$2,150	$3,860	$1,410	$1,170	$1,725	
TO GTO	$5,620	$5,635	$12,030				
COMMENTS	• FEW MODS TO CENTAUR • DOUBLES CURRENT ATLAS/CENTAUR CAPABILITY			• TITAN IV CLASS • HIGH DDT&E COST	• POSSIBLE INTERIM ALS • ASSURED ACCESS		

* PERFORMANCE REFERENCE VALUE ONLY - DOES NOT REFLECT CURRENT CENTAUR IIA STRUCTURAL LIMIT (~10,000 LBS)

6.1.2.1 LRB/Centaur. Table 6.1-2 shows that the LO2/LH2 pump-fed, and the LO2/RP-1 pump-fed LRBs, using a Centaur (Atlas IIA type) as an upper stage have about the same payload capability, DDT&E cost, and $/lb to orbit. The LO2/RP-1 pressure-fed booster with a Centaur delivers only about 60% of the payload capability of the other two, resulting in a greater expense per Lb to orbit. Thus, the pump-fed LRB concepts are more viable. The LRB/Centaur is an attractive ELV because it doubles the current Atlas/Centaur capability, but does not double the Atlas/Centaur cost per flight.

6.1.2.2 LRB with New Upper Stage. Analysis showed that the LO2/LH2 LRB booster, combined with a new upper stage which uses the LO2/LH2 booster engine as well, was the only combination of similar candidate boosters and upper stages that made sense. RP-1 upper stages are not desirable, and a new LO2/LH2 upper stage on top of a LO2/RP-1 booster was not as practical because this generally meant developing two new engines (i.e, a booster and an upper stage engine). The biggest draw back to this ELV concept is the high DDT&E cost necessary to develop a new upper stage.

6.1.2.3 LRB Core-to-Orbit. Table 6.1-2 shows the payload capability and cost data for the LO2/LH2 pump fed, and LO2/RP-1 pump-fed LRBs, in a core-to-orbit ELV application. The LO2/RP-1 pressure-fed vehicle did not exhibit a viable payload capability mainly because of its heavy inert weight and poor Isp. The LO2/LH2 LRB concept has the best payload capability, and lowest $/Lb to orbit. This concept could possibly become part of a vehicle family to meet ALS lower payload range requirements.

6.1.2.4 LRB Standalone ELV Application Evaluation Summary. Table 6.1-3 summarizes the benefits of the three LRB candidates for standalone ELV applications. The LO2/LH2 core-to-orbit vehicle is considered the most desirable ELV approach because it provides the best balance of DDT&E costs, payload capability, and costs per flight. This vehicle is described in more detail in Section 6.2.

Table 6.1-3. LRB Standalone Applications Comparison Summary

LRB Core-To-Orbit Vehicle

- The core-to-orbit vehicle provides a payload capability in the low range of the ALS requirements, and might fit into the ALS family of vehicles
- The LO2/LH2 booster is the most cost effective LRB for this role

LRB With A New Upper Stage

- The LO2/LH2 LRB is best suited for this role because its engine can be used on the upper stage, thereby reducing DDT&E costs (for a further discussion on the new upper stage LRB ELVs refer to section 4.3.2)

LRB With Centaur Upper Stage

- The LO2/LH2 and LO2/RP-1 LRBs are equally as well suited for this role, but the pressure-fed LRB is not.

6.1.3 ALS/LRB

Table 6.1-4 presents a comparison of the three LRB booster concepts used with the GDSS LO2/LH2 ALS Phase II proposal core (see section 3.0 for further description on the core vehicle). Two LRBs are used with the core, and the payload capability shown is with a core engine out at liftoff. The table also indicates system level compatibility considerations, and provides estimated cost reductions which might occur when LRBs are used with ALS and the Shuttle concurrently. It should be noted that the cost data presented is slightly outdated, but it is felt that the trends presented are still valid.

Table 6.1-4. LRB/ALS Application – Performance/Compatibility/Cost Comparison

LRB CONFIGURATION / FEATURE	LH2/LO2	LO2/RP-1 (PUMP-FED)	LO2/RP-1 (PRESSURE-FED)
P/L TO LEO (KLB) W/ ENGINE-OUT (TWO LRBS PER ALS FLT)	100	104	108
ALS/LRB SYSTEM LEVEL COMPATIBILITY	COMMON PROPELLANTS AND ENGINES(SHARED DEV'T POSSIBLE)	DIFFERENT PROPELLANTS AND ENGINES	DIFFERENT PROPELLANTS AND ENGINES
LRB INTEGRATION WITH THE ALS CORE	ACCEPTABE WHEN SIZED AT 18' DIA	SMALLEST; EASIEST INTEGRATION	CLEARANCE PROBLEMS DUE TO LENGTH (RESIZE TO 18' DIA?)
LRB NON-RECURRING COST - LESS ENGINES ($M)	1,815	1,732	1,966
NASA LRB ENGINE DDT&E ($M)			
NASA FUNDS	1,109	841	533
ALS FUNDS	0	—	—
TOTAL LRB NON-RECURRING COST ($M)			
NASA FUNDS ENGINE DEV'L	2,924	2,573	2,499
ALS FUNDS ENGINE DEV'L	1,815	—	—
AVE. COST PER LRB ($M)			
BASED ON STS FLT RATE	36	29	36
BASED ON STS+ALS FLT RATE *	32	26	31
NASA's LRB LIFE-CYCLE-COST ($M)			
LRBS FOR STS ONLY	12,196	← Δ_1 = 2,059 → 10,137	11,771
ALS USES LRBS & DEV'LS LRB ENG	10,453	← Δ_2 = 718 → 9,735	10,893

NOT THE LATEST LRB COSTS

*** ALS FLIGHT RATE AT 10 FLTS/YR**

If LRBs are used for ALS, the STS LRB average unit cost is reduced as shown in Table 6.1-4. Note that when the LO2/LH2 LRB is used for ALS, the average unit cost reduction accounts for using three LRB engines on the core as well. As the average unit cost is reduced, the STS LRB life-cycle-cost (LCC) numbers are consequently decreased. The LO2/RP-1 pump fed LRB, because of its lower average unit cost, still has the lowest STS LCC, but the difference between LCCs for the LO2/LH2 pump-fed LRB and the LO2/RP-1 pump-fed LRB (due to use with ALS) has been reduced by about 65%, i.e., $[(\Delta_1-\Delta_2)/\Delta_1]^*100$. Also, the total LO2/LH2 LRB DDT&E cost, as shown, can possibly be cut about in half.

This analysis is liberal in assuming that ALS would entirely fund the LO2/LH2 LRB engine development. Nevertheless, with a combined engine development program, the LO2/LH2 LRB is clearly favored.

In general, all the LRB configurations provide the ALS core (as proposed by GDSS for Phase II) nearly the same performance. By varying the number of LRBs used (2 thru 4) it is possible to provide a range of payload capabilities from 50 - 250 Klbs to LEO (with engine-out). In terms of integration, the RP-1 LRB is smallest and provides the best clearances with the core fairing used, but it would required a separate propellant supply system from that used for the core. For all LRBs, some modifications are necessary for structural attachment to the ALS core. Previously, in section 3.0, the concept of an engine recovery module was presented. This concept provides additional cost savings when compared to using fully expendable LRBs for ALS, however it is only applicable to the LO2/LH2 LRB configuration.

In summary, the LO2/LH2 LRB concept is favored for use with ALS.

6.1.4 LRB EVOLUTION AND GROWTH SUMMARY

Table 6.1-5 summarizes the advantages and disadvantages for the three LRB concepts.

Table 6.1-5. LRB Evolution and Growth Summary

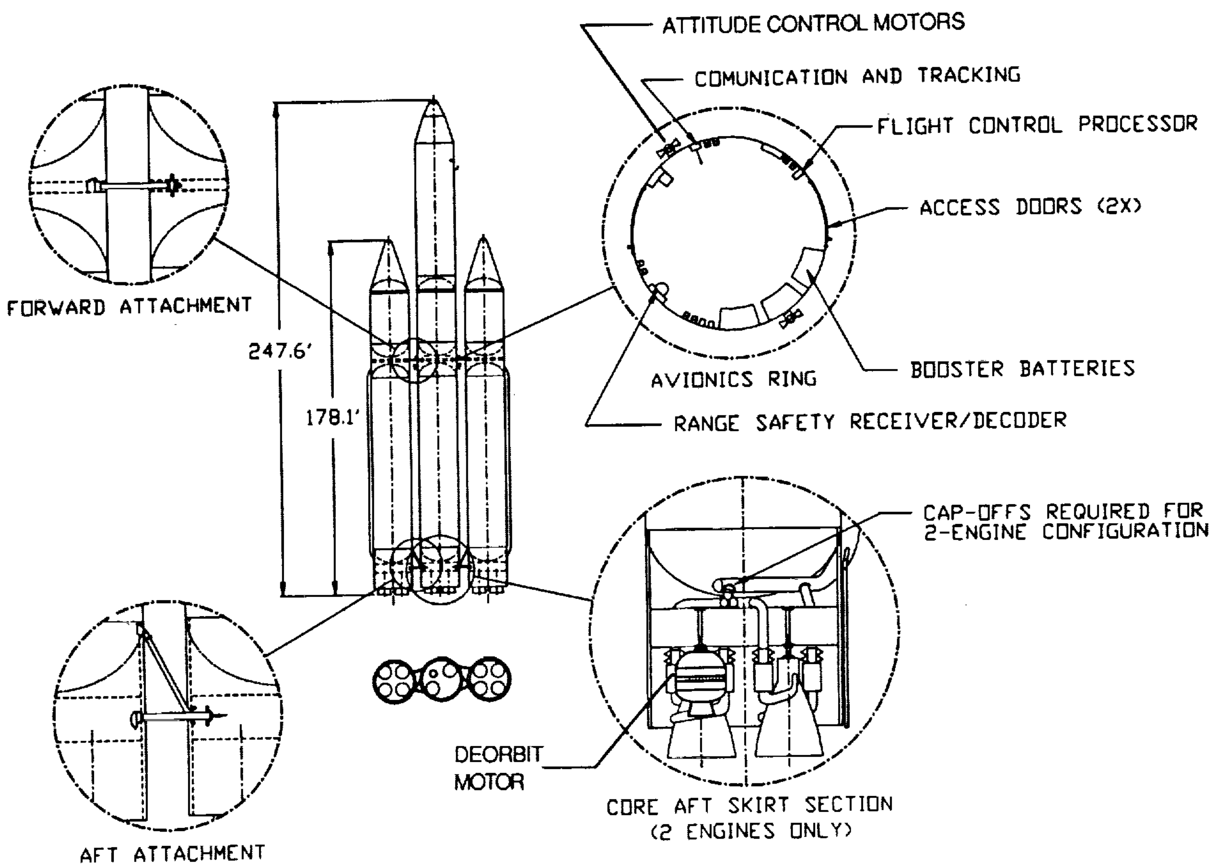
BOOSTER / APPLICATION	LO2/LH2	LO2/RP-1 (PUMP)	LO2/RP-1 (PRESSURE-FED)
ALS	• SAVES $400 -$880 M WITH COMMON ENGINE DEV'L • USAF COST SHARING OF ENGINE DEV'L COULD SAVE NASA UP TO $1.0 B • LRB RECURRING COST CUT $4 M BY USE ON STS & ALS • STS LRB LCC COST REDUCED SIGNIFICANTLY BY USE WITH ALS	• LRB RECURRING COST CUT $3 M BY USE ON STS & ALS • DIFFERENT PROPELLANT SYSTEM THAN PROPOSED ALS CORE	• LRB RECURRING COST CUT BY $5 BY USE ON STS & ALS • DIFFERENT PROPELLANT SYSTEM THAN PROPOSED ALS CORE
STANDALONE	• MOST COST EFFECTIVE FOR STANDALONE LAUNCH VEHICLES • CORE-TO-ORBIT VEHICLE POSSIBLE PART OF ALS	• NOT AS ATTRACTIVE FOR CORE-TO-ORBIT VEHICLE • ABOUT EQUAL TO LO2/LH2 FOR USE WITH CENTAUR UPPER STAGE	• WILL NOT WORK FOR CORE-TO-ORBIT VEHICLE • NOT WELL SUITED FOR USE WITH CENTAUR UPPER STAGE
SHUTTLE-C	• CAN USE LRB ENGINES ON CARGO CARRIER • SAME PROPELLANT AS ET	• SIMILAR PERFORMANCE AS LO2/LH2	• SIMILAR PERFORMANCE AS LO2/LH2 • BEST SUITED FOR IMPACT, LOADS IF CONSIDERED FOR WATER RECOVERY

6.2 SELECTED STANDALONE LAUNCH VEHICLE DEFINITION

The chosen standalone launch vehicle (Figure 6.2-1) from the evolution and growth study is a LRB core-to-orbit vehicle which uses either 1 or 2 LRB boosters. This vehicle would use a Titan IV fairing to carry shuttle-sized payloads of 80,500 lbs with 2 boosters, or 28,500 lbs with 1 booster, to a 80 by 150 nautical mile, 28.5° inclination orbit.

This core-to-orbit vehicle was favored due to its lower price per payload pound to low earth orbit, and because of the possibility it could become a lower payload range ALS vehicle. The overall downselection to this vehicle concept is pictured in Figure 6.2-2.

Figure 6.2-1. Selected core-to-orbit launch vehicle description



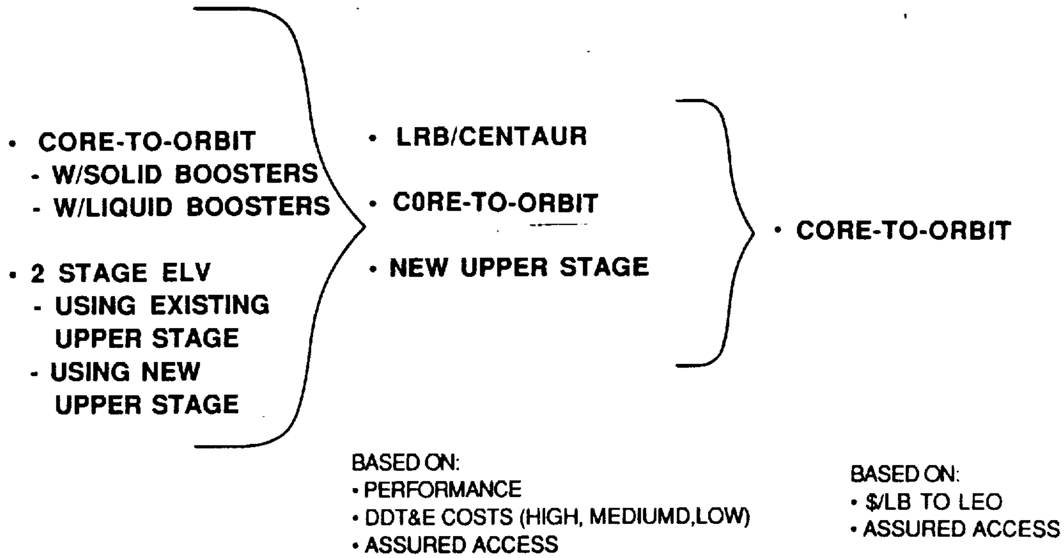


Figure 6.2-2. LRB Standalone ELV Applications Downselection Process

The design philosophy for this vehicle was focused on minimizing the required changes to the STS LRB. The mission model used was 10 flights/year (after a three year ramp-up) for 10 years yielding a total of 90 flights during the 1995-2005 time period. Launches will be from ETR, with the booster processing and operations being based at the launch site.

6.2.1 SYSTEM DESCRIPTION

This section presents details of the LRB core-to-orbit launch vehicle. This modular vehicle uses either one or two LRB "boosters" with a LRB derived core. In either case, the total vehicle length is 248' (18' dia core and boosters), and its lift-off weight is 2.56 Mlbs using 2 boosters, or 1.6 Mlbs using only one.

Required LRB Modifications. The vehicle is composed of modified LRBs with the core vehicle modifications being more extensive than those required for the "booster" LRBs.

The modifications for the core vehicle include changes to the propulsion and avionics systems, and to the booster structure. In terms of propulsion modifications, two engines are removed, leaving two engines on a diagonal; unused feed lines are simply capped off (2 engines are used to provide a better Δ velocity split, and to reduce core inert weight). The thrust structure should need little modification. The intertank area will require a heavier ring frame for the forward attachment hardware. The aft attach hardware will span from the booster fuel tank bulkhead to the core thrust structure. Thrust loads are reacted aft, while lateral loads are reacted forward. It should be noted that the LRBs are structurally very sturdy vehicles due to their requirement to support the entire shuttle stack prior to launch. Attachment struts are patterned after those used on the aft SRB to ET attachment. The Titan IV fairing used will require modification in order to mate with the larger diameter of the LRB, and the LRBs nose cone must be removed. Also, a cold GO2 gas attitude control system will be added for deorbit maneuvering. At this time, orbital deployment is baselined, but orbital vs. suborbital delivery is an item requiring further trade study. A small spherical solid propellant motor provides deorbit impulse. The motor is mounted to the thrust structure where an engine was removed.

Many of the avionics functions between the LRB and the standalone LRB launch vehicle are the same. The additional functions of the standalone LRB will include the guidance and navigation of the vehicle, generation of engine gimbal commands, and vehicle stability control. In addition all redundancy management processing and decisions in the areas of alternate mission scenarios must be handled on board the LRB. The standalone LRB will also have additional ground interfacing as well as implementing a payload interface. Most of the additional functions imposed upon the standalone LRB avionics can be met with the existing LRB avionics system. Some alterations and additions will have to be made to meet all of the additional functions, these include: 1) replacing the Booster Control Processor with inertial Navigation Units (INU); 2) interfacing the Rate Gyro Assemblies (RGA) onto the LRB system bus; 3) terminating all LRB/Orbiter interfaces with a dummy load; 4) providing additional power capabilities for longer duration mission times; 5) adding a vehicle tracking system; and, 6) adding payload interface capabilities.

For the "booster" LRBs, the intertank area must be modified to strengthen the existing ET attach ring and hardware, and the aft attach hardware must be secured to the aft fuel tank bulkhead and thrust structure. The "booster" LRBs will continue to use their separation motors (BSMs) for staging.

Many of these modifications are depicted in Figure 6.2-1.

Mass Properties. Table 6.2-1 lists the various components of the LRB core-to-orbit vehicle. The basic weight values are those of the STS LRB. The weight of items from the STS LRB which were to be removed for this application are not included in this weight summary. Weight was added to account for the reinforcing of the intertank area, and for the addition of attach struts, avionics, the attitude control system and deorbit motor. Note that in the summary, booster weights are for one unit.

Table 6.2-1 LRB Core-To-Orbit Launch Vehicle, Weight Summary

CORE WEIGHT SUMMARY:

(NOTE: CORE IS A MODIFIED LO2/LH2 STS LRB)

	SUBSYS	SYSTEM	GROUP	VEHICLE
STRUCTURE			71,635.5	
LH2 TANK (AL 2219 skin stiffner)		34,863.3		
LO2 TANK (AL2219 skin stiffner)		11,836.9		
LO2 TANK SLOSH BAFFLES		290.5		
LH2 TANK INSULATION		1,181.5		
LO2 TANK INSULATION		476.6		
INTERTANK ADAPTER		6,074.4		
(Note: Includes Structural Reinforcement)				
AFT ADAPTER		10,617.5		
THRUST STRUCTURE		4,297.3		
LAUNCH GEAR		110.0		
PAYLOAD ADAPTER		1,187.5		
BOOSTER ATTACH STRUTS/HARDWARE		700.0		
PROPULSION SYSTEM (Note: 2 Engines Used)			22,112.5	
MAIN ENGINES		11,475.9		
ENGINE GIMBAL SYSTEM		1,372.8		
ENGINE PURGE SYSTEM		736.6		
ENGINE MOUNTS		267.9		
MAIN PROPELLANT SYSTEM		8,259.3		
SUB-SYSTEMS			4,143.0	
PAYLOAD SEPARATION SYSTEM		300.0		
AVIONICS (NOMINAL FOR LRB)		806.0		
AVIONICS (ADDITIONAL GN&C,TELEMETRY)		500.0		
POWER		1,537.0		
ACS & DEORBIT MOTOR - ESTIMATE		1,000.0		
CONTINGENCY			11,085.0	
DRY WEIGHT				108,976.0
MAIN RESIDUALS			6916.8	
LH2 FUEL		988.1		
LO2 FUEL		5,928.7		
INERT WEIGHT				115,892.8

CON'T

ASCENT PROPELLANTS		691,679.1	
LH2 FUEL	98,811.3		
LO2 OXIDIZER	592,867.8		
LRB LIFT OFF WEIGHT			807,571.9
MAIN START-UP FUEL		29,491.0	
LH2 FUEL	5,525.9		
LO2 FUEL	23,965.1		
STEP WEIGHT			837,062.9
PAYLOAD FAIRING (Modified TITAN IV Fairing)		14,000.0	

CORE ENGINE PARAMETERS	NOMINAL
NUMBER	2.0
WEIGHT (EACH)	5,738.0
THROTTLE SETTINGS (2)	100% OR 75%
OXIDIZER FLOW RATE	1,163.4
FUEL FLOW RATE	193.9
VACUUM THRUST	558,058.6
SEA LEVEL THRUST	515,201.5
CHAMBER PRESSURE (psi)	2,250.0
VACUUM ISP (sec)	411.17
SEA LEVEL ISP (sec)	379.59
MIXTURE RATIO	6.0000
NOZZLE AREA RATIO	20.000
X-AREA (in^2)	2,916.2
THROAT RADIUS (in)	6.8127
EXIT DIAMETER (in)	60.935
OVERALL LENGTH (in)	105.47

CORE DIMENSIONS	LNG. (FT)
FUEL TANK SPACING	2.9167
ENGINE CLEARANCE	5.7500
EXIT PLANE	2.2
AFT ADAPTER	18.8
AFT FUEL TANK	89.1
INTERTANK ADAPTER	15.9
FORWARD FUEL TANK	27.1
PAYLOAD FAIRING ADAPTER	7.5
PAYLOAD FAIRING	87.0
TOTAL LENGTH	247.6
CORE DIAMETER	18.000

CON'T

WEIGHT SUMMARY PER BOOSTER:

(NOTE: EACH BOOSTER IS A MODIFIED LO2/LH2 STS LRB)

	SUBSYS	SYSTEM	GROUP	VEHICLE
STRUCTURE			73,427.9	
LH2 TANK (AL 2219 skin stiffner)		34,863.3		
LO2 TANK (AL2219 skin stiffner)		11,836.9		
LO2 TANK SLOSH BAFFLES		290.5		
LH2 TANK INSULATION		1,181.5		
LO2 TANK INSULATION		476.6		
NOSE CAP		2,508.1		
FORWARD ADAPTER		171.8		
INTERTANK ADAPTER		6,574.4		
(Note: Includes Structural Reinforcement)				
AFT ADAPTER		10,617.5		
THRUST STRUCTURE		4,297.3		
LAUNCH GEAR		110.0		
BOOSTER ATTACH STRUTS/HARDWARE		500.0		
PROPULSION SYSTEM			35,229.1	
MAIN ENGINES		22,951.9		
ENGINE GIMBAL SYSTEM		2,745.6		
ENGINE PURGE SYSTEM		736.6		
ENGINE MOUNTS		535.7		
MAIN PROPELLANT SYSTEM		8,259.3		
SUB-SYSTEMS			3,943.0	
BOOSTER SEPARATION SYSTEM		1,600.0		
AVIONICS		806.0		
POWER		1,537.0		
CONTINGENCY			11,085.0	
DRY WEIGHT				123,685.0
MAIN RESIDUALS			6,916.8	
LH2 FUEL		988.1		
LO2 FUEL		5,928.7		
INERT WEIGHT				130,601.8

CON'T

ASCENT PROPELLANTS		691,679.1	
LH2 FUEL	98,811.3		
LO2 OXIDIZER	592,867.8		
LRB LIFT OFF WEIGHT			822,280.9
MAIN START-UP FUEL		29,491.0	
LH2 FUEL	5,525.9		
LO2 FUEL	23,965.1		
STEP WEIGHT			851,771.9

BOOSTER ENGINE PARAMETERS	NOMINAL
NUMBER	4.0
WEIGHT (EACH)	5,738.0
THROTTLE SETTING (2)	100% OR 75%
OXIDIZER FLOW RATE	1,163.4
FUEL FLOW RATE	193.9
VACUUM THRUST	558,058.6
SEA LEVEL THRUST	515,201.5
CHAMBER PRESSURE (psi)	2,250.0
VACUUM ISP (sec)	411.17
SEA LEVEL ISP (sec)	379.59
MIXTURE RATIO	6.0000
NOZZLE AREA RATIO	20.000
X-AREA (in^2)	2,916.2
THROAT RADIUS (in)	6.8127
EXIT DIAMETER (in)	60.935
OVERALL LENGTH (in)	105.47

BOOSTER DIMENSIONS	LNG.(FT)
FUEL TANK SPACING	2.9167
ENGINE CLEARANCE	5.7500
EXIT PLANE	2.2
AFT ADAPTER	18.8
AFT FUEL TANK	89.1
INTERTANK ADAPTER	15.9
FORWARD FUEL TANK	27.1
FORWARD ADAPTER	1.1
NOSE CAP	23.9
NOSE TIP	0.0
TOTAL LENGTH	178.14
BOOSTER DIAMETER	18.000

Trajectory/Performance. A typical ascent trajectory for this vehicle is summarized in Table 6.2-2, which describes in detail the trajectory for the LRB core with two LRBs. Table 6.2-3 provides the performance summary for the LRB core with only one booster used. Both trajectories utilized a gravity turn through Max Q, and step throttling, using 75% and 100% settings.

Table 6.2-2 LRB core to Orbit Launch Vehicle, Performance Summary (2 Boosters Used)

Lift off conditions:		
Weight (lb)	=	2,546,169.0933
Payload (lb)	=	80,035.393260
Thrust (lb)	=	4,872,992.8229
Thrust to weight	=	1.9138527900
Initial inertial velocity (ft/sec)	=	1,342.4324022
Launch site latitude	=	28.307566153
Launch site longitude	=	-80.540959056
Max Q conditions:		
Max dynamic pressure (lb/ft**2)	=	850.60958506
Time (sec)	=	61.019351923
Angle of attack (deg)	=	0.00000000000
Altitude (ft)	=	41,971.739045
Mach number	=	1.8411694767
Q * ALPHA (deg-lb/ft**2)	=	0.00000000000
LRB separation:		
Staging time (sec)	=	139.63616924
Altitude (ft)	=	215,208.66265
Down range distance (nm)	=	65.787011820
Dynamic pressure (lb/ft**2)	=	15.903419252
Angle of attack (deg)	=	-1.3652986382
Mach number	=	10.319218441
Inertial velocity (ft/sec)	=	11,633.096635
Inertial flight path angle (deg)	=	14.746101954
Delta V (ft/sec)	=	14,076.895587
Weight after separation (lb)	=	617,326.46618
LRB core propellent remaining (lb)	=	407,398.27292
LRB propellent used (lb)	=	1,383,358.2000
Average back pressure (psi)	=	4.2340309303
Fairing Separation		
Time (sec)	=	213.06904928
Down range distance (nm)	=	203.24144477
Mach number	=	10.355675453
Angle of attack (deg)	=	-3.6202597781
Dynamic pressure (lb/ft**2)	=	4.29171286253E-03
Q * V (lb/ft-sec)	=	58.000000000

CON'T

MECO

Time (sec)	=	339.74651353
Altitude (ft)	=	501,660.99743
Inertial velocity (ft/sec)	=	25,764.837760
Inertial flight path angle (deg)	=	5.32443070583E-02
Delta V (ft/sec)	=	28,857.201339
Perigee (nm)	=	79.980173475
Apogee (nm)	=	149.98165783
Weight (lb)	=	195,928.19326
Core propellent weight used (lb)	=	691,679.10000
Average back pressure (psi)	=	1.7402281560

Losses to LRB separation

Total delta V	=	14,667.952000
Steering losses	=	1,469.0108662
Drag losses	=	478.90177233
Gravity losses	=	1,684.9775853
Pressure losses	=	248.32798534

Losses to MECO

Total delta V	=	28,857.201339
Steering losses	=	1,492.5168162
Drag losses	=	479.13298436
Gravity losses	=	2,208.7068676
Pressure losses	=	248.32859016

Min/Max conditions:

Max (+) angle of attack (deg)	=	0.17300587541
Time (sec)	=	5.7700946713
Max (-) angle of attack (deg)	=	-7.3548023824
Time (sec)	=	15.770094671
Max (+) Q * Alpha (lbf-deg/ft**2)	=	6.2053364680
Time (sec)	=	5.7700946713
Max (-) Q * Alpha (lbf-deg/ft**2)	=	-1,487.8121491
Time (sec)	=	15.770094671
Max acceleration (g's)	=	5.4999936348
Time (sec)	=	131.82870454

CON'T

LRB booster throttle @ lift off	=	1.0000000000
Launch azimuth (deg)	=	93.244109559
Pitch rate (10, deg/sec)	=	0.44345882256
Throttle Down Mach number	=	0.28602644301
LRB core throttle @ Max Q Throttle Down	=	0.75000000000
LRB booster throttle @ Max Q Throttle Do	=	0.75000000000
Throttle Up Mach number	=	1.3778944301
LRB core throttle @ Max Q Throttle Up	=	0.75000000000
LRB booster throttle @ Max Q Throttle Up	=	1.0000000000
Pitch rate (20, deg/sec)	=	2.0637000824
Pitch rate (3, deg/sec)	=	0.44751081827
Pitch rate (90, deg/sec)	=	2.94965530480E-02
Pitch rate (120, deg/sec)	=	0.26225706290
Pitch rate (150, deg/sec)	=	9.53079969309E-02
Pitch rate (200, deg/sec)	=	7.03565674364E-02
Pitch rate (220, deg/sec)	=	6.27748672255E-02

Trajectory Constraints:

Max q	(<= 850.00)	=	850.60958506
Max angle of attack	(<= 30.000)	=	0.17483409211
Min angle of attack	(>= -30.00)	=	-7.3548023824
q * V @ MECO	(<= 58.000)	=	25.784013696
Perigee altitude	(= 80.000)	=	79.980173475
Apogee altitude	(= 150.00)	=	149.98165783
Inclination	(= 28.500)	=	28.499999849

Table 6.2-3 LRB Core to Orbit Launch Vehicle, Performance Summary (1 Booster Used)

Lift off conditions:

Weight (lb)	= 1,672,391.3816
Payload (lb)	= 28,538.581600
Thrust (lb)	= 2,812,183.9737
Thrust to weight	= 1.6815346005
Initial inertial velocity (ft/sec)	= 1,342.4324022
Launch site latitude	= 28.307566153
Launch site longitude	= -80.540959056

Max Q conditions:

Max dynamic pressure (lb/ft**2)	= 850.53297492
Time (sec)	= 63.864290841
Angle of attack (deg)	= 0.00000000000
Altitude (ft)	= 39,436.582928
Mach number	= 1.7342892568
Q * ALPHA (deg-lb/ft**2)	= 0.00000000000

LRB separation:

Staging time (sec)	= 134.16349314
Altitude (ft)	= 177,295.79049
Down range distance (nm)	= 44.783495797
Dynamic pressure (lb/ft**2)	= 35.161414600
Angle of attack (deg)	= 3.7250532041
Mach number	= 7.0708675886
Inertial velocity (ft/sec)	= 8,815.3358134
Inertial flight path angle (deg)	= 18.731372131
Delta V (ft/sec)	= 11,379.160078
Weight after separation (lb)	= 576,971.30138
LRB core throttle @ separation	= 0.75000000000
LRB core propellent remaining (lb)	= 418,539.91978
LRB propellent used (lb)	= 691,679.10000
Average back pressure (psi)	= 4.8702594623

Fairing Separation

Time (sec)	= 219.53659636
Down range distance (nm)	= 169.63812206
Mach number	= 9.2124999817
Angle of attack (deg)	= -2.5731264335
Dynamic pressure (lb/ft**2)	= 5.01993898927E-03
Q * V (lb/ft-sec)	= 58.000008937

MECO

Time (sec)	=	339.74651353
Altitude (ft)	=	501,569.44967
Inertial velocity (ft/sec)	=	25,765.105066
Inertial flight path angle (deg)	=	5.30897335272E-02
Delta V (ft/sec)	=	29,233.582655
Perigee (nm)	=	79.933766607
Apogee (nm)	=	149.98518548
Weight (lb)	=	144,431.38160
Core propellent weight used (lb)	=	691,679.10000
Average back pressure (psi)	=	1.9234304034

Losses to LRB separation

Total delta V	=	12,686.418423
Steering losses	=	1,681.8333536
Drag losses	=	465.84608427
Gravity losses	=	1,766.6470162
Pressure losses	=	250.67153370

Losses to MECO

Total delta V	=	29,233.582655
Steering losses	=	1,712.6132417
Drag losses	=	466.05091553
Gravity losses	=	2,376.2395955
Pressure losses	=	250.67237140

Min/Max conditions:

Max (+) angle of attack (deg)	=	7.3160323492
Time (sec)	=	160.82951315
Max (-) angle of attack (deg)	=	-4.5995037083
Time (sec)	=	339.74651353
Max (+) Q * Alpha (lbf-deg/ft**2)	=	845.36530704
Time (sec)	=	95.829513146
Max (-) Q * Alpha (lbf-deg/ft**2)	=	-361.85855982
Time (sec)	=	21.665979490
Max acceleration (g's)	=	5.7957469444
Time (sec)	=	339.74651353

CON'T

LRB booster throttle @ lift off	=	1.0000000000
Launch azimuth (deg)	=	93.215286525
Pitch rate (10, deg/sec)	=	0.46767143876
Throttle Down Mach number	=	0.25350522162
LRB core throttle @ Max Q Throttle Down	=	0.75000000000
LRB booster throttle @ Max Q Throttle Do	=	0.75000000000
Throttle Up Mach number	=	0.71265707299
LRB core throttle @ Max Q Throttle Up	=	0.75000000000
LRB booster throttle @ Max Q Throttle Up	=	1.0000000000
Pitch rate (20, deg/sec)	=	0.80438644632
Pitch rate (3, deg/sec)	=	0.19596083564
Pitch rate (90, deg/sec)	=	1.44094570160E-02
Pitch rate (120, deg/sec)	=	0.54056355097
Pitch rate (150, deg/sec)	=	8.10058299125E-02
Pitch rate (200, deg/sec)	=	0.11660899866
Pitch rate (220, deg/sec)	=	5.89057347412E-02

Trajectory Constraints:

Max q	(<= 850.00)	=	850.53297492
Max angle of attack	(<= 30.000)	=	7.3160323492
Min angle of attack	(>= -30.00)	=	-4.5995037083
q * V @ MECO	(<= 58.000)	=	25.817602406
Perigee altitude	(= 80.000)	=	79.933766607
Apogee altitude	(= 150.00)	=	149.98518548
Inclination	(= 28.500)	=	28.499999795

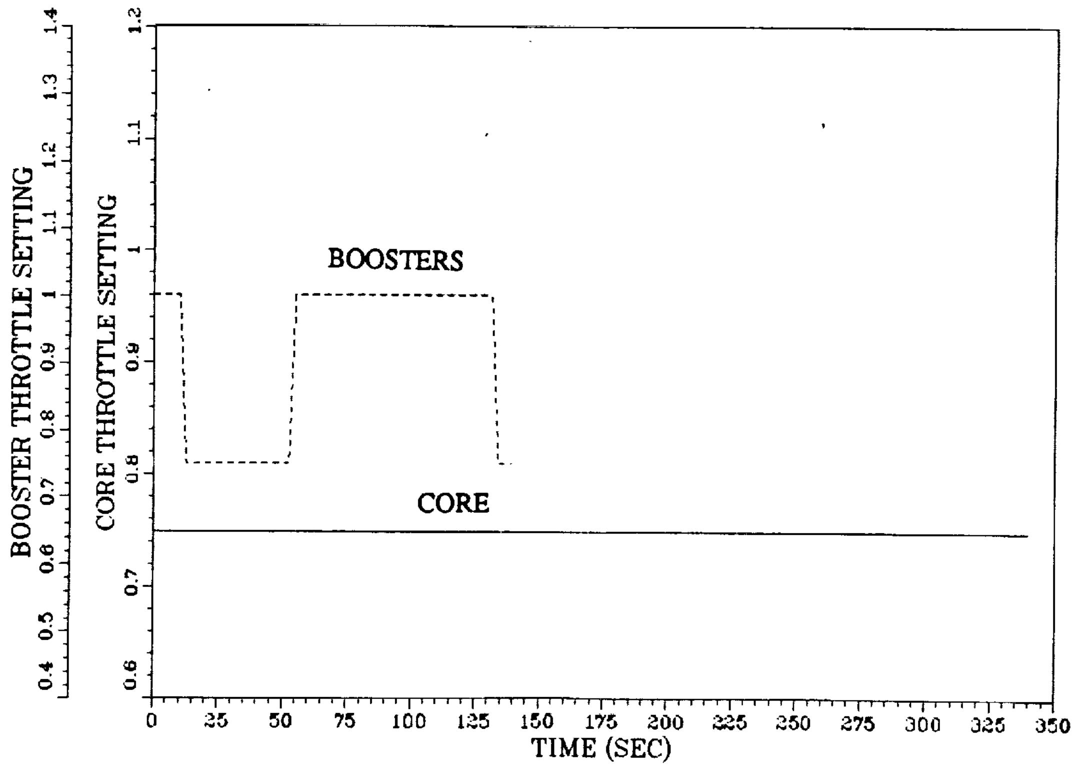


Figure 6.2-6. Throttle Setting vs Time

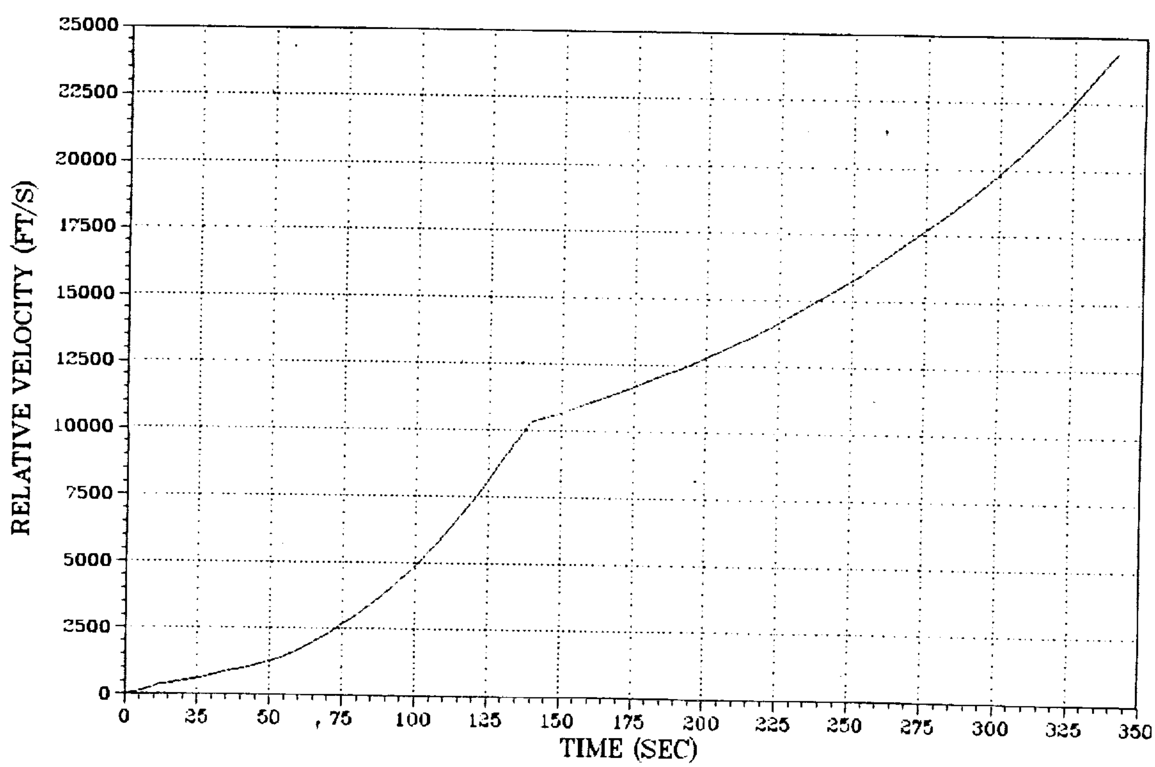


Figure 6.2-7. Velocity vs Time

COSTS. For the development of cost estimates, 4 major assumptions were employed, which are:

- LRB was developed originally for STS and modified for use as an ELV
- A 12.5% DDT&E cost increase over that for the STS was assumed for modifications of the LRB core and boosters.
- The estimate for the Titan IV fairing includes a small DDT&E expenditure for modification to fit with the 18' core LRB.
- Costs for launch facility modifications were excluded at this time.

Table 6.2-4 lists the costs of the LRB core-to-orbit configuration (two boosters used). Costs were calculated using the LRB cost spreadsheet which includes the benefits of rate effects, (i.e., the combined LRB ELV and STS LRB mission models). These costs are to be used for planning purposes only.

Table 6.2-4. Cost Summary of The Core-To-Orbit Launch Vehicle (2 Boosters Used) (1987 $M)

Core-to-Orbit	DDT&E	AUC/Vehicle
LRB	272.00	
Structure/TPS		17.37
Sep System		1.31
Propulsion		6.73
Main Eng		33.17
Actuators		1.90
Avionics/Power		10.33
Sustaining Engr/Tooling/FA		11.58
Spares/Syst Engr/PM		2.37
P/L Fairing	6.64	2.29
Upperstage	0.00	0.00
Integration	10.00	0.00
Additional Avionics-S/W	38.30	3.10
Operations	0.00	3.31
TOTAL	327	93.47

OPERATIONS.The core-to-orbit LRB standalone will be assembled in the following manner: final assembly of each element will take place at the LRB manufacturing facility. If this facility is located in the vicinity of the launch site, the elements (i.e. the core and boosters) will be mated there as well; if this is not the case, the vehicle will be assembled in a dedicated facility at the launch site. If the vehicle is part of the ALS family, ALS facilities might be used. The vehicle will be erected, the payload mated and the entire assembly will be taken to the pad for final pad operations and launch. In general the pre-launch operations will be fairly simple, as many tests and checkout procedures will be automated, such as component test and leak checks.

SECTION 7
CONCLUSIONS

The following briefly summarizes the major results of the alternate applications and LRB Evolution and Growth.

LRB APPLICATIONS TO ALS:

- The LO2/LH2 LRB is best suited for ALS because of common propellants.
- The LO2/LH2 LRB has very similar engines to the ALS, thus a common engine development is possible.
- A family of vehicles with payload capabilities ranging from 50-200k lbs can be derived by varying the number of LRBs used, and the number of engines used per LRB.
- Use of LRBs for ALS can reduce NASA's LRB DDT&E and recurring production costs (i.e., shared program with USAF).

LRB APPLICATION TO STANDALONE EXPENDABLE LAUNCH VEHICLES:

- LRB standalone expendable launch vehicles can be used as an initial building block for ALS in the lower payload range.
- New LRB standalone launch vehicles provide an additional measure of assured access to space.
- The LO2/LH2 LRB has the best performance of candidate LRB designs for standalone launch vehicle applications.
- The recommended LRB standalone launch vehicle is a core-to-orbit concept which use 1 or 2 LRB boosters in a modular approach to deliver 25-80 Klbs of payload to LEO (see Section 6.2).

LRB APPLICATION TO SHUTTLE-C:

- LRBs provide approximately 20k lbs greater payload capability than SRBs for Shuttle-C.
- Use of LRB engines as SSME replacements may lower Shuttle-C costs per flight.
- Applicability of LRBs and LRB engines to Shuttle-C provides NASA with an additional measure of assured access to space.
- The LRB provides many of the same benefits to the Shuttle "C" that it provides the shuttle,

such as improved reliability (i.e., engine out capability) and safer operations (i.e., hazardous propellants are removed from the VAB).

SECTION 8
RECOMMENDATIONS FOR FURTHER STUDY

Several growth areas need further study. The first is a more complete analysis (including more complete costs) of the possible applications of LRBs to ALS and Shuttle -C. Emphasis needs to be placed on identifying requirements for a common ALS/LRB engine.

The second area to be investigated is the potential upgrades to the LRB itself. Upgrades in the major booster subsystems should be analyzed and a growth plan for the recommended upgrades be generated. Table 8-1 shows some of the potential upgrades which need to be further addressed.

Table 8-1. Future LRB Growth/Upgrade Potential

APPLICATION OF AUTOMATED MANUFACTURING

- Robotics
- Non-Destructive Testing
- Simplification of Processes

SIMPLIFICATION OF LAUNCH OPERATIONS

- Incorporate Built-In-Test (BIT) to Greater Extent
- Use Launch History to Streamline Operations
- Develop Improved Check/Out Techniques

PROPULSION SYSTEM UPGRADES

- Incremental Increases of Isp, Thrust
- Incorporation of Design Simplifications
- Increased Use of Health Monitoring

USE OF NEW MATERIALS

- Composites
- Speciality Alloys

AVIONICS UPGRADES

- Adaptive GN&C
- Expert Systems

References

[1] Advanced Launch System (ALS), SDR Data Package, Volume II, Book 1, General Dynamics Space Systems Division, Contract No. F04701-87-C-0101 (June 1988).

[2] Advanced Launch System (ALS), System Requirements Document Issued By USAF Space Division (23 Nov. 88), #SD-ALS-R-SRD-v2.0.

[3] Advanced Launch System (ALS), SDR Data Package, Volume II, Book 1, Appendix A, General Dynamcs Space Systems Division, Contract No. F04701-87-C-0101 (June 1988).

[4] Advanced Launch System (ALS), SDR Data Package, Volume II, Book 1, Appendix A, General Dynamcs Space Systems Division, Contract No. F04701-87-C-0101 (June 1988).

[5] Space Transportation Architecture Study, Special Report - Final Phase, Book 1, Executive Summary, Contract NAS8-36615 (30 November 1987) p. 1-2.

[6] Launch Vehicle Simulation Data Book (Titan IV/Centaur Configuration), Issue 4 - September 1988, Martin Marietta p. 1-3.

[7] Launch Vehicle Simulation Data Book (Titan IV/Centaur Configuration), Issue 4 - September 1988, Martin Marietta pp. 1-1 & 1-2.

[8] Phase I Reference Configuration Data Package Memo (Enclosure #4) From PF24/Robert G. Eudy, NASA/MSFC, (May 16, 1988)

[9] "Shuttle - C Updated Trajectories" Data Package, S. Powell/EP55 (NASA/MSFC), (7/19/88).

[10] "Shuttle - C Updated Trajectories" Data Package, S. Powell/EP55 (NASA/MSFC), (7/19/88).

[11] "Liquid Rocket Booster Study Final Report, Volume II", General Dynamics Space Systems Division, February 1989, Section 9.3 - Ground Operations.