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NAS8-37136
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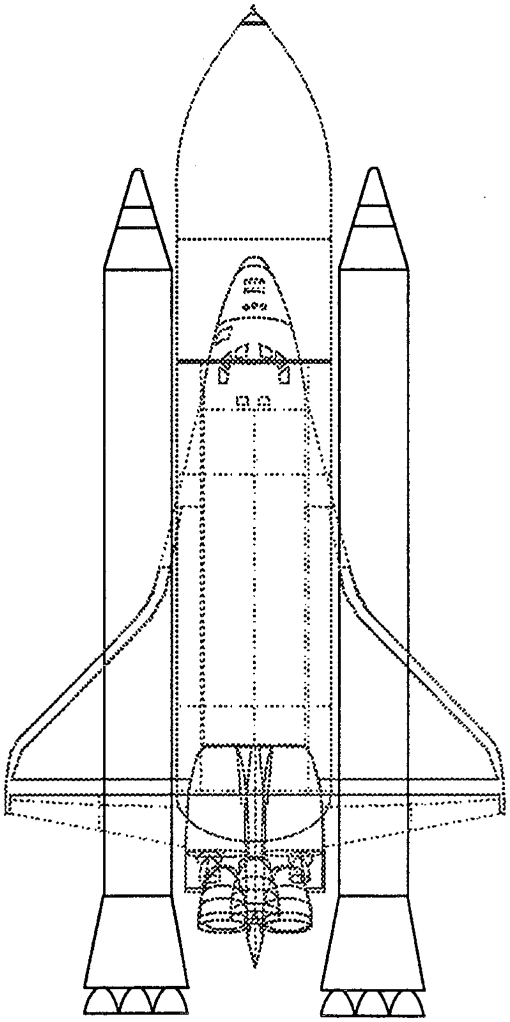
Volume II

March 1989

Final
Report

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



(NASA-CR-183786) LIQUID ROCKET BOOSTER
(LRB) FOR THE SPACE TRANSPORTATION SYSTEM
(STS) SYSTEMS STUDY, VOLUME 2 Final Report
(Martin Marietta Corp.) 301 p CSCL 21H

N90-28600

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G3/20 0251591

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FOREWORD

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

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

ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
ACU	Actuator Control Units
ALS	Advanced Launch System
BSM	Booster Separation Motor
CAD	Computer Aid Design
CARD	Computer Program
CDF	Confined Detonating Fuse
CEC	Lewis Code
CEI	Contract End Item
CG	Complementary Grading
CH4	Methane
CIL	Critical Items List
CNC	Computer Numerically Controlled
6-DOF	6 Degrees of Freedom
DR	Data Requirements
EB	Electron Beam
EPL	Engineering Propulsion Laboratory
ET	External Tank
ETR	Eastern Test Range
F-1	F-1 Engine
FCS	Flight Control System
FPL	Full Power Level
FSS	Fixed Service Structure
GDA	General Dynamics Astronautics
GG	Gas Generater
GHe	Gaseous Helium
GIDEP	Government-Industry Data Exchange Program
GLOW	Gross Lift Off Weight
GMA	Gas Metal Arc
GO2	Gaseous Oxygen
GSE	Ground Support Equipment
GTA	Gas Tungsten Arc
GUCA	Ground Umbilical Carrier Assembly
GVTA	Ground Vibration Test Article

H2	Helium
HAWs	Hazard Analysis Worksheets
HGDS	Hazardous Gas Detection System
HVAC	Heating, Ventilating, and Air Conditioning
IEAS	Integrated Electronic Assembly
ILRB	Integrated Liquid Rocket Booster
ILS	Integrated Logistics Support
INCO	Integrated Communications Officer
IOC	Initial Operating Capability
I/T	Intertank
IWTF	Industrial Wastewater Treatment Facility
KIMS	Kennedy Inventory Management System
Klb	Thousand, Pound(s)
KSC	Kennedy Space Center
LARIAT	Liquid Rocket Booster Automated Redundant Instrumentation for Anomaly Testing
lbf	Pound(s), Force
LCC	Life Cycle Cost
LEO	Low Earth Orbit
LH2	Liquid Helium
LO2	Liquid Oxygen
LRB	Liquid Rocket Booster
LRBUCA	Liquid Rocket Booster Umbilical Carrier Assembly
LRU	Line Replacement Unit
LSOC	Lockheed Space Operations Company
MAF	Michoud Assembly Facility
MARs	Martin marietta Anomaly Report
MCU	Motor Control Units
MECO	Main Engine Cut Off
MPTA	Main Propulsion Test Article
MSS	Manned Space Systems
MSFC	Marshall Space Flight Center
MLP	Mobile Launch Platform
NASA	National Aeronautics and Space Administration
NASTRAN	National Aeronautics and Space Administration Strucutral Analysis
NPL	Nominal Payload

NSTS	National Space Transportation System
OFO	Oxidizer-Fuel-Oxidizier
PF	Pressure-fed, Pump-fed
PFBTB	Pressure-Fed Booster Test Bed
PIC	Power (Pryotechnic) Initiator Controller
PHA	Preliminary Hazard Analysis
PHAROS	Preliminary hazard Analysis, Review of Overall System
PSIA	pressure square inch, absolute
RGA	Rate Gryo Assembly
ROM	Rough Order of Magnitude
RP-1	Rocket Propellant
RSS	Rotating Service Structure
SDH	System Definition Handbook
SETA	Single Engine Test Article
SFP	Single Failure Point
SLA	Super-Light Ablator
SOFI	Spray-On Foam Insulation
SPL	Sound Pressure Level
SRB	Solid Rocket Booster
SRU	Shop Replaceable Unit
SSC	Stennis Space Center
SSME	Space Shuttle Main Engine
STA	Structural Test Article
STARs	Software Technology for Adaptable, Reliable Systems
STS	Space Transportation System
TCA	Thrust Chamber Assembly
TEA	Torque Equilibrium Attitude
TEB	Triethylborane
TF	Turbopressure-fed, Turbopump-fed
TPA	Technical Procedures Analysis
TPS	Thermal Protection System
TVC	Thrust Vector Control
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VPPA	Variable Polarity Plasma Arc

TABLE OF CONTENTS

Vol. II Part 1 Systems Definition Handbook

1.0 Introduction 1-1
1.1 Study Summary 1-1
1.2 Systems Definition Handbook Arrangement 1-2
2.0 Overview 2-1
2.1 STS/LRB Configurations 2-1
2.1.1 STS Coordinate Convention 2-1
2.1.2 LRB/STS Coordinate System and Dimension 2-6
2.2 Mission Operations 2-6
2.2.1 Physical/Functional Flow 2-6
2.2.2 Impacts to Facilities and Processing Operations 2-6
2.2.2.1 New Facilities 2-9
2.2.2.2 Modified Facilities 2-11
2.2.2.3 Mobile Launch Platform 2-15
2.2.2.4 Pad Modifications 2-19
2.2.2.5 Processing Operations 2-21
2.2.3 Flight Operations 2-24
2.3 Manufacturing 2-24
2.4 Technology Requirements 2-24
3.0 LRB Requirements 3-1
3.1 STS Program 3-1
3.1.1 Requirement Source 3-1
3.1.2 System/Design Requirement 3-1
3.1.2.1 System Requirements 3-1
3.1.2.2 Design Requirements 3-2
3.2 Level II Requirements 3-3
3.3 Level III Requirements 3-3
4.0 Trade Studies 4-1
4.1 Trade Study Methodology 4-1
4.2 Structural Trade Summary 4-1
4.3 Propulsion Trade Summary 4-1
4.4 Avionics Trade Summary 4-7
5.0 Mission Analyses 5-1

5.1 Environment 5-1
5.1.1 Natural Environment 5-1
5.1.2 Thermal Environment 5-1
5.1.2.1 Ascent Aerodynamic Heating 5-1
5.1.2.2 LRB Base Heating 5-1
5.1.2.3 Acoustics Sources 5-2
5.1.2.4 Acoustics Environment 5-2
5.1.3 Overpressure 5-3
5.2 Loads Analysis 5-3
5.3 Vehicle Performance and Mission Operations 5-5
5.3.1 Prelaunch/Liftoff 5-5
5.3.2 Ascent 5-5
5.4 Flight Control Systems Analysis 5-17
5.4.1 STS/LRB Stability Analysis 5-17
5.4.2 6 DOF Trajectory Simulatin Analysis 5-21
6.0 LRB Description - Pump Fed 6-1
6.1 General Configuration 6-1
6.1.1 Shuttle/LRB Vehicle 6-1
6.1.2 LRB 6-1
6.1.3 Mass Properties 6-1
6.2 Structures 6-11
6.2.1 Nosecone 6-11
6.2.2 Fwd Skirt and Crossbeams 6-11
6.2.3 Oxidizer Tank 6-12
6.2.4 Intertank 6-12
6.2.5 Fuel Tank 6-12
6.2.6 Aft Skirt/Thrust Structure 6-13
6.2.7 Structural Interface 6-13
6.2.7.1 Forward LRB/ET Attach 6-13
6.2.7.2 Aft LRB/ET Attach 6-13
6.2.7.3 MLP Hold Down Supports 6-14
6.2.8 Cable Trays/Fairings and Fittings 6-14
6.2.9 Thermal Protection 6-14
6.2.10 Acoustic Protection 6-14
6.2.11 Major Ground Test 6-16
6.3 Propulsion/Mechanical 6-19

6.3.1 Turbopump-Fed (TF) Engine 6-19
6.3.1.1 Fuel Cooled Thrust Chamber Assembly (TCA) 6-19
6.3.1.2 Injector 6-22
6.3.1.3 Turbopump 6-22
6.3.1.4 Gas Generator 6-22
6.3.1.5 Main Propellant Throttling Valves 6-26
6.3.1.6 Silica Phenolic Nozzle Extension 6-26
6.3.1.7 Heat Exchangers 6-26
6.3.1.8 Engine Controller 6-26
6.3.2 Pressurization System 6-26
6.3.3 Fill, Feed, Drain, Vent Subsystems 6-30
6.3.4 Hazardous Gas Detection and Compartment Purge Requirements 6-30
6.3.5 Separation System 6-33
6.3.6 Thrust Vector Control 6-33
6.3.7 Umbilicals 6-33
6.4 Electrical/Avionics 6-39
6.4.1 General Configuration 6-39
6.4.2 Engine Controller 6-39
6.4.3 Software Language 6-39
6.4.4 Thrust Vector Control 6-44
6.4.5 Power 6-45
6.4.6 Electrical Interface 6-45
6.4.7 Range Safety System 6-45
6.5 Systems Analyses 6-46
6.5.1 Structural Analyses 6-46
6.5.1.1 Loads/Dynamics Analysis 6-46
6.5.1.2 Stress Analysis 6-65
6.5.1.3 Materials Properties 6-65
6.5.2 Thermal Analysis & TPS 6-71
6.5.3 Propulsion Analysis 6-71
7.0 LRB Description - Pressure Fed 7-1
7.1 General Configuration 7-1
7.1.1 Shuttle/LRB Vehicle Pressure-Fed 7-1
71.2 LRB 7-1
7.1.3 Pressure-Fed LRB-Mass Properties 7-1
7.2 Structures 7-11

7.2.1 Nosecone 7-11
7.2.2 Forward Skirt & Thrust Beam Assembly 7-11
7.2.2.1 Helium Pressurant Tank 7-11
7.2.3 Oxidizer 7-12
7.2.4 Intertank 7-12
7.2.5 Fuel Tank 7-12
7.2.6 Aft Skirt/Thrust Structure 7-13
7.2.7 Structural Interface 7-13
7.2.8 Cable Trays/Fairings 7-13
7.2.9 Thermal Protection 7-13
7.2.10 Acoustic Environment 7-13
7.2.11 Major Ground Test 7-13
7.3 Propulsion/Mechanical 7-14
7.3.1 Pressure-Fed (PF) Engine 7-14
7.3.1.1 Ablative Thrust Chamber Assembly (TCA) 7-14
7.3.1.2 Injector 7-18
7.3.2 Pressurization System 7-18
7.3.2.1 Gas Generators 7-23
7.3.2.2 Heat Exchangers 7-23
7.3.3 Fill, Feed, Drain, Vent 7-23
7.3.4 Hazardous Gas Detection and Compartment Purge Requirements 7-27
7.3.5 Separation 7-27
7.3.5.1 Booster Separation Subsystem 7-27
7.3.5.2 Release System 7-27
7.3.5.3 Booster Separation Motor (BSM) Cluster 7-27
7.3.5.4 BSM Critical Features 7-27
7.3.5.5 LRB Separation Sequence 7-31
7.3.5.6 Debris 7-31
7.3.6 Thrust Vector Control 7-31
7.3.7 Interfaces 7-31
7.3.7.1 LRB Umbilical Assembly (LRBUCA) 7-31
7.3.7.2 Ground Umbilical Carrier Assembly (GUCA) 7-31
7.4 Electrical/Avionics 7-31
7.4.1 General Configuration 7-31
7.4.2 Engine Controller 7-33
7.5 Systems Analyses 7-33

7.5.1 Structural Analyses 7-33
7.5.1.1 Loads/Dynamics Analysis 7-33
7.5.1.2 Stress Analysis 7-33
7.5.1.3 Materials 7-33
7.5.2 Thermal Analysis & TPS 7-34
7.5.3 Propulsion Analysis 7-34
8.0 Logistic Requirements 8-1
8.1 Overview 8-1
8.2 Maintainability Requirements 8-1
8.3 Reusability 8-1
8.4 Transportation 8-2
8.5 Ground Operations 8-2
8.6 Facilities 8-4
9.0 Safety, Reliability, and Quality Assurance 9-1
9.1 Safety and Hazard Analysis 9-1
9.1.1 Risk Management Approach 9-1
9.2 Preliminary Reliability Assessment 9-2
9.3 Quality Assurance Requirements 9-2
9.3.1 Approach 9-2
9.3.2 Controls and Inspections 9-9
9.3.3 Other Areas 9-9
9.4 Safety Engineering 9-10
9.4.1 General 9-10
9.4.1.1 Inspection and Access 9-10
9.4.1.2 Failure Control 9-10
9.4.1.3 Line Replaceable Units 9-11
9.4.1.4 Use of Strain Gauges During Proof Test 9-11
9.4.1.5 Draining 9-11
9.4.1.6 Nuclear Event Protection 9-12
9.4.1.7 Preflight Testing 9-12
9.4.1.8 Ground Temperature Conditioning 9-12
9.4.2 Structure 9-13
9.4.2.1 Thermal, Acoustic, Static and Dynamic Loads 9-13
9.4.2.2 Venting 9-13
9.4.2.3 Thermal Protection System (TPS) 9-14
9.4.2.4 LRB Interface Connections 9-14

9.4.2.5 Antigeysering System 9-14
9.4.3 Electrical System 9-15
9.4.3.1 Electrical Circuit Protection 9-15
9.4.3.2 Connectors 9-15
9.4.3.3 Transducer Simplicity 9-16
9.4.3.4 Momentary Interruptions 9-16
9.4.4 Instrumentation 9-16
9.4.4.1 Preflight Electrical Power 9-17
9.4.4.2 Integral Fire Detection System 9-17
9.4.4.3 Hazardous Gas Detection System (HGDS) 9-17
9.4.4.4 Range Safety System 9-17
9.4.4.5 Pyrotechnic Handling 9-18
9.4.5 Engine System 9-18
9.4.5.1 Engine Pressurization Capability 9-18
9.4.5.2 Engine Gimballing 9-19
9.4.5.3 Engine Drainage 9-19
9.4.5.4 Prevention of Heat Exchanger Single Point Leaks 9-19
9.4.5.5 Valve Timing 9-19
9.4.6 Separation System 9-19
9.4.6.1 LRB Separation Sequence 9-19
9.4.6.2 Separation Motor Thrust 9-20
9.4.6.3 Thrust Termination After Engine Start 9-20
10.0 Production 10-1
10.1 Manufacturing Overview 10-1
10.2 Pump-Fed Manufacturing 10-3
10.3 Pressure-Fed Manufacturing 10-3
10.4 Facilities Overview 10-5
10.5 Contamination Prevention 10-9
11.0 Environmental Assessment 11-1
12.0 Technology Requirements 12-1
12.1 Overview 12-1
12.2 Material 12-1
12.3 Propulsion Engine Development 12-1
12.4 Manufacturing Development 12-2
12.4.1 Thick-Wall Welding 12-2
12.4.2 Flow Turning 12-5

12.4.3 One-Piece Helium Pressurant Tank Domes 12-9
12.4.4 Al-Li Manufacturing Requirements 12-9
13.0 Optimization Studies 13-1
13.1 Configuration Design 13-1
13.1.1 Pump-Fed Vehicle Material 13-1
13.1.2 Vehicle Sizing 13-1
13.2 Propulsion System 13-3
13.2.1 Engine Ignition and Shutdown Transients 13-3
13.2.2 Pressure-Fed Engine Inlet Feedline Geometry 13-7
13.2.3 Ignition Sequence 13-7
13.2.4 Pressure-Fed Engine Pc Optimization 13-7
13.3 Vehicle Performance 13-9

Vol. II Part 2 PFBTB Support

1.0 PFBTB Support - Overview 1-1
1.1 CO NAS8-137136 Sup. Agreement 1 - 2/88-5/88 1-1
1.2 Contract Extension - 8/88-12/88 1-2
2.0 PFBTB Programmatics Support 2-1
2.1 Work Breakdown Structure (WBS) 2-1
2.2 Tasks 2-1
2.2.1 Task Tree 2-9
2.2.2 Task Plans 2-9
2.3 Program Schedule 2-18
2.4 Program Cost Estimates 2-19
2.5 Programmatic Summary 2-25
3.0 Pressure-Fed Booster Test Bed Support 3-1
3.1 Analysis 3-1
3.2 Criteria and Loading Conditions 3-1
4.0 MSFC Support 4-1
4.1 Program Documentation 4-1
4.2 Test Area Technician 4-1

Vol. II Part 3 Alternate Applications

1.0 Overview 1-1
2.0 Advanced Launch System (ALS) 2-1
2.1 ALS/LRB Option 1 Configuration 2-1
2.1.1 Engines 2-4
2.1.2 Performance 2-4
2.2 ALS/LRB Option 2 Configuration 2-6
2.2.1 Engine 2-10
2.2.2 Performance 2-10
2.3 ALS/LRB Option 3 Configuration 2-12
2.3.1 Engines 2-12
2.3.2 Performance 2-12

FIGURES

NUMBER TITLE PAGE

Vol. II Part 1 Systems Definition Handbook

2.1-1 Baseline Pump-Fed LRB Configuration.......... 2-2
2.1-2 Baseline Pressure-Fed LRB Configuration.......... 2-3
2.1-3 Shuttle LRB/SRB Configurations.......... 2-4
2.1.1-1 The Shuttle System Elements Coordinate System.......... 2-5
2.2.1-1 LRB Physical Flow.......... 2-7
2.2.1-2 LRB Functional Flow.......... 2-8
2.2.2.1-1 General Configuration/LRB Portion ET/LRB Horizontal Processing Facility.......... 2-10
2.2.2.2-1 Typical Integration Cell Modification.......... 2-12
2.2.2.2-2 VAB Exit Clearance Platform Modifications.......... 2-13
2.2.2.2-3 VAB Integration Cell Exit Doors.......... 2-14
2.2.2.3-1 SRB Over Pressure Plumbing.......... 2-16
2.2.2.3-2 Heat Shielding on the Outer Exhaust Hole Edges.......... 2-17
2.2.2.3-3 MLP Main Girder Layout.......... 2-18
2.2.2.4-1 ET & SRB Access Platforms.......... 2-20
2.2.2.4-2 ET LH2 Vent Arm.......... 2-20
2.2.2.5-1 LRB Processing Operations Timeline.......... 2-22
4.1-1 Trade Study Methodology.......... 4-2
4.1-2 Trade Studies Criteria Matrix.......... 4-3
4.1-3 LRB Trade Study Example.......... 4-4
5.3.1-1 Pump-Fed Ignition Sequence.......... 5-6
5.3.1-2 Pressure-Fed Ignition Sequence.......... 5-7
5.3.2-1 Pump-Fed Trajectory Thrust & Throttle-70.5 k.......... 5-8
5.3.2-2 Pump-Fed Trajectory Altitude & Acceleration-70.5 k.......... 5-9
5.3.2-3 Pump-Fed Trajectory Alpha & Dynamic Pressure-70.5 k.......... 5-10
5.3.2-4 Pressure-Fed Trajectory Throttle & Thrust.......... 5-12
5.3.2-5 Pressure-Fed Trajectory Acceleration & Altitude.......... 5-13
5.3.2-6 Pressure-Fed Trajectory Dynamic Pressure & Alpha.......... 5-14
5.3.2-7 Ascent Trajectory q^a vs Mach.......... 5-15
5.3.2-8 Ascent Scenario.......... 5-16

5.4.1-1 Flex Stability Margins 5-20
6.1.1-1 STS With Pump-Fed Liquid Rocket Booster 6-2
6.1.2-1 Pump-Fed Structural Arrangement 6-3
6.2.9-1 LRB TPS 6-15
6.2.11-1 Major Ground Test 6-17
6.3.1-1 LO2/RP1 Pump-Fed Engine Schematic 6-20
6.3.1-2 LO2/RP1 LRB Pump-Fed Engine 6-20
6.3.1-3 LRB for STS Turbopump Fed Rocket Engine Configuration... 6-21
6.3.1.3-1 LRB Oxidizer TPA Design Features 6-24
6.3.1.3-2 LRB Fuel TPA Design Features 6-25
6.3.1.5-1 LRB Main Propellant Throttling Valves 6-27
6.3.2-1 Pump-Fed Pressurization System Layout 6-29
6.3.3-1 Pump-Fed Propellant Feed System 6-31
6.3.3-2 Pump-Fed Propellant Fill/Vent/Relief 6-32
6.3.4-1 LRB Purge and HGDS Schematic 6-34
6.3.6-1 TVC Actuators 6-35
6.3.7-1 Pump-Fed Vehicle Umbilicals LO2 UCP 6-36
6.3.7-2 Pump-Fed Vehicle Umbilicals RP-1 UCP 6-37
6.3.7-3 LRB Umbilical Locations 6-38
6.4.1-1 Avionics Architecture 6-40
6.4.1-2 Avionics Subsystem Locations 6-41
6.4.2-1 Pump-Fed LRB Engine Control 6-43
6.5.1.1-1 On-Pad SSME Firing Results 6-50
6.5.1.1-2 LRB Engine Forcing Functions 6-52
6.5.1.1-3 LRB Ignition Sequence 6-53
6.5.1.1-4 Max Accelerations Allowable, ET LO2 Dome 6-56
6.5.1.1-5 ET LO2 Tank Dome Pressure
SRB - Nominal Lift-off 6-58
6.5.1.1-6 ET LO2 Tank Dome Pressure
Pressure-Fed LRB - Nominal Lift-off 6-59
6.5.1.1-7 ET LO2 Tank Dome Pressure
Monocoque Pump-Fed LRB - Nominal Lift-off 6-60
6.5.1.1-8 Z Deflection at ET Intertank Umbilical 6-61
6.5.1.1-9 ET LO2 Tank Dome Pressure for
Strength Design Pump-Fed LRB 6-64
6.5.1.3-1 Material Properties (Plate) 6-69

6.5.1.3-2 Material Properties 6-69
6.5.2-1 LRB Shock Impingement Zones on ET 6-72
7.1.1-1 STS with a Pressure-Fed Liquid Rocket Booster 7-2
7.1.2-1 Pressure-Fed Structural Arrangements 7-3
7.3.1-1 LO2/RP1 LRB Pressure-Fed Engine 7-15
7.3.1.1-1 M-1 Ablative Thrust Chamber 7-16
7.3.1.2-1 M-1 Coaxial Injector, 12-Rib Bolt-on Dome 7-19
7.3.1.2-2 Core Concept Injector 7-19
7.3.2-1 Phase A Pressure-Fed Propulsion System Operation 7-22
7.3.2-2 LRB Baseline Pressurization System Schematic 7-24
7.3.2.2-1 Aerojet Fuel Heat Exchanger 7-26
7.3.3-1 LRB Pressure-Fed Propellant Feed System 7-28
7.3.3-2 LRB Pressure-Fed Engine Feedline Inlet Design 7-29
7.3.3-3 LRB Pressure-Fed Engine Wrap Around Feedline Design 7-30
7.4.2-1 Pressure-Fed Engine Controller 7-32
8.4-1 Transporter Fixture 8-3
9.2-1 LRB Reliability Allocation 9-3
9.2-2 LRB Reliability Allocation 9-4
9.2-3 LRB Reliability Allocation 9-5
9.2-4 LRB Reliability Allocation 9-6
9.2-5 LRB Reliability Allocation 9-7
9.2-6 LRB Reliability Allocation 9-8
10.1-1 LRB Pump-Fed Structural Components 10-2
10.1-2 LRB Pressure-Fed Structural Components 10-2
10.2-1 Pump-Fed LO2 Tank Configuration 10-4
10.3-1 Pressure-Fed LO2 Tank Configuration 10-4
10.4-1 Facilities Overview-Michoud Assembly Facility (MAF) Site Plan 10-6
12.4.1-1 Electron Beam Weld in 6.0 inch Aluminum 12-3
12.4.1-2 EB Weld Versus VPPA for 2219-T87 Plate 12-4
12.4.1-3 Pressure-Fed Tank Electron Beam Welding Cell 12-6
12.4.1-4 Electron Beam Welding Cell Detail 12-7
13.1.1-1 LRB Trade Studies Plan 13-2
13.1.2-1 Weldalite™049 Vehicle Size/Payload Relationships 13-4
13.1.2-2 2219 AL Vehicle Size/Payload Relationship 13-5
13.2.1-1 Pressure-Fed Engine Start Transient 13-6

13.2.2-1 Pressure-Fed Engine Inlet Feedline Geometry 13-8
13.2.4-1 Engine & Structure Analysis As Function of Pressure 13-10

Vol. II Part 2 PFBTB Support

2.1-1 WBS Tree Diagrams 2-4
2.2.1-1 Program Task Trees 2-10
2.2.1-2 Program Task Trees 2-10
2.3-1 Pressure-Fed Booster Test Bed Project Schedule 2-20

Vol II Part 3 Alternate Applications

2.1-1 ALS/LRB Option 1 2-3
2.1.1-1 ALS Cor Engine - Option 1 & 2 2-5
2.2-1 ALS/LRB Option 2 2-9
2.2.1-1 Pump-Fed Engine LO2/LH2 - Option 2 2-11
2.3-1 ALS/LRB Option 3 2-13
2.3.1-1 ALS/Core/Booster Engine - Option 3 2-14

TABLES

NUMBER TITLE PAGE

Vol. II Part 1 Systems Definition Handbook

2.2.2.2-1 VAB Platform Modification Summary 2-12
2.2.3-1 LRB Abort Capabilities 2-25
4.2-1 Structural/Mechanical Trades Summary 4-5
4.3-1 Propulsion Trades Summary 4-6
4.4-1 Avionics Trades Summary 4-8
5.2-1 ET Interface Loads - Ultimate 5-4
5.3.2-1 LRB Optimum Performance Configuration 5-11
5.4.1-1 Honeywell Control Model 5-18
5.4.1-2 SRB/LRB Free-Free Modes Comparison 5-19
6.1.3-1 Pump-Fed Dry Weight Mass Properties 6-4
6.1.3-2 Pump-Fed Weight Summary 6-5
6.1.3-3 NSTS/LRB Pump-Fed Launch Vehicle Properties 6-6
6.3.1.2-1 Principal Descriptors of the LRB Main Injector Design 6-23
6.3.1.3-1 LRB Turbopump Requirements 6-23
6.3.1.7-1 Results of the Preliminary Design of the Heat Exchanger 6-28
6.4.1-1 LRB Avionics 6-42
6.5.1.1-1 As-Modeled Mass and CG 6-48
6.5.1.1-2 Vehicle Mass and CG 6-48
6.5.1.1-3 ET Loads Due to the Launch Transient 6-54
6.5.1.1-5 Strength-Designed Pump-Fed LRB: Loads for Optimum and Non-Optimum Launch 6-63
6.5.1.3-1 LRB Trade Study (Materials) - Sheet 6-67
6.5.1.3-2 LRB Trade Study (Materials) - Plate 6-68
6.5.1.3-3 Structural Weight Comparison Estimates for Selected Materials 6-70
7.1.3-1 Pressure-Fed Dry Weight Material Properties 7-4
7.1.3-2 Pressure-Fed Weight Summary 7-5
7.1.3-3 NSTS/LRB Pressure-Fed Launch Vehicle System Properties 7-6

7.3.1.1-1 Comparison of LRB with Other System's
Exhaust Species 7-17
7.3.1.2-1 Pressure-Fed Frequency Stability Trades 7-20
7.3.1.2-2 Stability Aids Required for Pressure-Fed 7-21
7.3.2.2-1 Pressurization System Heat Exchanger 7-25
12.4.1-1 ROM Cost Estimates Electron Beam Welding
Vs VPPA-GTA/GMA 12-8

Vol. II Part 2 PFBTB Support

2.1-1 WBS Matrix 2-2
2.4-1 PFBTB Project Cost Estimate (Phase O) 2-22
2.4-2 WBS Spreadsheet 2-23
2.5-1 Comprehensive Spreadsheet 2-26

Vol. II Part 3 Alternate Applications

2.0-1 Mission Support Requirements 2-2
2.1.2-1 STS/LRB Performance 2-7
2.1.2-2 ALS/LRB Performance 2-8

VOLUME II PART 1

SYSTEMS DEFINITION HANDBOOK

VOL II PART 1 - SYSTEMS DEFINITION HANBDBOOK

1.0 INTRODUCTION

The LRB Systems Definition Handbook, Volume II of the LRB Study Final Report, presents the analyses and design data developed during the study. Contents and data enclosed are consistent with the data presented in Volume I, Executive Summary, and Volume III, Program Cost Estimates. Included in this volume are the results of all trade studies; final configurations with supporting rationale and analyses; technology assessments: long lead requirements for facilities, materials, components, and subsystems; operational requirements and scenarios; and safety, reliability and environmental analyses.

A summary of the program is presented in Section 1.1, the arrangement of the handbook is described in 1.2. This volume satisfies the data requirements of DR Number 4 of the Documentation Requirements listed in the Work Statement.

1.1 STUDY SUMMARY

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

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

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

Two booster engine designs were studied. The first engine design was a turbo pump-fed engine with state of the art design and the second was a pressure-fed engine which was to provide a lower cost alternative to the pump-fed concept. Both booster concepts were carried through to completion of conceptual design and all system impacts and program costs were identified.

Alternative applications for LRB use in the Advanced Launch System (ALS) program were studied using pump-fed LRB baseline concept and variations on the baseline concept. Support for the Pressure-Fed Booster Test Bed (PFBTB) included test program planning and costs and technical support

During the course of the program key issues were identified and resolved so that final assessment of the program could be accomplished. These issues included:

- Program costs for both concepts
- LRB recoverability;
- LRB integration into the STS;
  - Loads
  - Operations
- STS/LRB abort options;
- Technology Requirements,

At the conclusion of the study, it has been determined that;

- All study requirements have been met
- LO2/RP-1 is the recommended propellant for both the pump-fed and the pressure-fed systems;
- Both pump and pressure-fed vehicles are expendable;
- Both vehicles can achieve equivalent abort capabilities;
- There are no enabling technology requirements for the pump-fed system;
- Technology requirements for the pressure-fed system involve high strength materials, i.e. Weldalite-™049, and pressurization systems components;
- Liquid propellant booster vehicles with multiple engines increase STS performance and provide increased STS safety and reliability;
- Using current technology, the pump-fed vehicle results in the lowest program LCC
- Using advanced technology, the pressure-fed vehicle results in the lowest program LCC

1.2 SYSTEMS DEFINITION HANDBOOK ARRANGEMENT

This Systems Definition Handbook (SDH) on the LRB contains three major parts. Part 1 is the LRB vehicles definition, Part 2 presents the Pressure-Fed Booster Test Bed (PFBTB) study results and Part 3 presents the ALS/LRB study results. Part 1 contains 13 sections organized on a functional/system bases.

Section 1.0-**Introduction**-Briefly describes the subject of the SDH, its purpose and content arrangement.

Section 2.0-**Overview**-Contains an overview of the Space Transportation System (STS) with the LRB as a shuttle vehicle element and including a description of mission operations, manufacturing requirements, and technology requirements.

Section 3.0-**LRB Requirements**-Presents the design and operational requirements for the LRB based on STS constraints and processing.

Section 4.0-**Trade Studies**-Briefly summarizes the trade study process used and presents the results.

Section 5.0-**Mission Analyses**-Contains descriptions of load analysis, mission operations and vehicle performance.

Section 6.0-**LRB Description-Pump-Fed**-Describes the overall pump-fed LRB configuration.

Section 7.0-**LRB Description-Pressure-Fed**-Describes the overall pressure-fed LRB configuration.

Section 8.0-**Logistics Requirements**-Discusses the overall supportability factors which influence the LRB program.

Section 9.0-**Safety, Reliability, and Quality Assurance**-Discusses the Safety and Hazard analysis performed as well as preliminary reliability and quality assurance evaluations.

Section 10.0-**Production-Manufacturing and Facilities Requirements**-Describes the LRB Facility requirements and manufacturing flow.

Section 11.0-**Environmental Assessment**-Discusses the environmental impacts of the LRB on the launch pad and any special requirements impacting the LRB processing.

Section 12.0-**Technology Requirements**-Discusses materials, propulsion and manufacturing technologies necessary for the LRB program.

Section 13.0-**Optimization Studies**-Discusses areas selected for further studies. Included are the aft-skirt, design update, one-engine failure impacts analyses and further refinements for the propulsion system.

2.0 OVERVIEW

This section presents an overview of the STS/LRB study program results relating to the recommended baseline configurations for the pump-fed and pressure-fed vehicles and summarizes the impacts on the Space Transportation System. Vehicle configurations are presented in Section 2.1 . Mission operations including impacts to ground and launch operations are summarized in Section 2.2. Section 2.3 summarizes LRB manufacturing approach, and Section 2.4 summarizes new technology required to complete a successful LRB program.

2.1 STS/LRB CONFIGURATION

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

Baseline configurations for two LRB concepts, a turbopump-fed engine design and a pressure-fed engine design, are shown in Figures 2.1-1 and -2 respectively. A composite of the two configurations with the SRB is shown in Figure 2.1-3. These two configurations were selected after extensive trade studies were completed for the propulsion, structural and mechanical systems.

2.1.1 STS Coordinate System Convention

The Shuttle system and Shuttle elements X, Y, Z coordinate systems are shown in Fig 2.1.1-1. The X, Y, Z coordinate systems for the orbiter, external tank, solid rocket booster, and Shuttle System are designated by the subscript letters O, T, B, and S and are shown in inches. The Shuttle vehicle dimensions are presented in the inset for reference.

Positive directions on the X,T, and Z axes are aft, to the right looking forward and up respectively. The Z location of all elements of the ET and orbiter systems are positive as the Z=0 coordinate for these systems is 400 in below the ET centerline. The Z=0 coordinate for the SRB is in the SRB centerline.

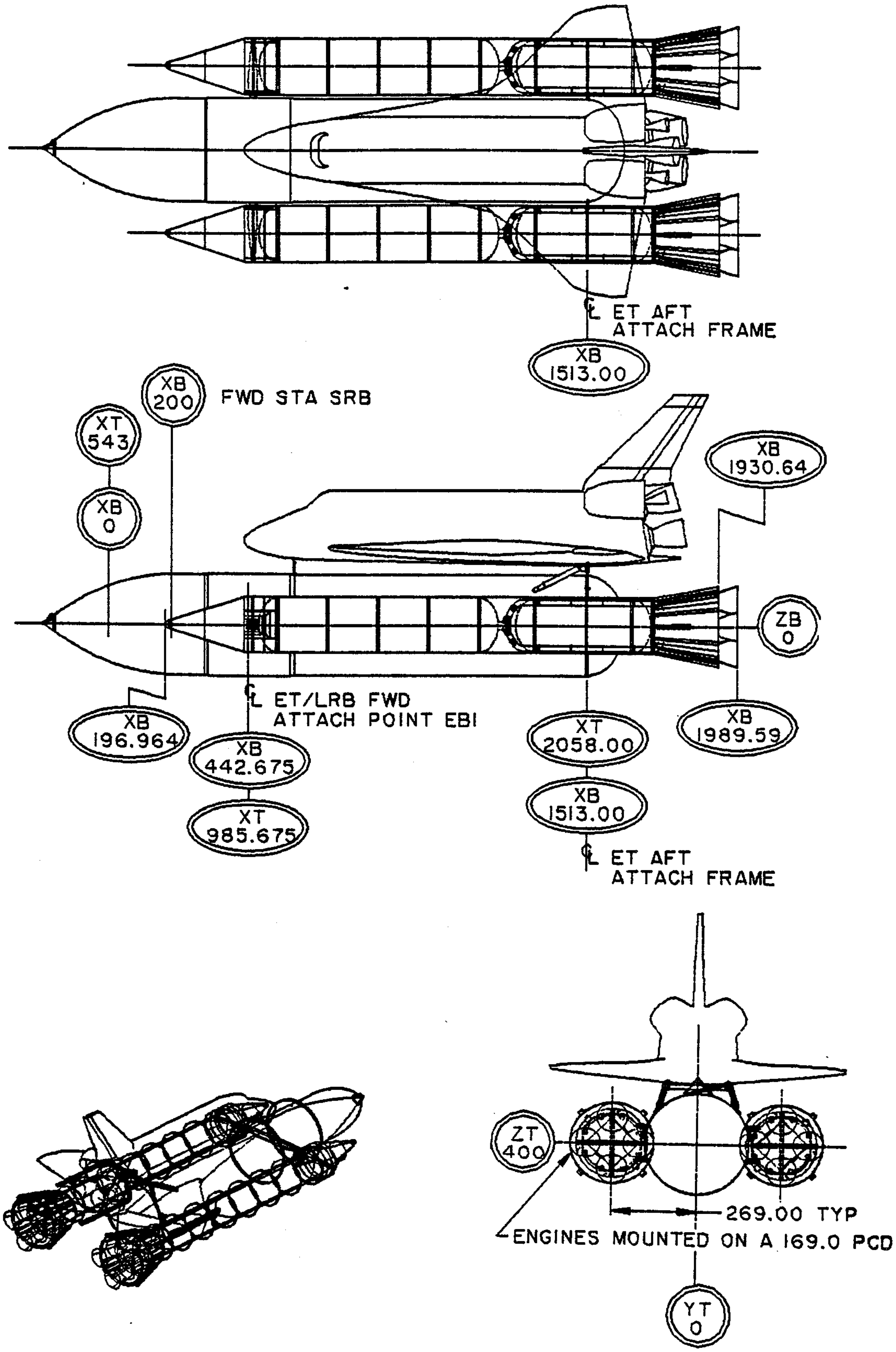


Figure 2.1-1 Baseline Pump-Fed LRB Configuration

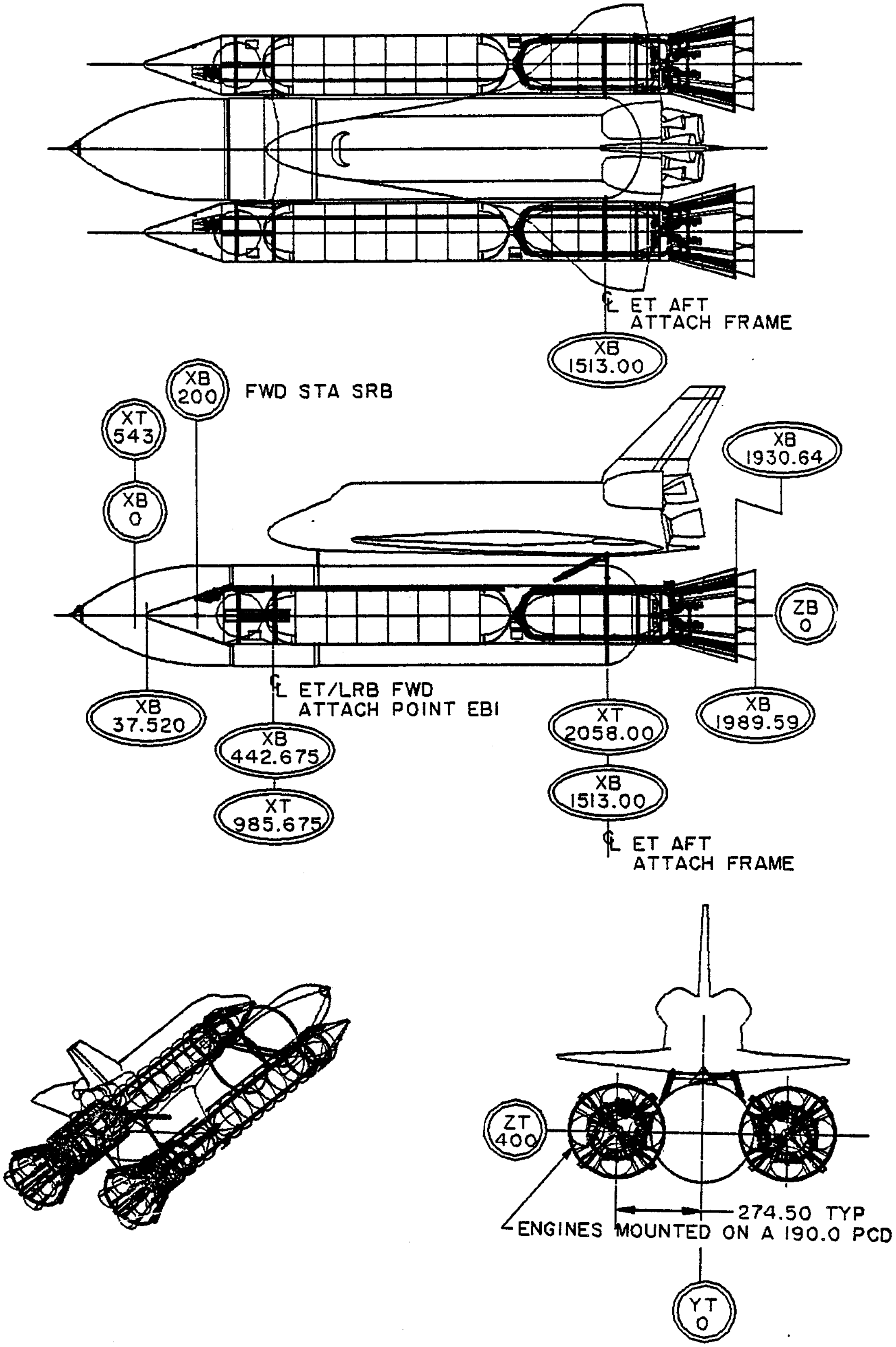


Figure 2.1-2 Baseline Pressure-Fed LRB Configuration

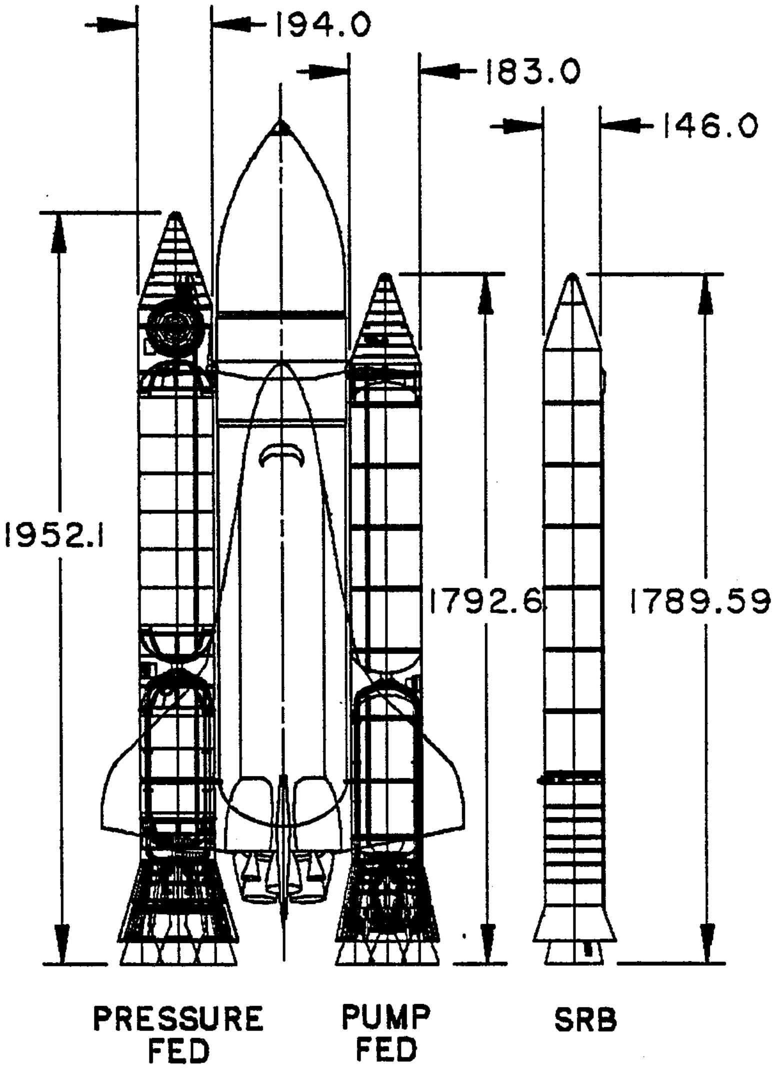


Figure 2.1-3 Shuttle LRB/SRB Configurations

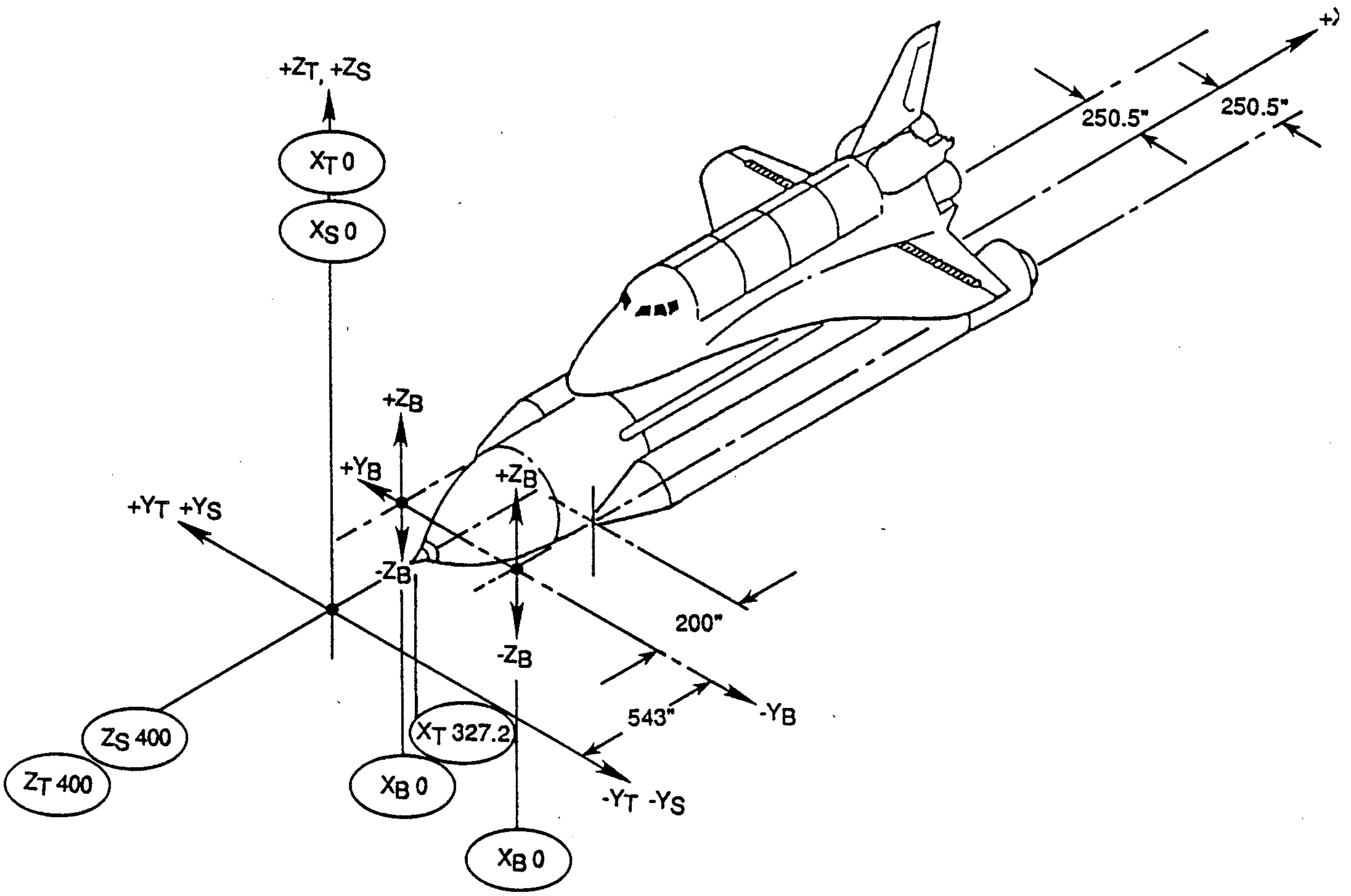


Figure 2.1.1-1 The Shuttle System Elements Coordinate System

2.1.2 LRB/STS Coordinate System and Dimensions

The coordinate system used for the LRB/STS is the same as the SRB/STS. Dimensions of the pump-fed and pressure-fed LRBs are shown in Figures 2.1-1 through 2.1-3. As shown on Figure 2.1-1 and 2.1-3, the Pump-fed LRB is slightly longer, 3.0 in., than the SRB as the forward station Xb is 197.0 while the SRB is 200.0. The centerline of the LRB Pump-fed moves outboard from the ET centerline to Yb = 269.0 in. from the SRB's 250.5 in. due to the increase in diameter from 146 in. for the SRB to 183 in. for the LRB.

Figures 2.1-2 and 2.1-3 show the Pressure-fed LRB is 162.5 in. longer than the SRB and the centerline moves outboard to Yb = 273.5 in. due to the diameter increase to 194.0 in. As shown in the figures, forward and aft ET attach points and aft skirt tie-down to the launch pad remain the same as SRB.

2.2 MISSION OPERATIONS

This section summarizes how the LRBs will be integrated into the STS program and what impacts on ground, launch, and flight operations will result. Section 2.2.1 provides a brief physical flow plan of the LRB at KSC; Section 2.2.2 describes impacts to ground facilities and processing operations; and Section 2.2.3 describes changes to flight operations.

2.2.1 Physical/Functional Flow

The LRB physical flow at KSC, shown in Figure 2.2.1-1, begins with LRB arrival at the External Tank (ET) docking area. The LRBs will be off loaded and transported to the new ET/LRB Processing Facility (see Section 2.2.1.2.1) for receiving and inspection operations prior to transport to the Vehicle Assembly Building (VAB) for integration with the Mobile Launch Platform (MLP), ET, and orbiter. After operations in the VAB are completed, the assembled vehicle will be transported to the launch pad and prepared for launch. The physical flows for the Orbiter and ET will remain the same as for current National Space Transportation System (NSTS) prelaunch operations. The LRB will be expendable and therefore no recovery operations are required. The corresponding functional flow for the LRBs is shown in Figure 2.2.1-2.

2.2.2 Impacts to Facilities & Processing Operations

Section 2.2.2.1 describes new facilities that will be required for LRB operation; Section 2.2.2.2 describes facilities that will require modification; Section 2.2.2.3 describes changes to the

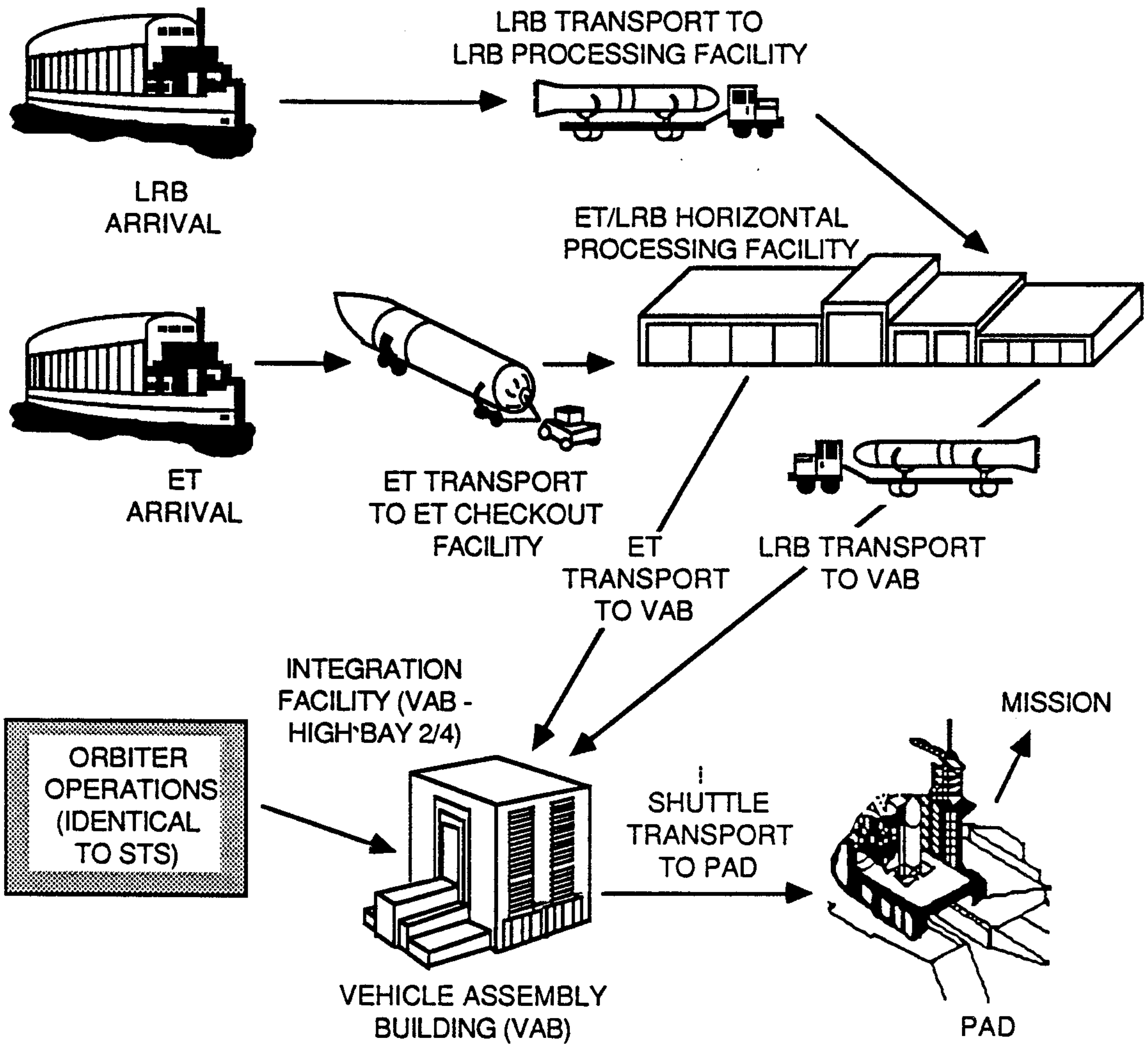


Figure 2.2.1-1 LRB Physical Flow

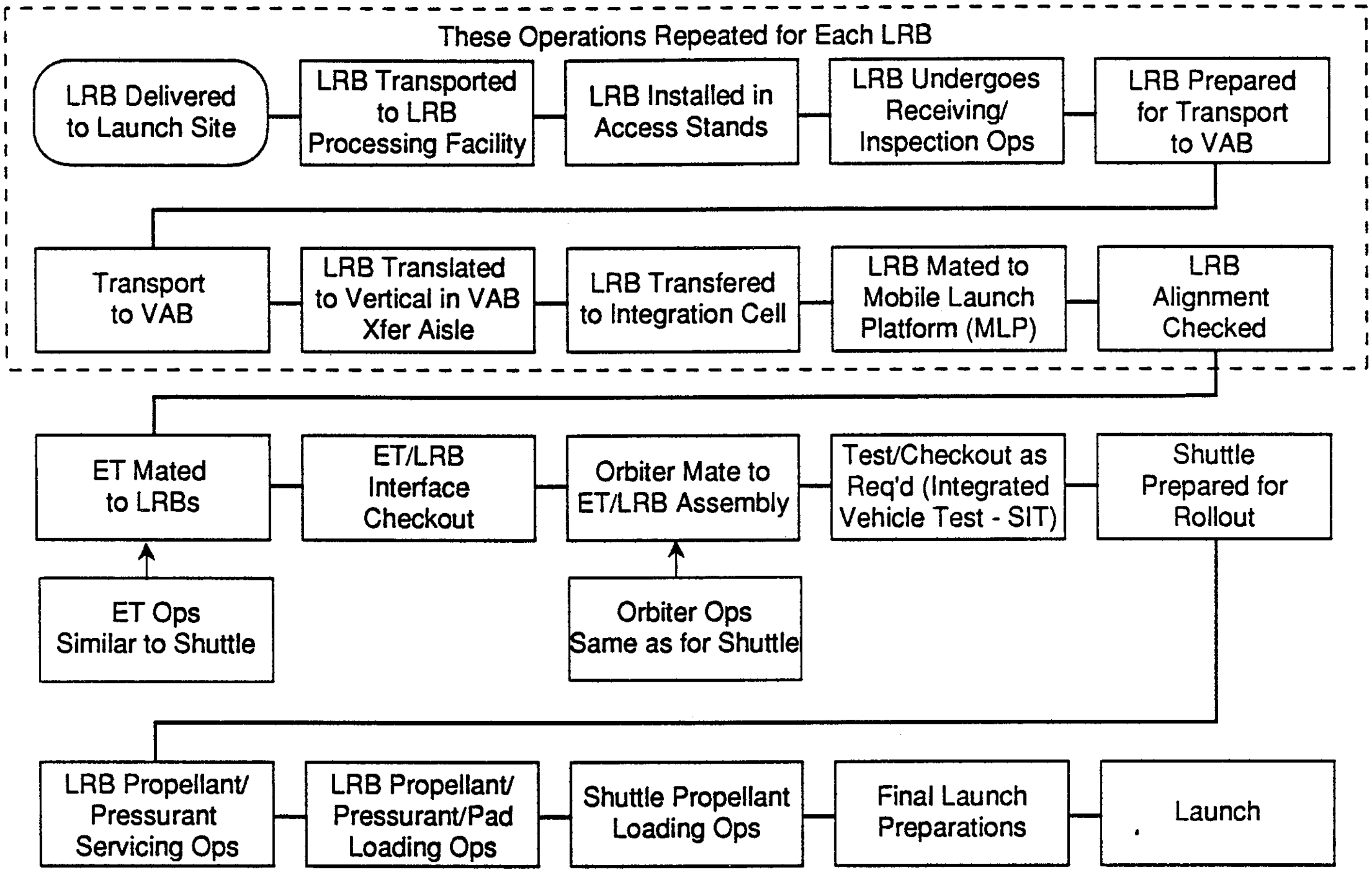


Figure 2.2.1-2 LRB Functional Flow

Mobile Launch Platform; and Section 2.2.2.4 describes pad modifications. Section 2.2.2.5 describes changes in Processing Operations.

2.2.2.1 New Facilities

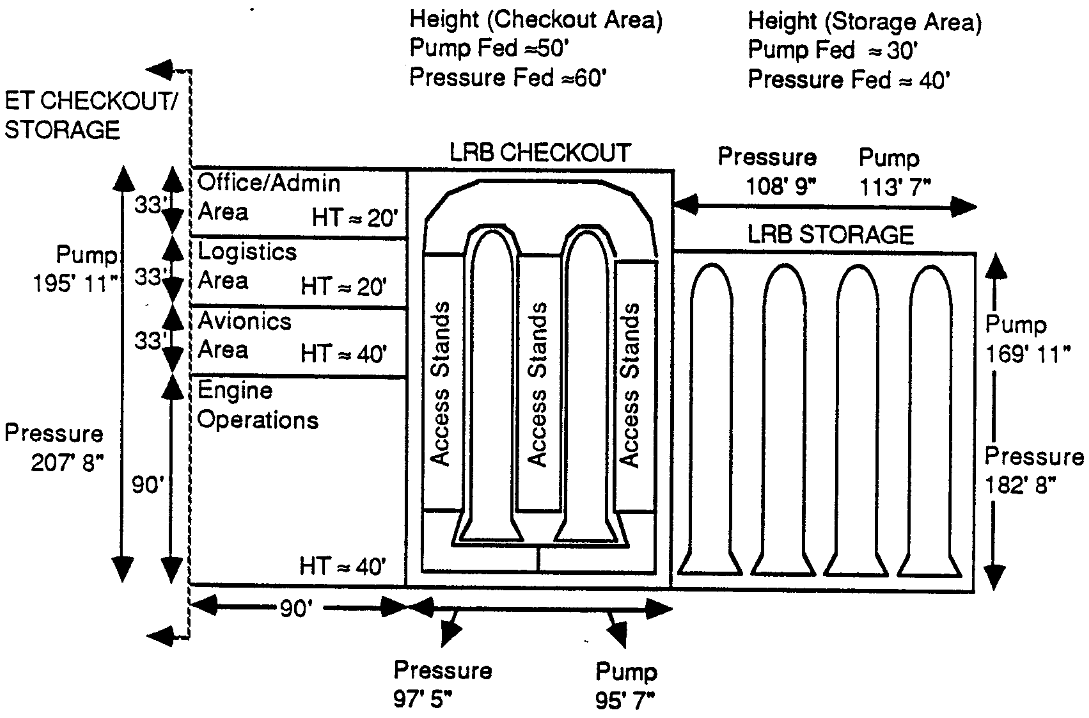
New facilities will be required for LRB ground operations processing at the launch site to permit the use of LRBs with no impact to the projected combined LRB/SRB NSTS launch schedule. The new ET/LRB horizontal Processing Facility will provide checkout and storage areas for both ETs and LRBs. In addition,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

ET /LRB Horizontal Processing Facility—A new facility will be required for LRB processing at the launch site. This facility will also accommodate horizontal ET checkout and storage, replacing the existing ET checkout and storage cells located in VAB High Bay 2 and 4. In order to meet the projected NSTS launch rates for SRB and LRB flights, either High Bay 2 or 4 will be converted into a new integration cell configured for LRBs. Analysis has shown that converting an existing VAB High bay and providing the new area for ET processing would be more cost effective than building a new integration cell.

The new ET/LRB Horizontal Processing Facility, similar to that built for horizontal ET Checkout at Vandenberg Air Force Base will be used to perform horizontal checkout, processing and storage of ETs and LRBs. The horizontal processing, which has been verified for ETs at VAFB, will allow greater access and will reduce the number of handling operations required. The ETs and LRBs will remain on their transporters during checkout operations and will not be removed from their transporters until they are rotated to vertical in the VAB transfer aisle and moved into the integration cell

A general plan for the LRB portion of the ET/LRB Horizontal Processing Facility is shown in Figure 2.2.2.1-1. The facility will provide areas for LRB checkout and storage, as well as office/administrative, logistics, and avionics areas and contingency engine operations. The location of the LRB and the ET Checkout Facility has not yet been determined but is under study by the LSOC/KSC LRB Integration Study.

Mobile Launch Platform (MLP)—A new MLP will be required prior to LRB IOC in order to maintain the combined LRB/SRB NSTS flight rate. This MLP will maintain the present general MLP configuration but will incorporate all modifications required for use with the LRB as detailed in section 2.2.2.2.



AREA	APPROX DIMENSIONS	FT3
PUMP		
Checkout	95'7" x 195'11" x 50'	≈ 936,300
Storage	113'7" x 169'11" x 30'	≈ 579,000
PRESSURE		
Checkout	97'5" x 207'8" x 60	≈ 1,213,800
Storage	114'10" x 182'8" x 40	≈ 838,800
ENGINE	90' x 90' x 40'	≈ 324,000
AVIONICS	90' x 33' x 40'	≈ 118,800
LOGISTICS	90' x 33' x 20'	≈ 59,400
OFFICE/ADMIN	90' x 33' x 20'	≈ 59,400

Figure 2.2.2.1-1 General Configuration/LRB Portion ET/LRB Horizontal Processing Facility

2.2.2.2 Modified Facilities

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

Vehicle Assembly Building (VAB)—The larger diameter and height of both pump and pressure fed LRBs will necessitate modifications to existing integration cell platforms to maintain required standard dynamic and static clearances, 18" and 6" respectively, between the vehicle and facility. Additionally, either High Bay 2 or 4 will require extensive modification to convert it to an additional integration cell. An additional crawler way from the new integration High Bay to the existing crawler way will also be needed. The modifications to the VAB are discussed in the following sections.

Platform Modifications—Two types of modifications will be required for VAB High Bay 1/3 integration cell platforms. The first modification is to enlarge the openings in the access platforms when they are in their lowered positions (Figure 2.2.2.2-1) to accommodate the larger diameter pressure and pump-fed LRBs. This modification is required for both types of LRBs since any increase in diameter above the SRB diameter of 12' 2" violates the standard 6" required static clearance between vehicle and facility. The platforms requiring this modification for pump and pressure-fed LRBs are summarized in Table 2.2.2.2-1. Modification of Platform -Main is not required for the pump fed LRB, but is needed for the pressure fed LRB due to it's greater height.

The second modifications is required to permit removal of the vehicle from the integration cell when the access platforms are in their raised and retracted positions (Figure 2.2.2.2-2). As previously stated, the dynamic clearance of 18" between the vehicle and facility must be maintained. The platform summarized in Table 2.2.2.2-1 must be modified to permit this minimum clearance. The greater diameter of the pressure fed LRBs requires modification of the Platform E-Room. This modification is not required for the pump fed LRB. As shown in Figure 2.2.2.2-3, no clearance problems exists between the pressure fed or pump fed LRBs and the VAB integration cell exit doors.

Modified High Bay/Integration Cell—A new integration cell will be required in order to meet the projected NSTS flight rate. Modification of High Bay 2 or 4 to become this additional integration cell (configured for LRB usage) will be completed prior to LRB IOC. As stated in this section converting an existing high bay and accommodating the ET processing function in the new ET/LRB Horizontal Processing Facility has been determined to be more cost

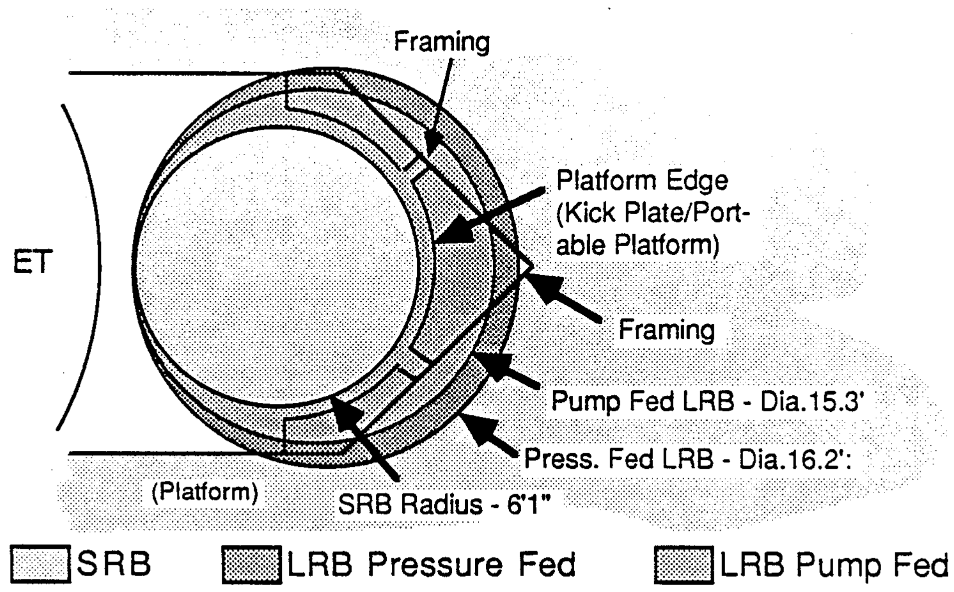


Figure 2.2.2.2-1 Typical Integration Cell Modification

Table 2.2.2.2-1 VAB Platform Modification Summary

MODIFICATIONS - VAB EXIT/PLATFORM CUTOUTS				
PLATFORM LEVEL	EXIT CLEARANCE		CUTOUT MODIFICATION	
	PRESS. FED	PUMP FED	PRESS. FED	PUMP FED
C ROOF	NO	NO	NO	NO
C 2ND	NO	NO	NO	NO
C MAIN	NO	NO	YES	NO
E ROOF	YES	NO	YES	YES
E 2ND	NO	NO	YES	YES
B ROOF	YES	YES	YES	YES
B 2ND	YES	YES	YES	YES
B MAIN	YES	YES	YES	YES
D ROOF	YES	YES	YES	YES
D THIRD	NO	NO	NO	NO
D 2ND	NO	NO	YES	YES
D MAIN	NO	NO	YES	YES

MOD REQ'D TO MAINTAIN 18" DYNAMIC CLEARANCE DURING VEHICLE EXIT

MODIFICATION OF PLATFORM CUTOUT DUE TO LARGER LRB DIA.

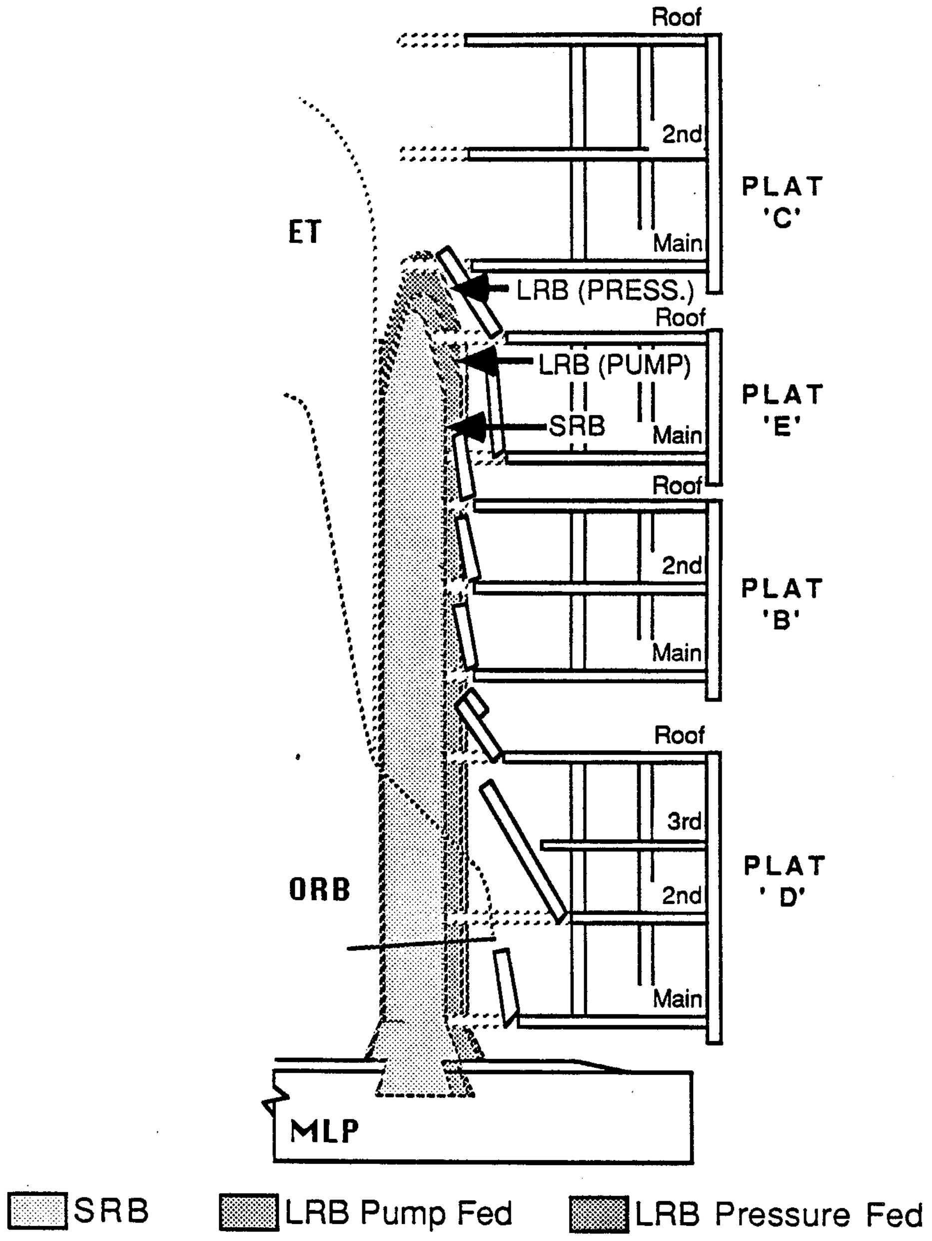


Figure 2.2.2.2-2 VAB Exit Clearance Platform Modifications

Dimensions	
ET	331" (27'7")
ET/LRB Sep.	12" (1')
Door Width	871.5" (72' 7.5")
SRB/Door Sep.	103 " (8'7")
SRB Diameter	146" (12' 2")
Min. Dynamic Clearance	18" (1'6")
Pump Fed LRB/Door Sep.	65" (5' 5")
Pressure Fed LRB/Door Sep.	54" (4'6")

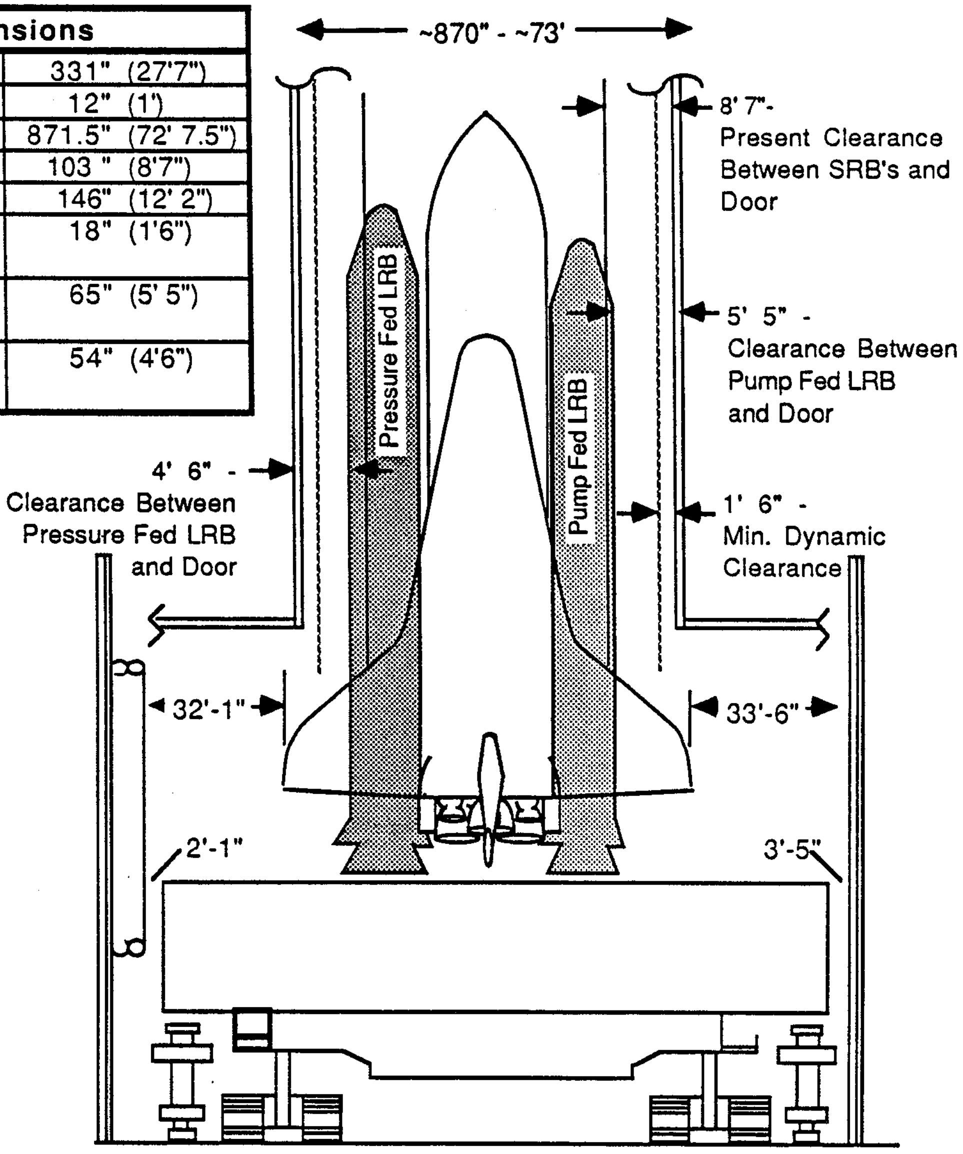


Figure 2.2.2.2-3 VAB Integration Cell Exit Doors

effective than the fabrication of a completely new integration cell configured for LRBs. The modification of High Bay 2 or 4 will involve the removal of current existing ET checkout platforms and the installation of new integration cell platforms identical to those in the modified integration cells. In addition, use of the High Bay 2 or 4 will require the addition of a crawler way linking the cell to the existing crawler way for High Bay 1 and 3. No modifications are anticipated for the exit doors and the existing 175 T and 250 T cranes can be used.

2.2.2.3 Mobile Launch Platform

Exhaust Holes—Both pump-fed and pressure-fed LRB configurations will require enlargement of the SRB exhaust holes due to their increased diameter. The current and modified MLP configurations are shown in Figures 2.2.2.3-1 As indicated in the figure, the current LRB with the engines configured in a "T" pattern necessitates increasing the exhaust hole opening from 232.25" to 357.97" in the ±Y direction and from 487.31" to 560" in the ±Z direction. Although the "T" pattern LRB configuration increases the size of the exhaust hole opening as compared to the "X" pattern, it distributes the load across two holddown posts during the pitch over moment at SSME engine ignition.

As shown in Figure 2.2.2.3-2, sloping the heat shielding on the outer exhaust hole edges will allow the opening on the underside of the MLP to remain at the current dimensions. This will eliminate the need to modify the flame deflectors or the flame trench. The impingement angle of the engines of the LRB must be less than 30° in order to ensure all exhaust is deflected into the flame trench.

SRB Holddown Posts—The holddown posts for the SRBs will be used for the LRBs; however, they will be relocated (maintaining the same configuration as for SRBs) due to the enlargement of the exhaust hole and the larger diameter of the LRBs (Figure 2.2.2.3-1). Any relocation of the SRB the holddown posts necessitates reframing of the MLP. Moving the holddown posts up to 1/2" in the east/west direction could be accommodated by the built in adjustment capability of the holddown posts; however, movements of more than 1/2" require the removal of haunches and rewelding of the haunches to the MLP. Moving of the holddown posts any amount in the north/south direction requires reframing of the MLP area indicated by shading in Figure 2.2.2.3-3. This modification can be accommodated at the same time the SRB exhaust holes are being enlarged.

Over Pressure Plumbing—SRB over pressure plumbing must be relocated to accommodate the enlarged SRB exhaust holes (Figure 2.2.2.3-1). The 6.4% Scale Acoustic Model Test Program performed at MSFC was used to develop the sound suppression system used on the current Shuttle program. This testing must be performed for the LRBs to verify noise levels will not be exceeded. The testing will show, depending upon engine ignition sequence, the LRBs

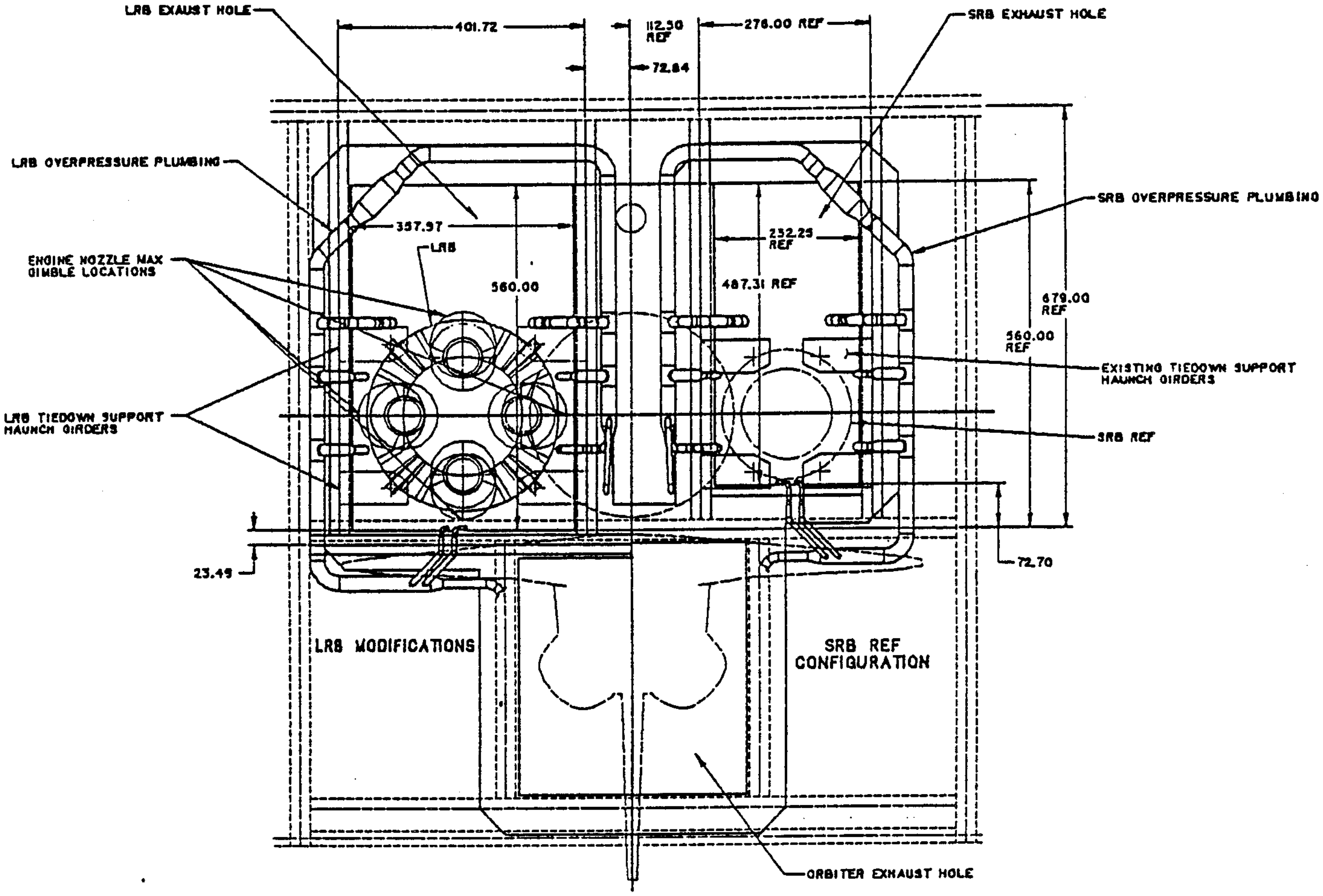


Figure 2.2.2.3-1 SRB Over Pressure Plumbing

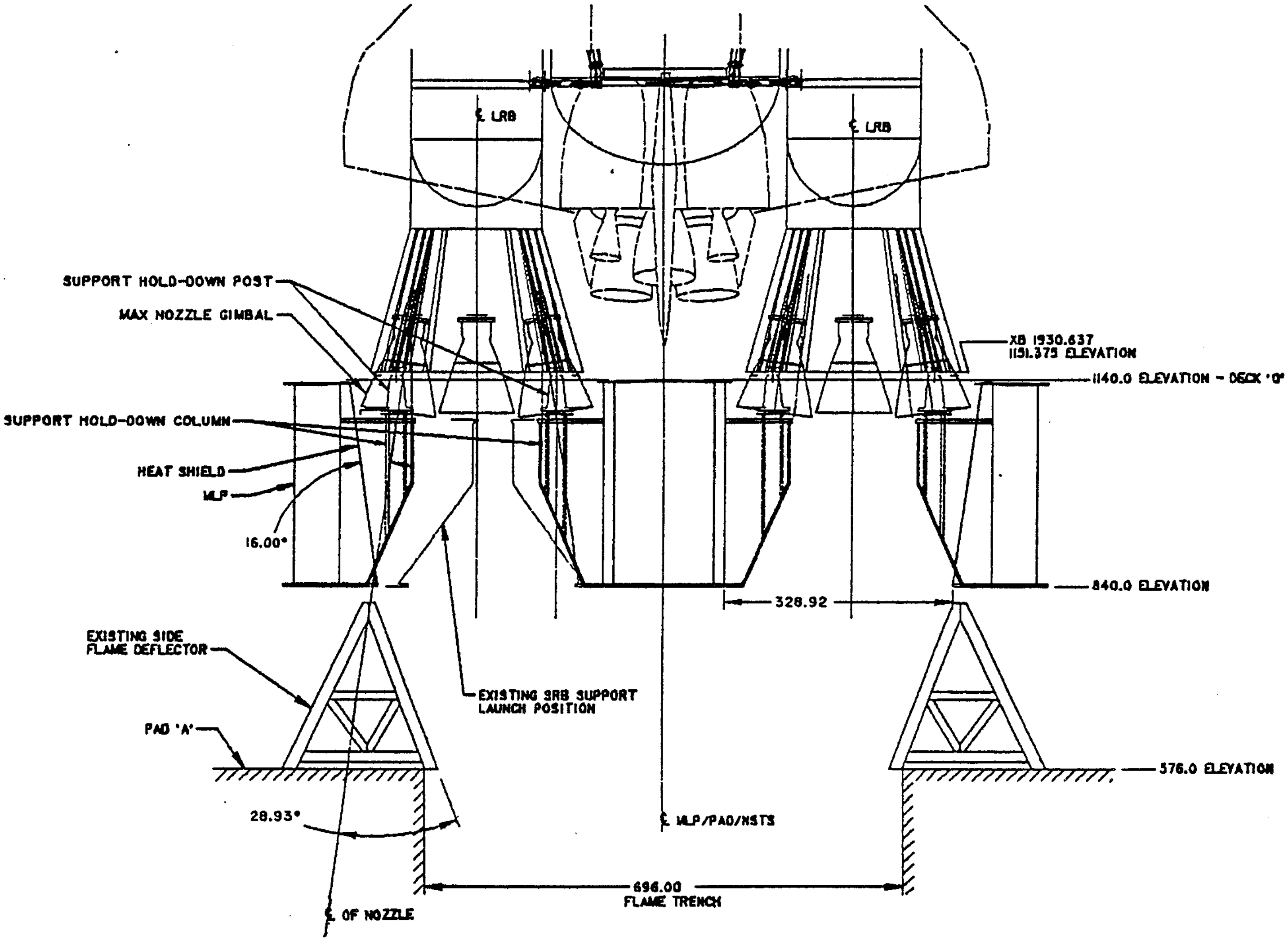


Figure 2.2.2.3-2 Heat Shielding on the Outer Exhaust Hole Edges

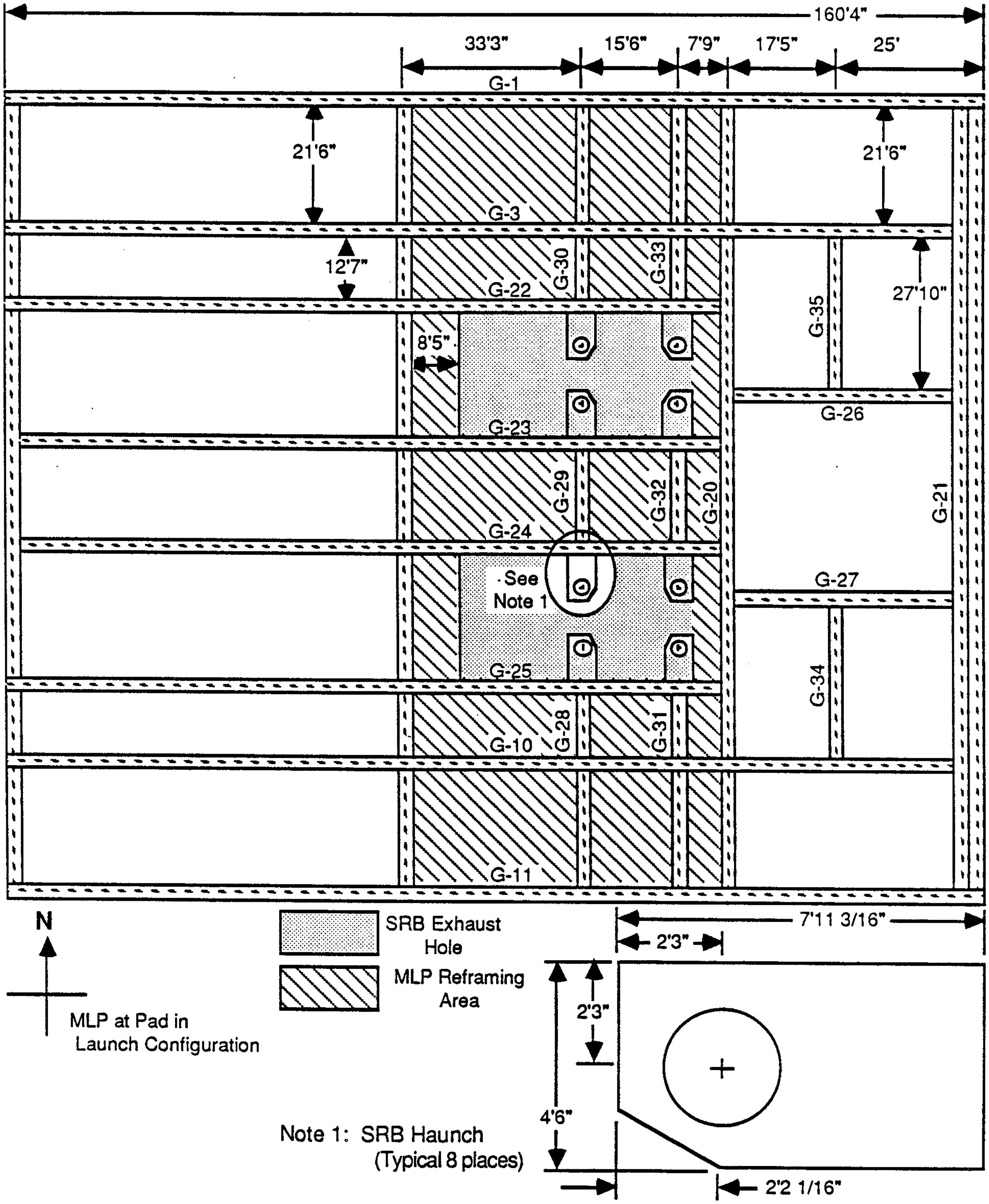


Figure 2.2.2.3-3 . MLP Main Girder Layout

sound suppression system requirements, and it is possible that the over pressure plumbing will not be required.

2.2.2.4 Pad Modifications

Modifications will be required at the pad to accommodate the LRB's size and to provide for the propellants required.

Propellants—Each pump-fed LRB will require 10,769 ft3 of Liquid Oxygen (LO2) and 5,798 ft3 of RP-1. Each pressure-fed LRB will require 12,012 ft3 of LO2, 6,329 ft3 of RP-1, and additionally 900 ft3 of gaseous helium.

At both pads, the LO2 requirements will be met by the existing LO2 storage facilities. Additional skids on the MLP to rise off type umbilicals will be required from the LO2 storage areas to service the LRBs. Loading of the LRB with LO2 will be performed in parallel with ET LO2 loading.

The RP-1 storage facility at Pad A consists of three 86 gallon (=11,500 ft3) underground storage tanks. These tanks may be refurbished, depending on their condition; however, piping, valves, etc. must be added to the system. There are no RP-1 storage facilities at Pad B, hence this capability must be added for this pad. Modifications to the MLP will be required to provide the rise off type umbilicals with access to the RP-1. RP-1 loading will be performed two to three days prior to LO2 loading. The RP-1 servicing system will be scaled from the Saturn-C5 servicing system.

The helium required for the pressure-fed LRB will be supplied from the Helium Converter/Compressor Facility, located approximately 1/3 of the distance from the pad to the VAB. This facility currently provides GHe for pad orbiter processing at 4,500 psia.

ET Access Platforms—Due to the LRBs increased diameter, the corner of the ET Access Platforms on the Rotating Service Structure (RSS) at elevations 220'0", 207.2", 185'0", 176'11", 158'10", and 148'4" require modification. Figure 2.2.2.4-1 illustrates the typical impact to the platforms.

SRB Access Platform—The SRB Access Platform, also shown in Figure 2.2.2.4-1, must be modified to accommodate the pump and pressure-fed LRB's larger diameters. In addition, adjustment in the elevations of the platform may be required to facilitate pad operations.

Umbilicals—The existing ET LH2 vent arm will required modifications for both LRB configurations. Boosters with diameters greater then 13'2" would impact with the vent arm after launch as the arm retracts to the Fixed Service Structure (FSS) (Figure 2.2.2.4-2). Neither LRB will necessitate modification of the GOX Vent Arm and no impact with the Orbiter Access Arm is

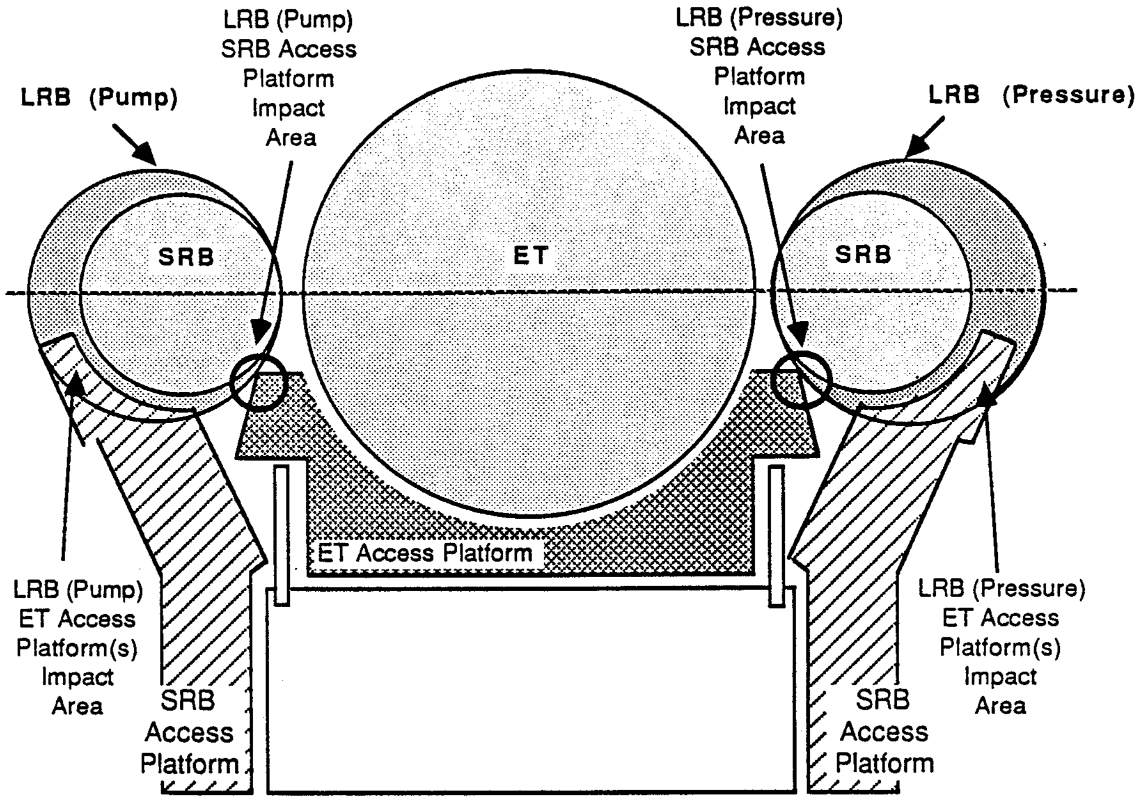


Figure 2.2.2.4-1 ET and SRB Access Platforms

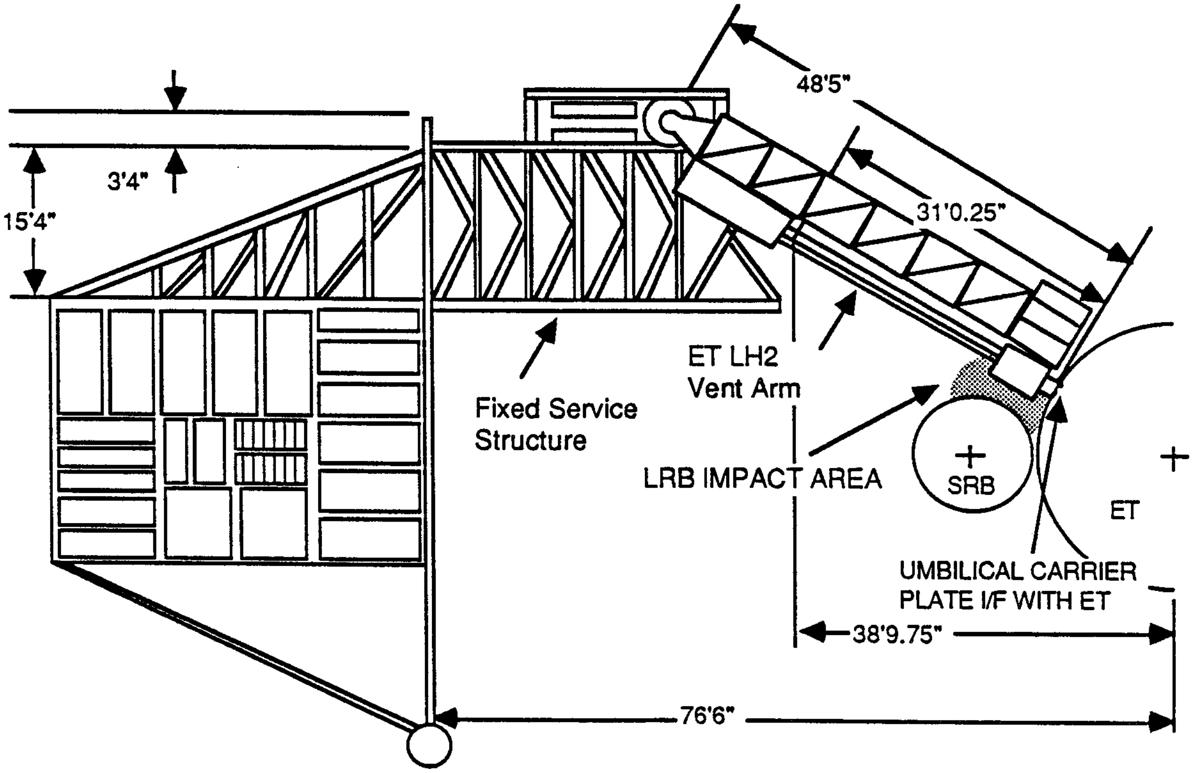


Figure 2.2.2.4-2 ET LH2 Vent Arm

anticipated. New umbilicals will be required to load the LRB LO2, RP-1, and GHe tanks. These umbilicals will require be incorporated into the MLP modifications.

2.2.2.5 Processing Operations

Ground Support Equipment—Specialized Ground Support Equipment (GSE) will be required for processing the LRB configurations. Transporters for each LRB will be required for transporting the LRBs on the barge from the manufacturing facility to the launch site. These transporters will support the LRBs during checkout, processing, and storage in the ET/LRB Horizontal Processing Facility. Other ET/LRB Horizontal Processing Facility GSE consists of access stands, checkout/test sets/equipment, interface simulators, and contingency engine operation GSE such as engine handling slings, inserters and rotators. Tow vehicles will be used to tow the LRBs on the transporters to the VAB. Handling slings will be required in the VAB transfer aisle for rotating the LRBs to vertical and translating access kits will be required for contingency access to the LRBs. Contingency for engine removal while the LRB is mated to the MLP will also be required.

Processing Times—Figure 2.2.2.5-1 illustrates the LRB processing timeline and the NSTS 1994 baseline, provided by the KSC NASA Mission Planning Office. Shaded bars in the LRB timeline indicate those operations involving the LRB. The NSTS and LRB timelines and facility analysis presented reflect theoretical maximum times for independent/single flow utilization of the facilities.

The LRB reduces VAB integration cell usage from 117 shifts per flight to 60 shifts per flight, which increases the flight rate that can be supported from 8.9 flights per year to 17.5 flights per year for each cell. The reduction in integration cell usage also affects the MLP usage. The MLPs with LRBs will be utilized 144 shifts per flight, which allows each MLP to support 7.4 flights per year (2 flights more per year than with SRBs). Additional shifts are required at the pad due to LRB propellant loading; however, the number of flights per year available is not significantly reduced (14 flights per year - LRB, 14.4 flights per year - SRB).

Processing in the LRB Horizontal Processing Facility is performed off line and does not affect the Shuttle launch rate.

Ground Operations Processing Summary—Differences in pump-fed versus pressure-fed ground processing operations and facility impacts arise from the following factors: (1) Size (diameter, height, volume), (2) Complexity due to additional Helium pressurization system for pressure-fed LRBs, (3) additional engine checkout requirements for pump-fed LRBs, (4) Loading operations.

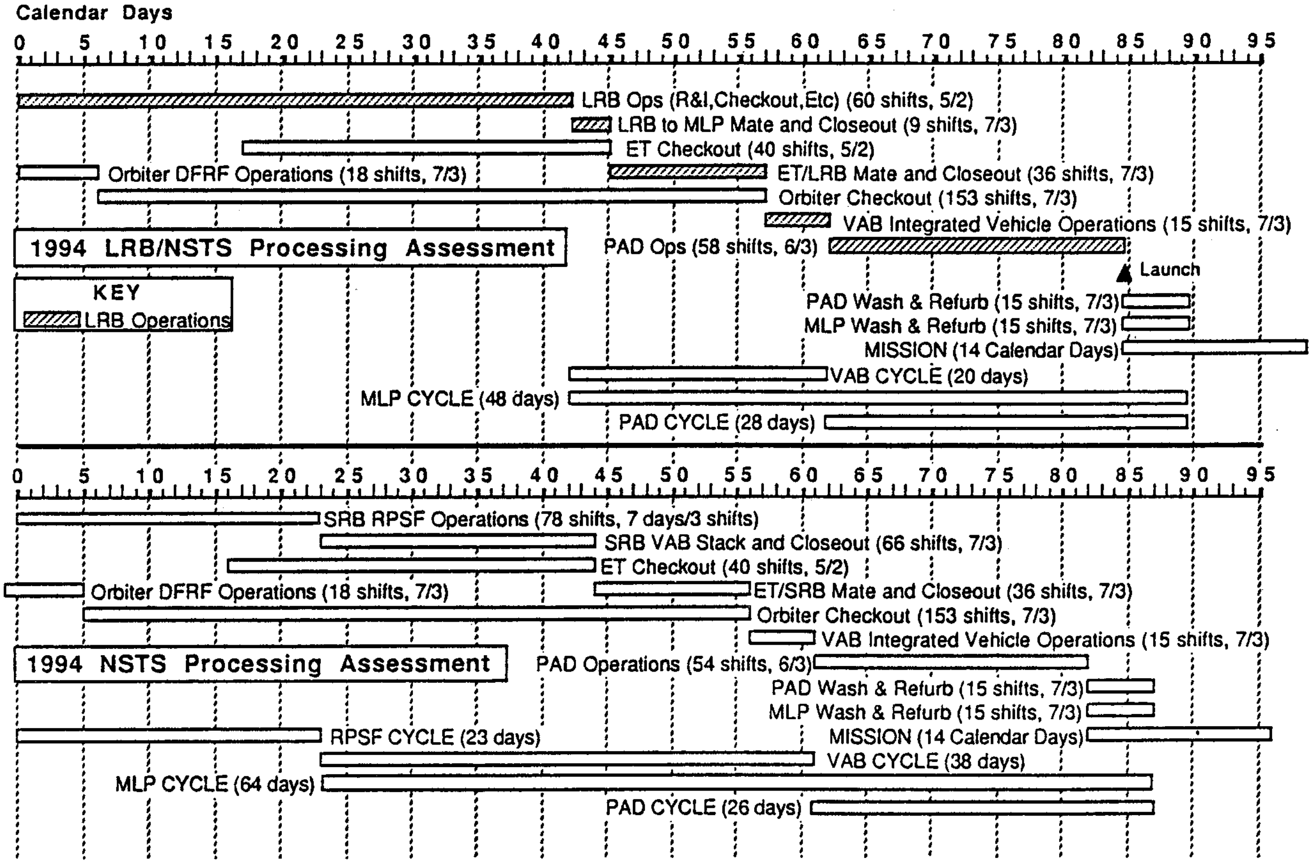


Figure 2.2.2.5-1 LRB Processing Operations Timeline

Pump-fed Versus Pressure-fed Impacts—The pressure-fed LRB has a greater impact on launch processing facilities than does the pump-fed LRB due to it's greater height and diameter, larger propellant volumes, and additional requirements for gaseous helium.

Both pump and pressure-fed LRBs require the addition of the ET/LRB Horizontal Processing Facility; however, the pressure-fed facility must provide an additional 277,00 ft3 to accommodate the LRB's larger size.

Any LRB with a diameter greater than 12'2" requires enlargement of the openings in the VAB access platforms. Thus, these platforms will require modification to accept both LRB's diameters. The pressure-fed LRB will require modification of 1 more platforms than the pump-fed due to its greater height. The VAB platforms must also be modified to permit removal of the Shuttle vehicle. Again, the pressure-fed LRB will require modification of an additional platform due to it's larger diameter. Conversion of the VAB High Bay 2 or 4 to an additional integration cell is required for both LRB configuration, with no major differences in the extent of modification required.

The MLP must be modified to accommodate both LRB configurations in their clocked positions. Both configurations require relocation of the SRB holddown posts and SRB haunches, as well as reframing of structure to provide enlarged exhaust hole openings. The exhaust hole opening for the pressure-fed booster will be larger than that for the pump-fed LRB.

Pad and MLP modifications are required to provide LO2 and RP-1 propellant servicing for the pump and pressure-fed LRB; however, the pressure-fed configuration also requires modifications to permit gaseous helium loading. Both LRB configurations will require modification of the ET LH2 vent arm, and neither configuration will impact the GO2 vent arm or the Orbiter Access Arm.

Pump-fed versus Pressure-fed Operational Impacts—Differences in configuration processing arise from alternate engines and pressurization systems and from larger propellant quantities and additional helium requirements for the pressure-fed configuration.

Engine checkout for the pump-fed LRB will take slightly longer and will be more complex due to the addition of turbo pumps to the engine system. Both LRB configurations will require checkout of the LO2 and RP-1 pressurization systems; however, additional checkout will be required for the pressure-fed LRB helium pressurization system.

Loading operations at the pad will take slightly longer for the pressure-fed LRB due to its requirement for an additional 1,200 ft3 of LO2, 500 ft3 of RP-1, and 900 ft3 of gaseous helium.

2.2.3 Flight Operations

Flight operations for the LRBs will be very similar to those for the SRBs; however, the LRB has the capability for flight continuation to Main Engine Cutoff (MECO) with one LRB engine shutdown. Other LRB abort capabilities, provided by analysis using the CARD computer program with a single SSME failure during the second stage, are summarized in Table 2.2.3-1. The flight scenario for the LRB is illustrated (Figure 5.3.3-1) and discussed in Section 5.3, Mission Analyses.

2.3 MANUFACTURING

Martin Marietta will integrate LRB production with External Tank (ET) operations at the Michoud Assembly Facility (MAF). Production activities will occur in existing buildings 103, 131, and 318. In addition, new structures will be constructed to contain LRB final assembly, test, and checkout. The manufacturing plan in accordance with the LRB Mission Model provides a five day, three-shift tool and facility capacity for fourteen (14) flight sets per year. Descriptions of the pump-fed and pressure-fed manufacturing plans are provided in section 10.0 in this volume.

From the study analysis, we have not identified any mandatory new manufacturing technology requirements for production of the pump-fed LRB. Use of the new aluminum-lithium alloy Weldalite™ 049 for the pressure-fed LRB will require a prior development program. Weldalite™ 049 can be used for the pump-fed LRB and be an enhancing technology as 2219 aluminum alloy could be used (with increased weight and cost). Other programs are expected to drive the use of Weldalite™ 049 in advance of an LRB program so that this new alloy will be available when needed.

Manufacturing development requirements are more extensive and higher risk for the pressure-fed LRB. Items of concern are cost effective thick wall welding, one piece domes for the helium pressurant tank, flow-turned barrels, and use of the Aluminum-lithium alloy Weldalite™ 049. These manufacturing development requirements are discussed in Section 12.4 in this volume.

2.4 TECHNOLOGY REQUIREMENTS

No new technology requirements have been identified for the pump-fed LRB. The use of Weldalite™ 049 for the pump-fed vehicle was recommended as an enhancing technology to reduce

Table 2.2.3-1 LRB Abort Capabilities

LRB Abort Capabilities	**Time (seconds)**	
	Pressure-Fed	Pump-Fed
Complete Mission LRB Engine Out	T>30	T>30
Intact Abort LRB Engine Out	Anytime	Anytime
RTLS SSME Out	T>=0 T<=220	T>= 0 T<=215
TAL - Ban Jul SSME Out	T>=123 T<=405	T>=131 T<=400
TAL - Ben Guerir SSME Out	T>=126 T<=344	T>=138 T<=349
TAL - Moron AFB SSME Out	None	T>=280 T<=300
PTATO SSME Out	T>=305	T>=300
PTM SSME Out	T>=355	T>=345

booster weight and costs and increase performance. The alternate material selected for the pump-fed system was 2219 Aluminum alloy.

The enabling technology requirements for the pressure-fed LRB include:

1 high specific strength material;
2 high capability, low weight, high thrust (750 klb engines);
3 low volume pressurization systems; and
4 relatively low Pc (300-800 psia) injector and thrust chamber development.

Enhancing technologies which would benefit both pump and pressure-fed systems include:

1 electromechanical actuators;
2 flex seal gimbaling;
3 low cost autonomous avionics; etc.

3.0 LRB REQUIREMENTS

3.1 STS PROGRAM

NSTS Program requirements which reflect use of the Liquid Rocket Boosters in place of SRBs were developed at a top level. These top level and conceptual design requirements were developed to guide the definition phase of the Liquid Rocket Booster (LRB) for the Space Transportation System (STS) Systems Study.

3.1.1 Requirements Source

The source of these top level requirements were the study Request for Proposal (RFP) Statement of Work (SOW), subsequent modification to the SOW, and NSTS 07700, Volume I, "National Space Transportation System, Program Description and Requirements Baseline".

3.1.2 System/Design Requirements

The developed Systems Requirements (3.1.2.1) and conceptual Design Requirements (3.1.2.2) are presented below.

3.1.2.1 System Requirements

The LRB shall be capable of replacing the SRB stage of the STS while minimizing impacts on other parts of the STS system.

Mission Requirements–The mission requirements for the Eastern Test Range (ETR) shall be:

a. Nominal - 70.5K lb. payload to 160 nmi orbit, 28 1/2° inclination, with SSME'S limited to 104% power level (109% for abort).

b . Alternate - 59K lb. payload to 150 nmi orbit, 28 1/2° inclination, with SSME's limited to 104% power level (109% for abort).

Performance–The LRB ascent stability and control performance shall maintain the vehicle within STS (Orbiter/ET) trajectory and stability constraints (acceleration,, Max q, angle of attach, etc.). The Space Shuttle System shall be a variable azimuths launch capability to satisfy the acceptable launch-to-insertion azimuths from Kennedy Space Center (KSC). The vibro-acoustic environments and heating environments applied to the Orbiter Vehicle/ET shall be no more severe than current NSTS specifications.

The LRB system shall have single engine-out capability at lift off and engine shutdown on command capability as well as capability for hold-down prior to launch release.

The LRB will meet the requirements specified in the approved Space Shuttle Orbiter Vehicle/ET/LRB Interface Control Document (TBD). The LRB's will operate in parallel with the SSME's to provide impulse to the Orbiter Vehicle from lift-off to staging. The Space Shuttle system, with a LRB, shall be designed to accomplish all current NSTS missions.

Operational Requirements–The LRB shall have a range safety flight termination system and shall be designed and tested for electromagnetic compatibility in accordance with NSTS specification SL-E-0001. Subsystems and/or individual equipment shall be designed and tested in accordance with NSTS specification SL-E-0002.

Program Impacts–A major goal of the Space Shuttle Program including the LRB shall be to minimize the national investment in launch facilities, GSE, and other support equipment (including the launch processing system and associated software) through maximization of the commonality of requirements, design, and procurement of these items. LRB commonality with current NSTS launch systems will be maximized.

The Space Shuttle System design shall provide the capability to be launched from a standby status with 4 hours, and hold a standby status for 24 hours. Standby status is defined as ready for launch except main propellant fill, crew ingress, and final systems verification.

To fulfill the space rescue role, the space shuttle system shall have the capability to launch within 26.5 hours after the vehicle is mated and ready for transfer to the pad.

The Space Shuttle system shall provide a safe mission termination (abort) capability through all mission phases. The allowable ascent longitudinal, lateral and vertical CG envelopes for the Spaced Shuttle Flight Vehicle (including LRB's) are TBD.

3.1.2.2 Design Requirements

Reliability and safety are primary design requirements for the LRB systems and components. LRB avionics and power systems shall include redundancy schemes. The LRB avionics and power systems shall interface with other STS elements with minimum impacts on the other elements.

The redundancy requirements for all flight vehicle subsystems (except primary structure, thermal protection systems, and pressure vessels) shall be established on an individual subsystem basis, but shall not be less than fail-safe. "Fail-safe" is defined as the ability to successfully terminate the mission. A successful abort is considered successful termination. Redundant systems shall be designed so that their operational status can be verified prior to flight, during ground turnaround and, to the maximum extent possible, while in flight.

The provisions of NHB 5300.4 (ID-20), 1979 "Safety, Reliability, Maintainability, and Quality Provisions for the Space Shuttle Program" will apply to the LRB. The LRB design shall include provisions for fill, vent, drain, and dump of all liquid propellants.

3.2 LEVEL II REQUIREMENTS

Shuttle system requirements which reflected use of LRB's in place of SRB's were developed from NSTS Level II requirements.

The Level II requirement developed were a modification of NSTS 07700 Volume X, Rev. F. Change 88, "Space Shuttle Flight and Ground System Specification", Section 3.0 Requirements, June 2, 1986. Paragraphs which were changed from the NASA document to reflect LRB use were identified with an asterisk (*) in the right hand margin.

The Level II requirements developed are shown in Appendix G, "LRB for the STS System Study, Level II Requirements, Revision 1", January 1988.

3.3 LEVEL III REQUIREMENTS

Level III requirements for the LRB were developed in the form of a preliminary Contract End Item (CEI) Specification.

This CEI specification was developed by modification of appropriate sections of "Contract End Item Specification, Integrated Solid Rocket Booster (ISRB), IOCEI-001G, March 6, 1987 and "SSME Contract End Item Engine Specification", CP320R003B, August 10, 1979.

The LRB CEI Specification is presented in appendix H, "LRB for the STS System Study, CEI Specification, Revision 1", May 1988.

4.0 TRADE STUDIES

4.1 TRADE STUDY METHODOLOGY

Figure 4.1-1 presents the trade study methodology utilized by Martin Marietta. A preliminary criteria matrix and weighting factors were determined during the trade study initiation meeting. A sample trade studies criteria matrix is shown in Figure 4.1-2. The leading candidate in a particular criteria received a score of 10 when scoring the various criteria and candidates. Other scores were evaluated relative to the score of 10. The minimum score for any candidate is 1. However, if all candidates are equal in any criteria, i.e. all receive a score of 10, the criteria was omitted from that trade study matrix. The weighted score for each candidate was the total of the product of the criteria weight and the candidate score. An example of an LRB Trade Study is shown in Figure 4.1-3.

The following paragraphs summarize the trade studies performed during the LRB study contract. Detailed trade study documentation is contained in Appendix D, "LRB Trade Study Documentation', Mar, 1988.

4.2 STRUCTURAL TRADES SUMMARY

Ten detailed structural trades were performed to select LRB materials, design approach and manufacturing concepts. The results of these trades are summarized in Table 4.2-1. The trade studies were completed during the first four months of the study. Redesign of the pump-fed booster to meet STS stiffness requirements modified the early trade study conclusions regarding unpressurized structure construction. The redesign uses a monocoque construction rather than stiffened skin and stringer for the forward skirt, intertank and aft skirt designs.

4.3 PROPULSION TRADES SUMMARY

Detailed trade studies selected the perferred pump and pressure-fed booster propellants, pressurization system concept, and TVC approach. In addition, both the pump and pressure-fed propulsion systems were evaluated with regard to reuse. Table 4.3-1 summarizes the results of these trades. Although the reuseable pump-fed propulsion system results in a LCC saving, the vehicle expendable vs reuseable trade overroad these results and both systems are expendable.

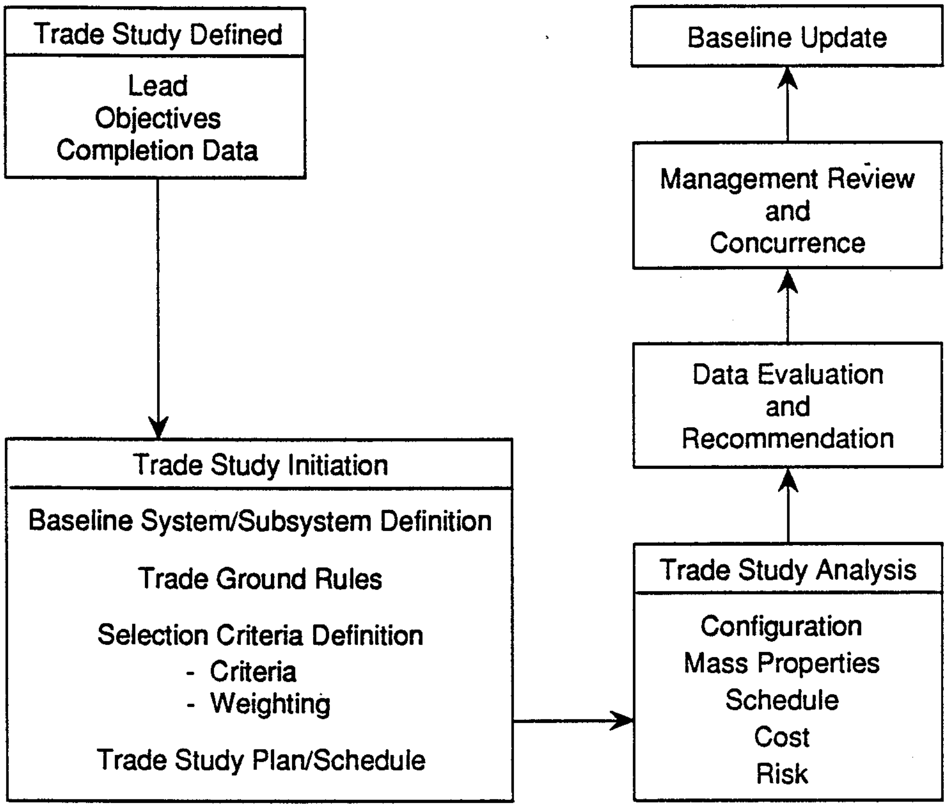


Figure 4.1-1 Trade Study Methodology

Criteria	Wt	Candidate 1		Candidate 2		Candidate 3	
		Sc	Wgt Sc	Sc	Wgt Sc	Sc	Wgt Sc
STS Integration Impacts	x	a	a·x	b	b·x	a	a·x
• Facility Impacts							
• STS Loads							
• STS Interface							
Costs	y	b	b·y	a	a·y		
• DDT&E							
• LCC							
Operational Complexity							
• Ground Ops							
• Flight Ops							
Mission Safety/Reliability							
Vehicle/Processing Safety							
Environmental Impacts							
Reliability							
Maintainability/Supportability							
Weight/Performance/Stability	z	c	c·z				
Subsystem Integration							
• Size							
• Interface							
• Power							
Risk							
• Technical							
• Schedule							
• Recovery/Reuseability							
• Growth/Evolution							
	100						

Figure 4.1-2 Trade Studies Criteria Matrix

Discipline: Propulsion
Trade No: P-9
Title: Engine Cycle Trades
Baseline: LO2/RP-1 Gas Generator Cycle
Candidates: LO2/LH2, LO2/CH4, Split Expander Cycle
Selection Criteria:

Criteria	Wgting Factor	Gas Generator Cycle				Split Expander Cycle			
		LO2/RP-1		LO2/CH4		LO2/CH4		LO2/LH2	
		Sc	Wgt Sc	Sc	Wgt Sc	Sc	Wgt Sc	Sc	Wgt Sc
STS Integration Impacts	15	10	150	8	120	8	120	[illegible]	60
Costs	15	10	150	10	150	9	[illegible]	2	30
Operational Complexity	10	10	100	8	80	8	[illegible]	[illegible]	60
Safety	10	10	100	[illegible]	[illegible]	[illegible]	80	6	60
Reliability	5	10	[illegible]	5	[illegible]	[illegible]	40	9	45
Weight	5	[illegible]	45	[illegible]	50	8	40	5	25
Maintainability	5	[illegible]	[illegible]	8	40	7	35	7	35
Subsystem Integration	5	[illegible]	50	8	40	8	40	6	30
Facility Impacts	15	10	150	9	135	9	135	2	30
Env. Impacts	5	8	40	9	45	9	45	10	50
Risks (Sched. & Tech.)	10	8	80	10	100	10	100	10	100
	100		965		882.5		850		525

Figure 4.1-3 LRB Trade Study Example

Title	Options	Results	Rationale
Common Bulkhead	Separate Domes or Common Fuel/Oxidizer Bulkhead	Separate Domes	Less Expensive, Easier to Manufacture, Safer
FWD ET/LRB Attachment	Crossbeam or Ring Frame	Crossbeam	Less Expensive, Easier to Manufacture, Less Weight
Dome Optimization (Pressure-Fed)	Elliptical or Hemispherical Domes	Hemispherical Domes	Less Expensive, Easier to Manufacture, Less Weight
Unpressurized Structure Construction	Hat-Stiffened, Waffle, Z-Stiffened, Monocoque, or Truss Core	Hat-Stiffened	Least Expensive, Easy to Manufacture
Cryo Tank Location	Forward or Aft	Forward	No ET Loads Impacts, No Weight/Performance Penalty
Tank Wall Design	Machined Integral Stiffeners or Thick Wall (Monocoque)	Thick Wall (Monocoque)	Less Expensive, Easier to Manufacture, Less Supportability
Pressure-Fed Tank Materials	Weldalite™049, 2219 Al, 2090-T8E41, HP 9-4-30	Weldalite™049	Least Weight/Most Performance
Pump-Fed Tank Materials	Weldalite™049, 2219 Al, 2090-T8E41, HP 9-4-30	Weldalite™049	Least Weight/Most Performance
Aft Skirt & Tie Down Attachment	Skin/Stringer or Monocoque	Skin/Stringer	Less Expensive, Easy to Manufacture, Less Weight
Filament Wound Composite Tank	Welded (Weldalite™049), Filament Wound (Gr/Pk), or Composite Overwrap	Welded (Weldalite™049)	Least Technical Risks, Safest, Best Supportability

Table 4.2-1 Structural/Mechanical Trades Summary

Title	Options	Results	Rationale
Pump-Fed Propellants	N2O4/MMH, LO2/RP-1, LO2/CH4	LO2/RP-1	Lowest Cost, Minimum Operational Complexity, Mininum STS Impacts
Pressure-Fed Propellants	N2O4/MMH, LO2/RP-1, LO2/CH4, LO2/C3H8, N2O4/ALMMH	LO2/RP-1	Lowest Cost, Minimum Operational Complexity, Mininum STS Impacts
Pressurization System Study - N2O4/MMH	ScHe/Hx/GG, ScHe-LH2/2Hx/GG, ScHe/Hx/High Pc GG, ScHe/Stoich GG, ScHe/Stoich GG/TPA	ScHe/Hx/GG	Lowest Cost, Least Complex/ More Reliable, Low Technical Risks
Pressurization System Study - LO2/RP-1	ScHe/Hx/GG, ScHe-LH2/2Hx/GG, ScHe-LH2 Stoich GG, ScHe-LH2/Stoich GG/TPA, ScHe/Stoich GG/TPA	ScHe/Hx/GG	Lowest Cost, Least Complex/ More Reliable, Low Technical Risks
Thrust Vector Control	Gimbals or Liquid Injection	Gimbals	Less Expensive, Less Weight/ More Performance, MoreReliable
TVC Gimbals	Hydraulic or Electromechanical	Electromechanical	Less Expensive, Less Complex/ More Reliable, Safer, Less Wgt
Expendable vs Reusable Propulsion for Pump-Fed	Expendable or Reusable Engines	Reusable Engines	LCC Advantage
Expendable vs Reusable Propulsion for Pressure-Fed	Expendable or Reusable Engines	Expendable Engines	Less Complex System, Fewer Facilities/Ground Impacts, Less Supportability
Engine Cycle	Gas Generator Split Expander	LO2/RP-1 Gas Generator	Lowest Cost, Minimum Operational Complexity, Mininum STS Impacts

Table 4.3-1 Propulsion Trades Summary

4.4 AVIONICS TRADE SUMMARY

Five trade studies were completed by Honeywell, Inc. in support of the LRB avionics system definition. The results of those trades are summarized in Table 4.4-1. The detailed trade study results are provided in the Honeywell report Appendix I.

It is noted that although hydraulic TVC actuators are perferred from an avionics view point, electromechanical actuation is the preferred TVC concept from a total vehicle/operations standpoint.

Title	Options	Results	Rationale
Avionics Architecture	Centralized or Distributed Control	Centralized Control for Pump or Pressure	Minimizes Interfaces & Orbiter Impacts
Expendable vs Reusable	Expendable or Reusable Avionics	Expendable Avionics	LCC Cost Advantage Less Than Facilities, Operational Complexity & Maintainability Impacts
Thrust Vector Control	Electromechanical or Hydraulic Actuators or Fluid Injection	Hydraulic Actuators	Least Expensive Avionics, Less Weight, Proven System
Engine Control Electronics	Pump-Fed or Pressure-Fed	Pressure-Fed Engine Control	Less Complex, Fewer Interfaces, Smaller & Less Power
STS Avionics Interfaces	MDM Serial Channels, Orbiter Bus Taps, or Analog/Discrete	Orbiter Bus Taps	Fewer Channels Required, Less Integration Impacts
Software Development	HAL-S, ADA, C or Assembly Language	ADA	Endorsed by NASA & DOD, Highly Structured, Growth Capability

Table 4.4-1 Avionics Trades Summary

5.0 MISSION ANALYSES

5.1 ENVIRONMENT

The following sections describe the external environments which affect the LRB design.

5.1.1 Natural Environment

STS natural environments at KSC are defined in chapter 5 of the Structural Design Loads Data Book, Vol.1 Baseline Vehicle, Design Criteria and Missions. The neutral atmosphere, launch pad wind criteria, and lightening data is included. Chapter 6 describes STS missions and trajectories (ascent environment), and chapter 7 defines the STS orbital mission design conditions.

5.1.2 Thermal Environment

The preliminary LRB ascent acoustic and thermal environment was predicted by REMTECH Inc. under contract to Martin Marietta Manned Space Systems. Their report, Appendix B, describes the analysis approach and resulting data. These results are summarized below.

5.1.2.1 Ascent Aerodynamic Heating

Since STS/LRB trajectories are similar to the STS with SRBs, aeroheating results are also similar. Ascent aeroheating data is summarized in Appendix B.

A potential ET TPS design impact results from the bow shock wave off the longer Pressure-fed LRB impinging on ET LO2 tank instead of the intertank. This amplifies heating rates by a factor 7 between XT = 750 to 852.

5.1.2.2 LRB Base Heating

Base heating sources are radiation from the LRB and SSME plume and convection from reversed plume flow at higher altitudes. Primary heating at liftoff is by radiation which increases slightly with altitude for the bright opaque plumes of LO2/RP-1 engines. At higher altitudes, reversed flow from the plume to the LRB base extends the area of convective heating and causes an increase in radiation as the radiation source grows. On STS, increase in radiation associated with reversed flow is not significant. On Saturn however, radiation from reversed flow increased by a factor or 2-3 above sea level rates because of soot in the LO2/RP-1 plumes.

Radiation—The pump-fed LRB has plume temperatures similar to Saturn; Pressure-fed LRB has a higher plume temperature than Saturn F-1 engine but is expected to have less soot, hence the same emissive power.

ET base heating rates for Pressure-fed are just slightly higher than SRBs; Pump-fed LRB heating rates are lower. Radiation heating rates are given in Appendix B.

Convection—Plume induced convective heating cannot be calculated analytically but can be estimated from flight test data. Plume recirculation starts at 36000 ft and reaches its maximum at 75000 ft. LRB convective base heating is expected to be similar to Saturn 5. Results are given in Appendix B.

5.1.2.3 Acoustics Sources

It is shown in Appendix B that the overall sound power level of the LRB's is the same as SRBs, however the frequency spectrum changes. Acoustics spectrum shift ratios caused by replacing SRBs by LRBs are presented for various nozzle exit conditions. Shift ratios that are recommended (1.49 for Pump-fed and 1.20 for Pressure-fed) are considered negligible, being less than 1.2 octave. This data forms the basis of acoustic environment predictions discussed in the next section below.

5.1.2.4 Acoustic Environment

Several reports giving estimates of the LRB compartment acoustic environment were prepared by Technology Integration and Development Group, using estimates of LRB external acoustic power levels developed in Appendix K. These reports deal with acoustics environment in the far field and environment near the nozzles. A summary of the results is given below.

LRB Ascent External Acoustics—SRB's are main acoustic sources for the Shuttle. LRB's emit the same acoustical energy as SRB's (within 1dB). However the spectra shift by 0.84 to 1.49 depending on nozzle exit conditions selected.

There are two nozzle exit conditions possible: a) 1-D plume characteristics at nozzle exit plane, based on Lewis CEC code; b) isentropic expansion (or contraction) of 1-D flow to sea level pressure. It is recommended that the 1-D sea level condition be used. Spectra ratios for this condition are 1.49 for the pump-fed, and 1.20 for the pressure-fed i.e., LRB spectra will be slightly higher frequency than SRBs.

It is recommended in Appendix K that near SSME's (i.e. at Orbiter aft bulkhead) use measured data from STS 1, 2 and 3 without any changes. At other locations on the Orbiter, take measured spectra and shift them by appropriate amounts.

Data presented in the report is to be used as external sound pressure level (SPL) for the calculation of interior acoustic field.

The greatest difference from SRB data in any 1/3 octave band is 4.5 dB for a frequency shift of 0.84 (at Orbiter bottom panels, aft). This implies an acoustic power increase of 2.8 in that band width. This is a concern which must have further evaluations, but is not considered a major impact.

LRB Acoustics near Skirt—LRB acoustic environment near the nozzle is developed in Appendix K. Estimates based on simple theory (SPL of plume, and radiation laws) give answers that do not correlate with known data. Hence STS measured data for basic SPL is used as a baseline. Measured data from Saturn V is used to obtain increments to basic SPL as the nozzle is approached for the near field effects. A SPL of 166.7 dB is obtained near LRB nozzle exit plane using this method.

The frequency shifted LRB spectra is used to form near field LRB spectra. Results are given in Tables 1 and 2 in Appendix K for various frequency shift factors. However estimates in 12 to 120 Hz range are suspect because they do not include cavity resonance effects.

5.1.3 Overpressure

LRB overpressure effect is shown to be negligible compared to SRBs (Appendix B).

5.2 LOADS ANALYSIS

The first estimation of launch loads involved a simple rigid body loads calculation. Total vehicle mass and inertia matrices were obtained from the component mass and inertia terms. This rigid vehicle was subjected to estimates of thrust and aerodynamic forcing functions, and the resulting ET interface loads were obtained. Dynamic components of the launch transient were obtained from prior ACC Launch Analysis studies (1983). Rigid body loads were factored by 1.25 and the dynamic loads components by 1.4, and summed to give the ultimate loads shown in Table 5.2-1. STS 3D REV4/REV5 loads currently used for the ET program are also shown for comparison.

It can be seen from Table 5.2-1 that the initial aft attach Y loads FTB9U exceed the STS design value. The exercise was repeated for a rigid body loads calculation for the STS (SRB vehicle) as a check case; FTB9U again exceeded the REV4/REV5 values. The FTB9U exceedance was hence a function of the rigid body loads calculation method, which ignored any radial relief due to structural flexibility. When radial flexibility of the aft attach frame in the LRB RP-1 tank is

Table 5.2-1 ET Interface Loads - Ultimate

FTB	3D Rev4/Rev5 Loads		Preliminary LRB STUDY Loads - Rev1								SRB Rigid Body Analysis	
			Pump-Fed				Pressure-Fed					
	MAX	MIN	MAX		MIN		MAX		MIN		MAX	MIN
1	285.4	-288.8	3	247.5	3	-172.5	8	252.5	8	-167.5	296.3	-123.8
3	296.5	-122.3	3	220.0	3	-60.0	8	200.0	8	-80.0	225.0	-55.0
5	223.3	-2205.6	-	-	5	-2069.0	-	-	10	-2066.0	-	-
7	346.1	-319.8	3	205.5	3	-130.5	8	210.5	8	-125.5	172.0	-164.0
9U	302.1	-248.4	3	157.0	3	$\boxed{-347.0}$	8	160.8	8	$\boxed{-343.3}$	154.0	$\boxed{-350.0}$
A	414.0	-353.8	3	197.0	3	-167.0	8	213.3	8	-150.8	196.0	-168.0

Loads = KIPS (ULT)
Loads on L.H. Side of Vehicle are Shown
Loads on R.H. Side are Identical

Load Condition Key:

1 - Pump Fed - On Pad - Gravity Loads Only
2 - Pump Fed - On Pad - Gravity & SSME's - Max Pitchover
3 - Pump Fed - Lift Off
4 - Pump Fed - Max Q
5 - Pump Fed - BA
6 - Pressure Fed - On Pad - Gravity Loads Only
7 - Pressure Fed - On Pad - Gravity & SSME's - Max Pitchover
8 - Pressure Fed - Lift Off
9 - Pressure Fed - Max Q
10 - Pressure Fed - BA

taken into account by a full math model in future analyses, the FTB9U load will reduce to an acceptable level below the allowable.

Loads shown in Table 5.2-1 were used for preliminary sizing of the structure. Complete documentation of the LRB loads analyses is contained in Section 6.5.1.1.

5.3 VEHICLE PERFORMANCE AND MISSION OPERATIONS

5.3.1 Prelaunch/Liftoff

The LRB pump-fed ignition sequence is shown in Figure 5.3.1-1. SSME ignition begins at 1.9 seconds with each engine start staggered by 0.182 seconds. The SSMEs achieve 100% thrust at approximately 4.0 seconds. Pump-fed LRB engines have a thrust build-up time of 2.9 sec. Pressure-fed LRB engine start will require approximately 1.9 seconds to reach a steady operation as shown in Figure 5.3.1-2. LRB engine ignition and thrust build-up can be accomplished after SSME 100% thrust and prior to null stack tip-over.

During SSME buildup the maximum allowable motion at the ET intertank umbilical is 20 inches. Based on analysis of both the pump-fed and pressure-fed configurations maximum z motion is slightly below that currently experienced with the SRBs (see section 6.5.1.1).

5.3.2 Ascent

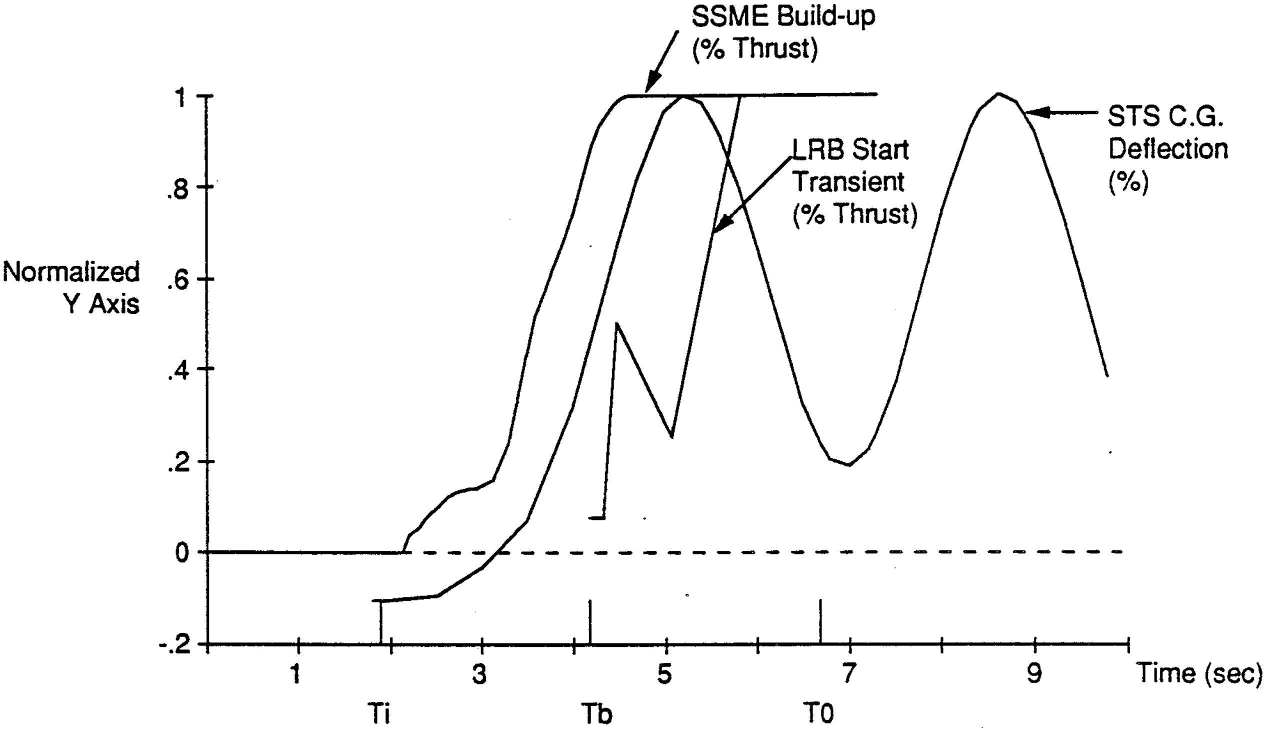
Results of the pump-fed trajectory analysis are shown in Figures 5.3.2-1 thru -3. The pump-fed LRB analysis is based on nominal power levels (75% of EPL to allow for the engine-out operation in the four engine arrangement). The pump-fed LRB is also capable of launching approximately 72,500 lb. of payload as shown in Table 5.3.2-1.

Pressure-fed LRB trajectory data are shown in Figures 5.3.2-4 thru -6 based on a payload capacity of approximately 72,850 lb.

Both the pump-fed and pressure-fed LRBs require a throttle back during boost flight to maintain the dynamic pressure limits for STS ascent.

Another STS ascent constraint is a q-alpha limit of -3000 psf deg. Both pump-fed and pressure-fed LRBs meet this requirement as shown in Figure 5.3.2-7.

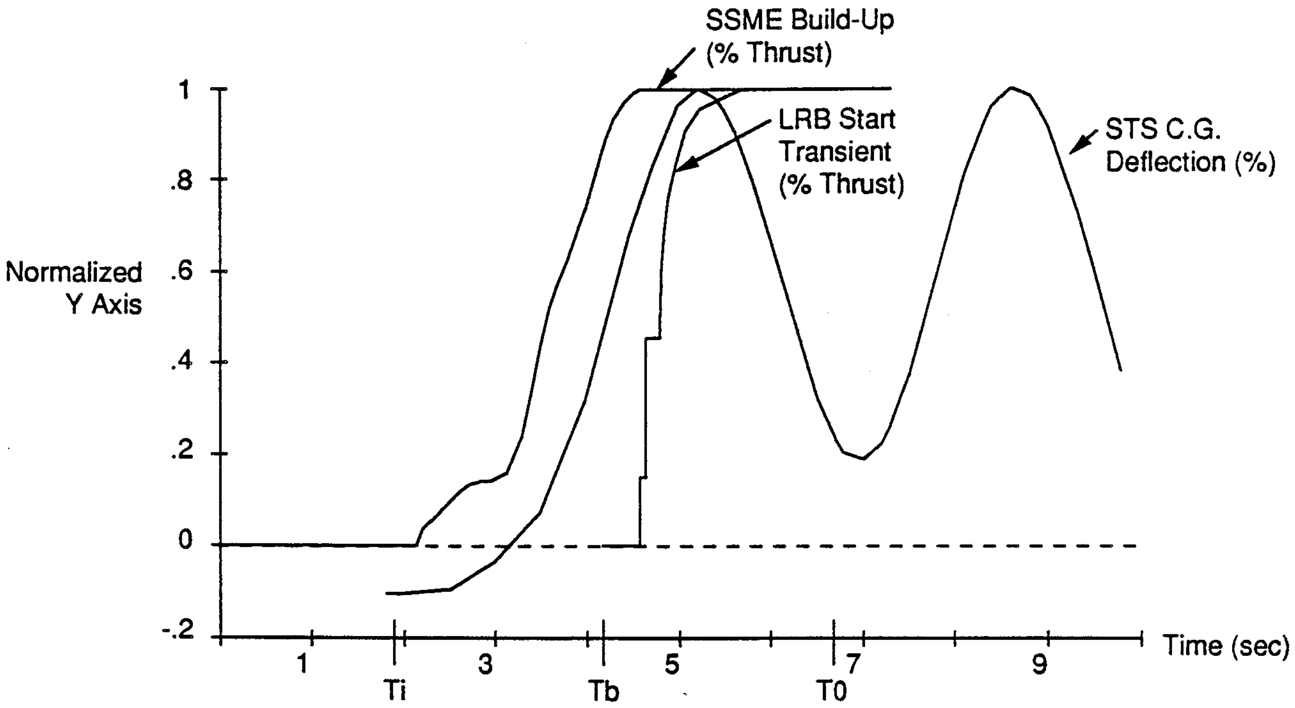
The ascent scenario shown in Figure 5.3.2-8 illustrates the abort capability of the LRB .



Ti	SSME ignition (1.9 sec., engines staggered by 0.182 sec)
Tb	LRB ignition (4.18 sec)
T0	Nominal Lift-off (6.68 sec)

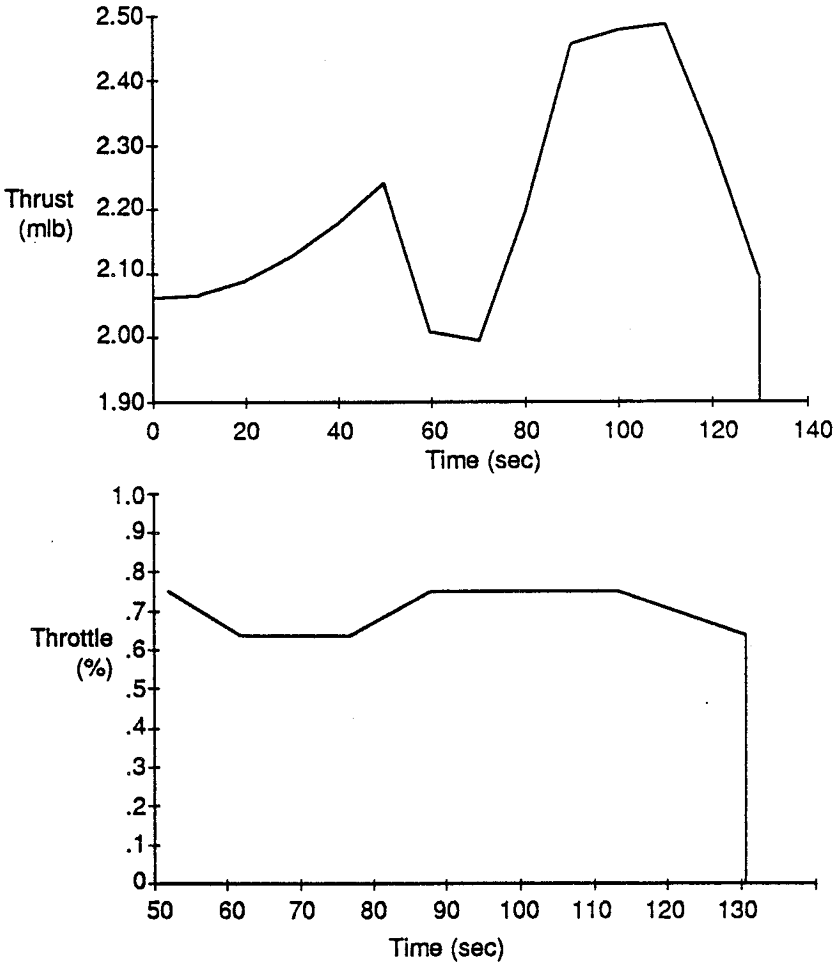
Figure 5.3.1-1 Pump-Fed Ignition Sequence

N-032/jer



Ti	SSME ignition (1.9 sec., engines staggered by 0.182 sec)
Tb	LRB ignition (4.18 sec)
T0	Nominal Lift-off (6.68 sec)

Figure 5.3.1-2 Pressure-Fed Ignition Sequence



Engines at Normal Power Level
(75% of Emergency Power Level)

Figure 5.3.2-1 Pump-Fed Trajectory Thrust & Throttle - 70.5 k

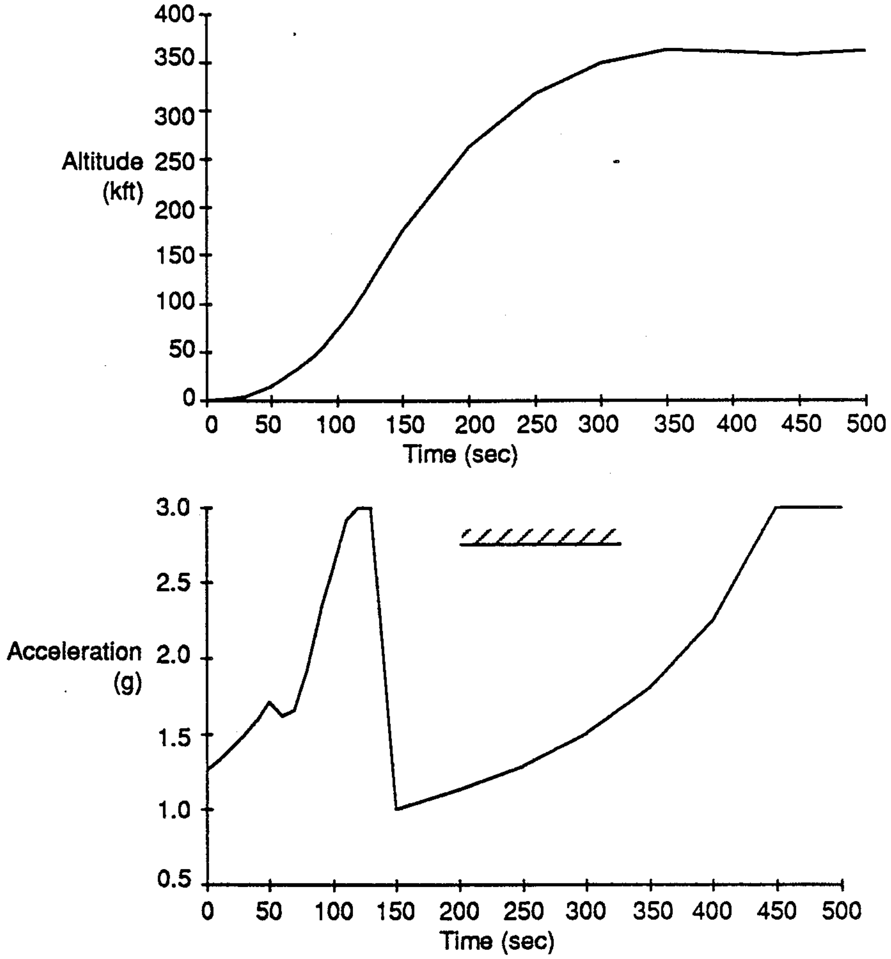


Figure 5.3.2-2 Pump-Fed Trajectory Altitude & Acceleration - 70.5 k

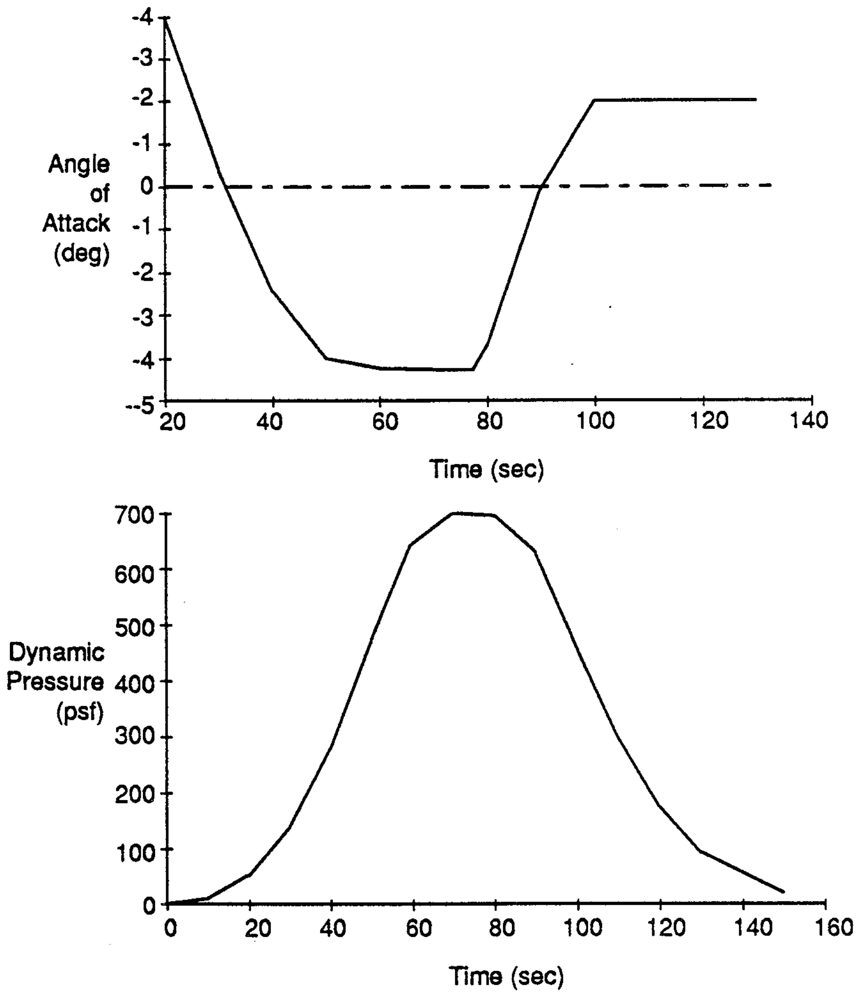


Figure 5.3.2-3 Pump-Fed Trajectory Alpha & Dynamic Pressure - 70.5 k

Table 5.3.2-1 LRB Optimum Performance Configuration

	Pump-Fed	Pressure-Fed
Payload	72,499 lb	72,853 lb
Manager's Reserve	1,999 lb	2,353 lb
Thrust/Weight @ T0 sec	1.253	1.524
Gross Lift-Off Weight (GLOW)	4,175,938 lb	4,664,931 lb
Max Dynamic Pressure	702 psf	710 psf
Burn Time	131.8 sec	123.7 sec
Coast Time	2.4 sec	2.4 sec
Jettison Weight	271,304 lb	473,618 lb
LRB Engine-Out Capability	T0 sec & Make Mission	T0 & Intact Abort
Sea Level (Vac) Isp	266.3 (322.3) sec @NPL	269.5 (318.7) sec @EPL
Usable Propellant Wgt/Boster	979,543 lb	1,122,705 lb
Mixture Ratio	2.6:1	2.67:1
Engine Exit Area	51.11 ft2	65.038 ft2
Booster Lift-Off Weight (BLOW)	1,115,195 lb	1,359,514 lb
Booster Outside Diameter	15.3 ft	16.2 ft
Booster Length	151.0 ft	163.0 ft

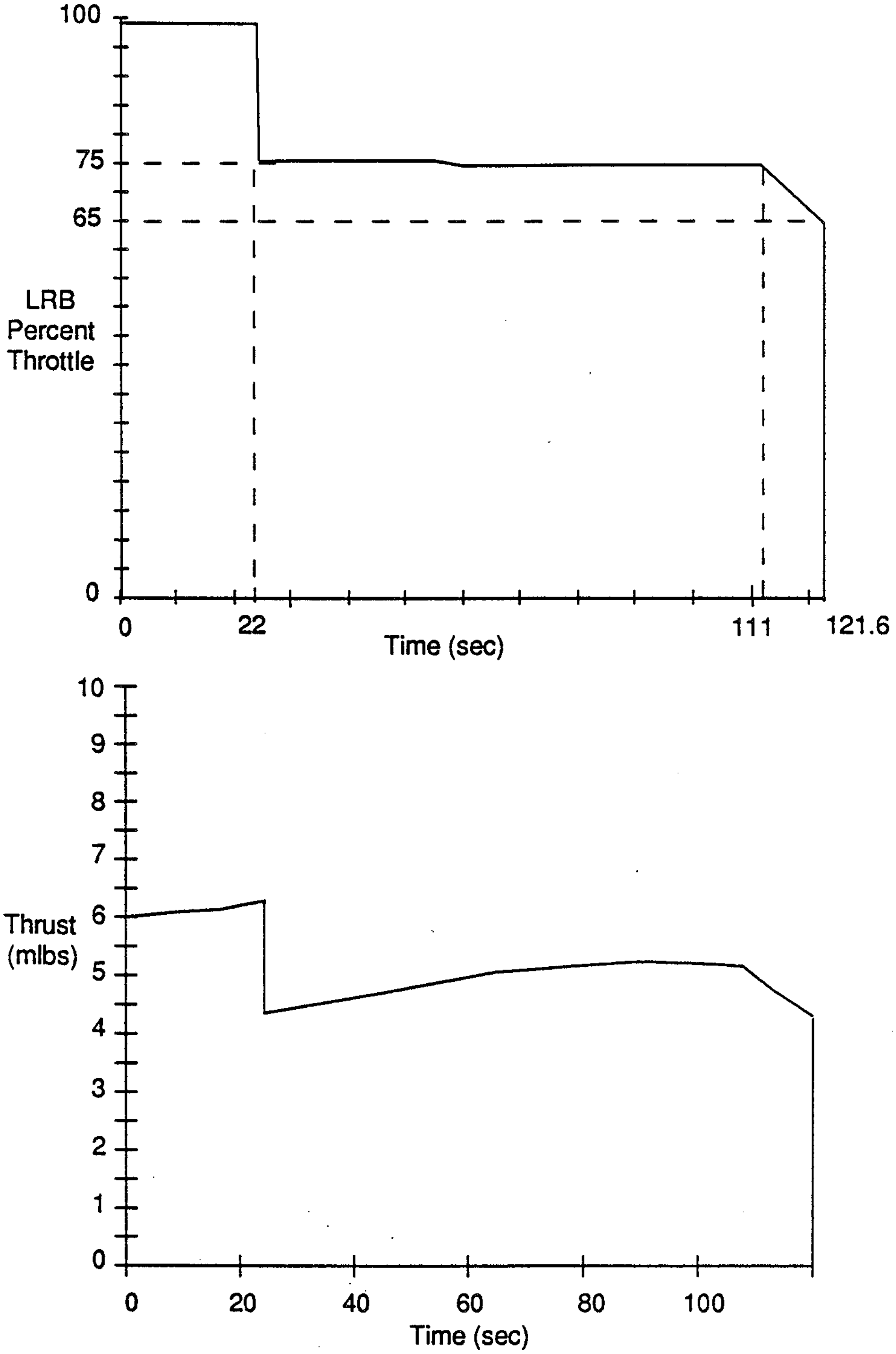


Figure 5.3.2-4 Pressure-Fed Trajectory Throttle & Thrust

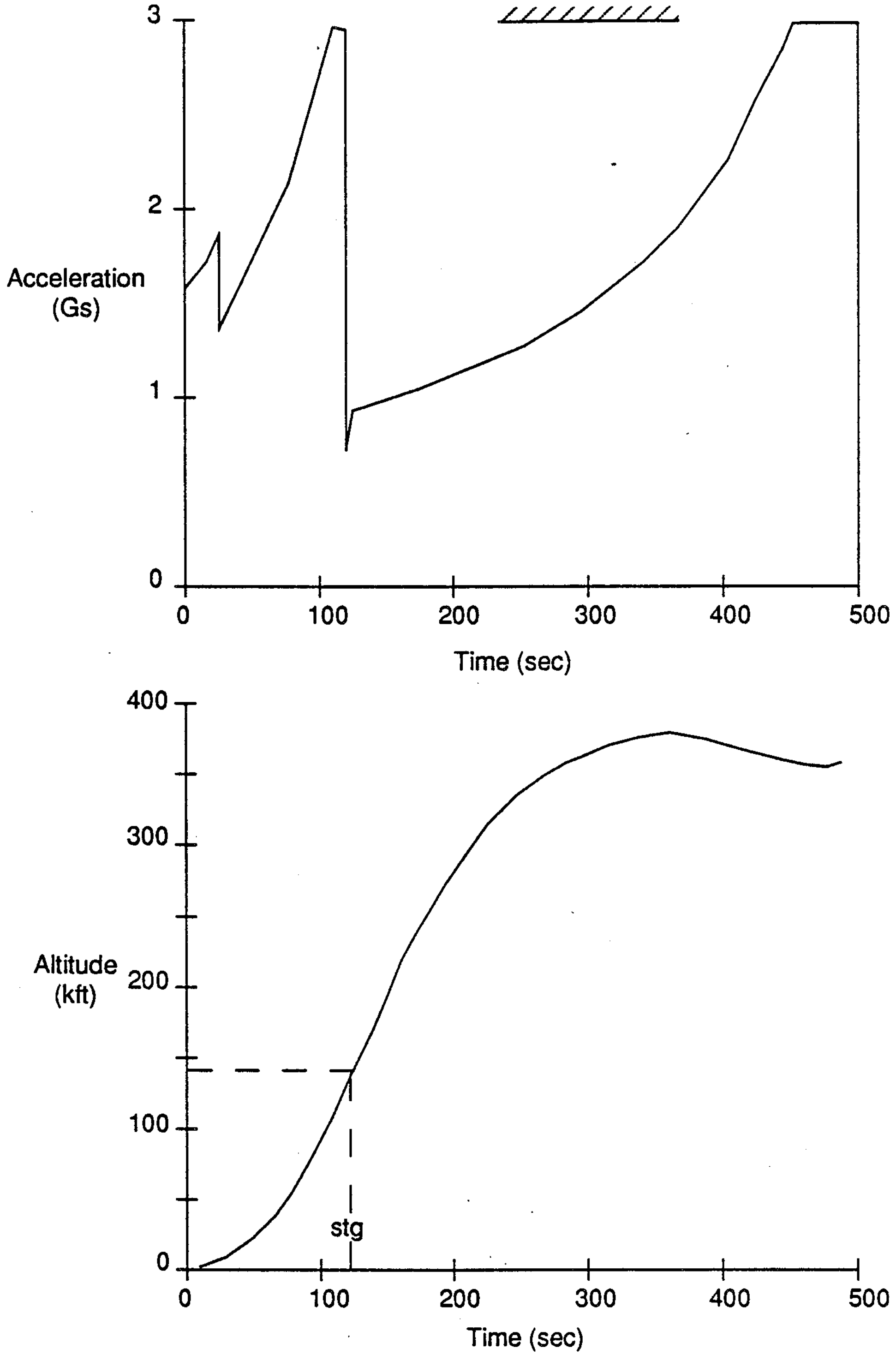


Figure 5.3.2-5 Pressure-Fed Trajectory Acceleration & Altitude

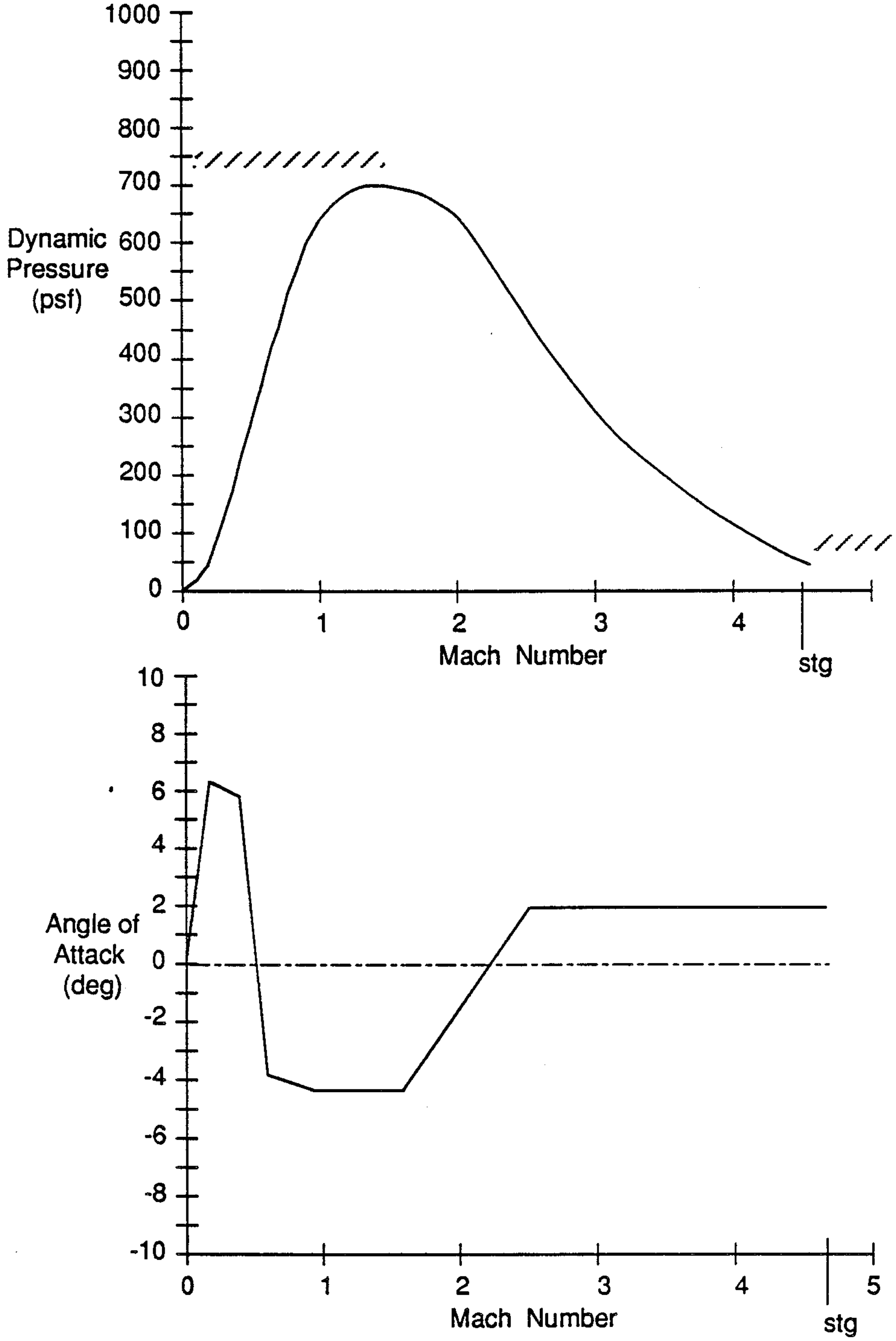


Figure 5.3.2-6 Pressure-Fed Trajectory Dynamic Pressure & Alpha

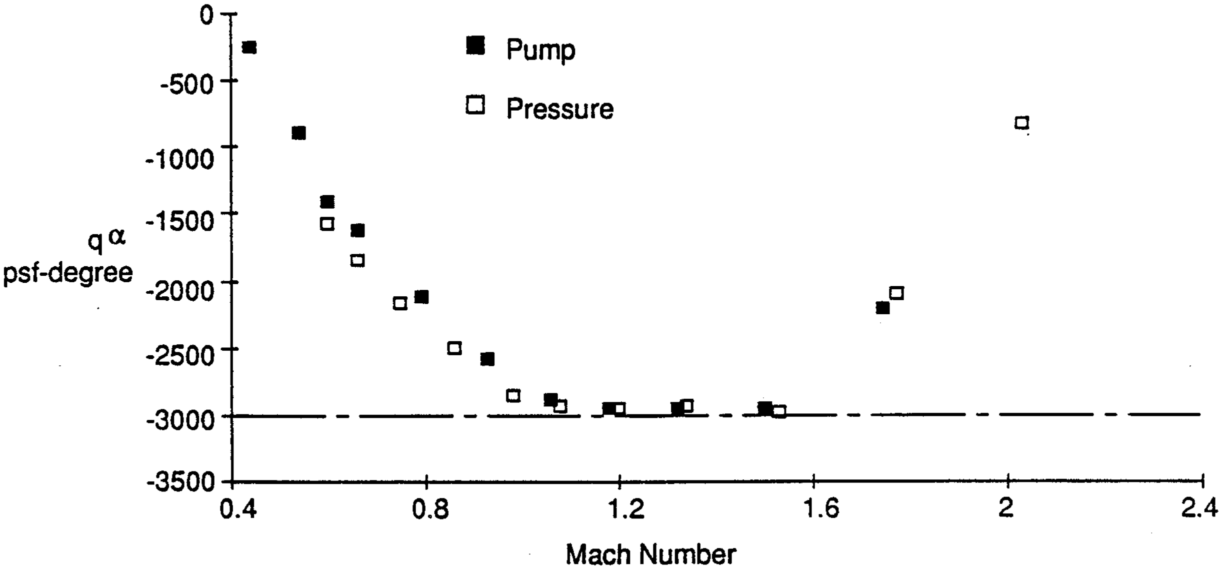


Figure 5.3.2-7 Ascent Trajectory q^a vs Mach

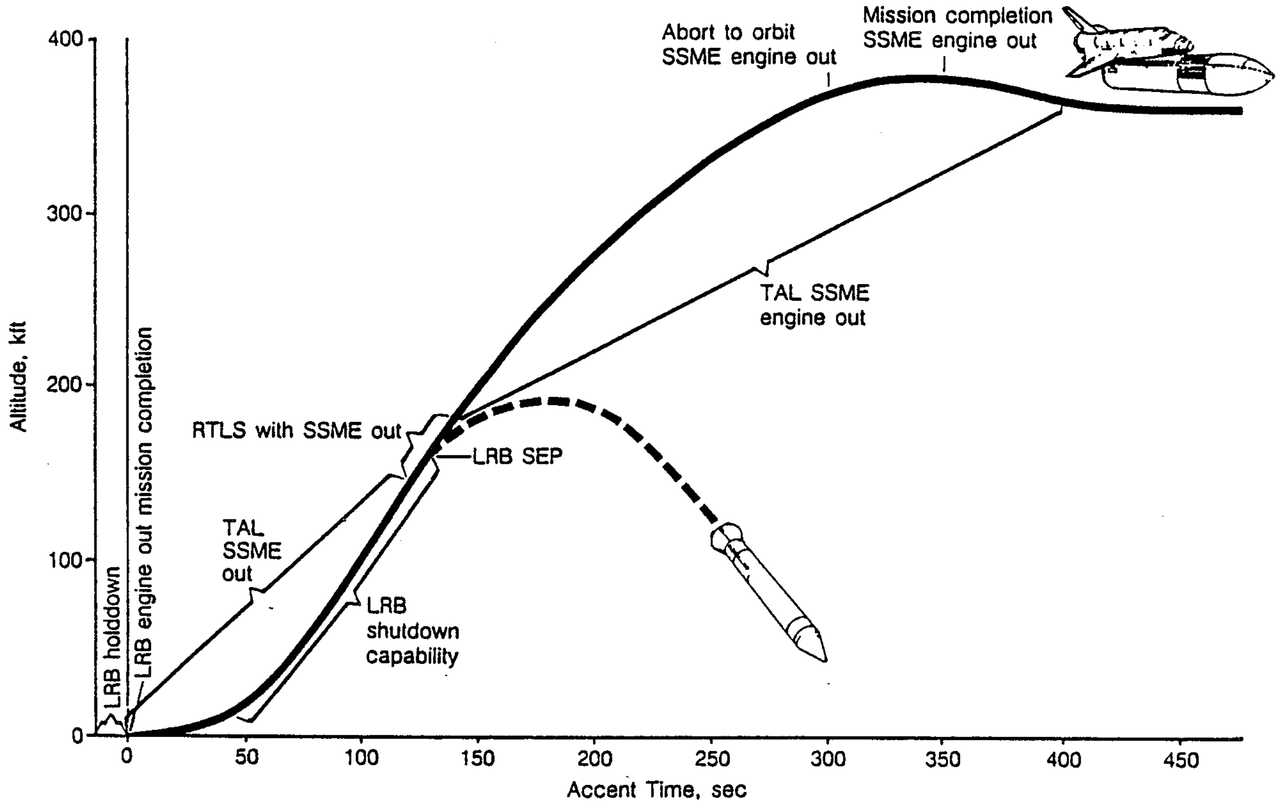


Figure 5.3.2-8 Ascent Scenario

5.4 FLIGHT CONTROL SYSTEM ANALYSIS

Flight control analysis tasks were performed to assess the impact of the current STS flight control system for preliminary LRB configurations. Both 6 DOF trajectory simulation analyses and Flight Control System stability (FCS) analyses were performed. LRB slosh dynamics, LRB/ET slosh interaction and STS control, and limit cycle impact were obtained from 6 DOF trajectory simulation. FCS stability analysis determined the impact of structural flexibility on rigid body and slosh control and dynamics. A detailed report prepared by Honeywell, Inc. is attached as Appendix N. The main conclusions from this analysis are:

1) Adequate flex stability margins were obtained for both the pressure-fed and the monocoque pump-fed LRB configurations.

2) LRB propellant slosh stability is a concern, and the likely solution is addition of baffeling in the LRB propellant tanks.

Sections 5.4.1 describes the FCS stability analysis and Section 5.4.2, the 6 DOF trajectory simulation analysis.

5.4.1 STS/LRB Stability Analysis

Flight control analysis models were created at Martin Marietta Michoud during the generation of transient response models. Flight control model data is summarized in Table 5.4.1-1. A comparison of LRB only and LRB launch vehicle flex modes to the STS (with SRBs) is shown in Table 5.4.1-2. It shows that the baseline LRB configurations (pressure-fed and monocoque pump-fed) have slightly higher low frequency flex modes than the SRBs.

The pressure-fed LRB minimum modal frequencies are 12% higher than with the SRB. Low frequency modes are 8-20 db stronger than with SRB (partially offset by improved attenuation through FCS bending filters).

The initial pump-fed LRB configuration was a light weight stiffened skin design which had modal frequencies 5% lower than the SRB. The low frequency modes were 15-28 db stronger than the SRB and the flex stability margins were not within current STS FCS criteria. When the pump-fed configuration was changed to a heavier and stiffer monocoque design to solve launch transient problems, the flex stability margins became acceptable for STS. Comparison of the flex stability margins of the final baseline and the initial stiffened skin concept is made in Figure 5.4.1-1.

Table 5.4.1-1 Honeywell Control Model

Stick ET	Full 360 degree model from sym-antisym half models sent to RI. Loaded with propellents. Simulated bulge modes for LO2 tank (4 Hz approximately), and for LH2 tank (8.5 Hz approximately). Fluid slosh characteristics determined and simulated by Honeywell.
Orbiter	Empty orbiter descent controls model M60B. Same model as used in transient response analysis, but with extra control degrees of freedom.
LRBs	Same as for transient response, with extra control degrees of freedom.
SRBs	Same as for transient response, with extra control degrees of freedom.

Weight Comparison for Various Vehicles

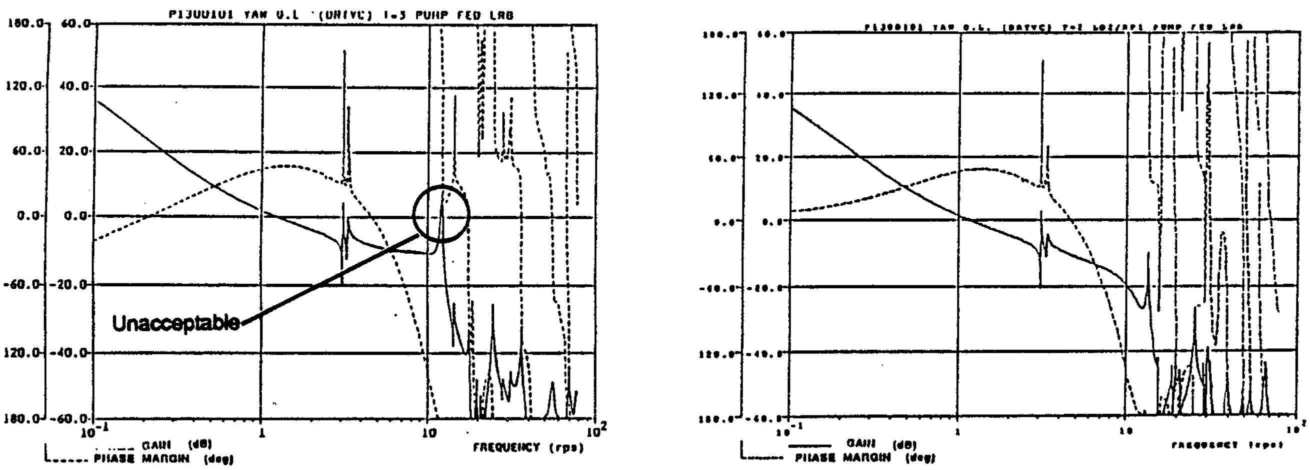
	SRB	Pressure-Fed	Pump-Fed	Monocoque Pump-Fed
Weight (lbf)	4,447,000	4,639,000	3,928,000	4,044,000
X cg (in.)	770.7	826.3	875.5	845.47
Y cg (in.)	0.0	0.0	0.0	0.0
Z cg (in.)	-14.1	-13.4	-15.9	-15.5

Table 5.4.1-2 SRB/LRB Free-Free Modes Comparison

	Modes			
	1	2	3	4
Components				
SRB	4.962 (29.48)	4.694 (29.49)	9.457 (59.42)	9.352 (59.89)
LRB Pressure-Fed	5.590 (35.12)	5.591 (35.13)	9.517 (59.80)	12.231 (76.85)
LRB Pump-Fed	3.936 (24.73)	3.938 (24.74)	8.049 (50.57)	8.064 (50.67)
LRB Monococque Pump-Fed	4.634 (29.12)	4.634 (29.12)	9.860 (61.95)	9.860 (61.95)
Vehicles				
SRB	1.983 (12.46)	2.068 (12.99)	2.344 (14.73)	2.534 (15.92)
LRB Pressure-Fed	2.174 (13.66)	2.193 (13.78)	2.518 (15.82)	2.622 (16.48)
LRB Pump-Fed	1.844 (11.58)	1.882 (11.83)	1.941 (12.20)	2.238 (14.06)
LRB Monococque Pump-Fed	2.103 (13.21)	2.138 (13.43)	2.424 (15.24)	2.474 (15.54)

Note: Frequencies are Hz (rad/sec)

FLEX STABILITY IMPACT OF PUMP-FED LRB CONFIGURATIONS



ORIGINAL DESIGN

CURRENT DESIGN

- ACCEPTABLE FLEX STABILITY IS ACHIEVED WITH CURRENT PUMP-FED STS/LRB CONFIGURATION

Figure 5.4.1-1 Flex Stability Margins

5.4.2 - 6 DOF Trajectory Simulation Analyses

The LRB propellant slosh masses (about 6200 slugs) are comparable to those of the External Tank. The LRB slosh frequencies (3.0-4.2 rps) are within the current flight control system bandpass (5-6 radians/seconds) but generally exceed the ET slosh frequencies.

6 DOF trajectory simulation analysis reveals considerably more pronounced STS/LRB vehicle cycling than observed/predicted with the STS/SRB configuration. Limit cycling at the LRB propellant slosh frequency is predominantly in the lateral (roll/yaw) axes. The amplitudes build through first stage ascent but maximum cycle amplitudes appear to be within current STS flight control system criteria.

Linear stability analysis at selected first stage flight conditioned reveal inadequate yaw axis rigid body/slosh stability margins during "late" first stage. The proximity of the LRB slosh modes to the flight control system "180° crossover" frequency appears to be the prime cause. These stability margins do not satisfy current STS criteria.

Potential solutions to the slosh stability problem include obtaining a waiver on current STS margins, adding baffling inside the LRB propellant tanks, or modifying the current STS flight software to improve stability.

6.0 LRB DESCRIPTION - PUMP-FED

6.1 GENERAL CONFIGURATION

6.1.1 Shuttle/LRB Vehicle

The STS with a pump-fed liquid rocket booster is presented in Figure 6.1.1-1. The solid rocket boosters are replaced with liquid boosters which have four 685K pound thrust (EPL) engines that use LO2 and RP-1 as propellants. This configuration was selected as the optimum pump-fed design to meet the requirements specified in the LRB for the STS definition study.

6.1.2 LRB

The optimum pump-fed liquid rocket booster for the STS is defined in detail in the following paragraphs. Figure 6.1.2-1 presents an overview of the pump-fed structural arrangement. The booster is approximately 194.4 feet in length and 15.3 feet in diameter. The aft skirt flares to 22.1 feet at the STS mobile launch pad structural interface. Appendix J contains the detailed engineering drawings for the pump-fed LRB.

6.1.3 Mass Properties

Mass properties are presented for the pump-fed Liquid Rocket Booster (LRB) and the NSTS/LRB launch vehicles system configuration in this section. Table 6.1.3-1 presents the LRB dry weight mass properties and Table 6.1.3-2 shows how the NSTS/LRB Gross Lift Off Weight (GLOW) was developed. The reference coordinate system is shown in Section 2, Figure 2.1.1-1.

Mass properties data presented in Table 6.1.3-3 are the complete NSTS/LRB launch vehicle system properties from lift-off through LRB separation taken in 10 sec intervals. The data shows the propellant usage schedule for the shuttle system which was used in the performance and trajectory analyses. Although only the ET fuel and oxidizer weights are shown in Table 6.1.3-3, the total weight shown includes the usage of LRB propellants.

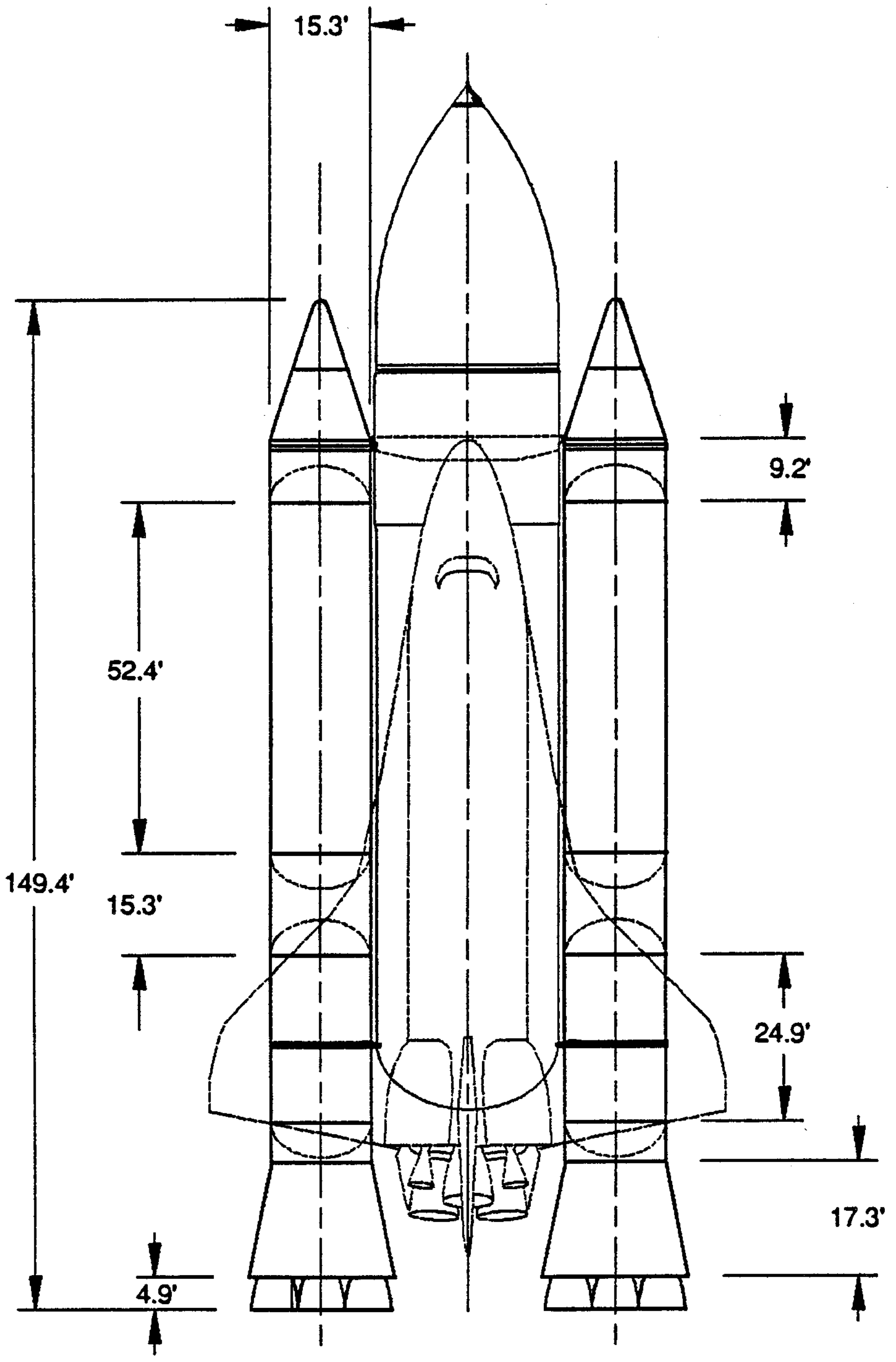


Figure 6.1.1-1 STS with Pump-Fed Liquid Rocket Booster

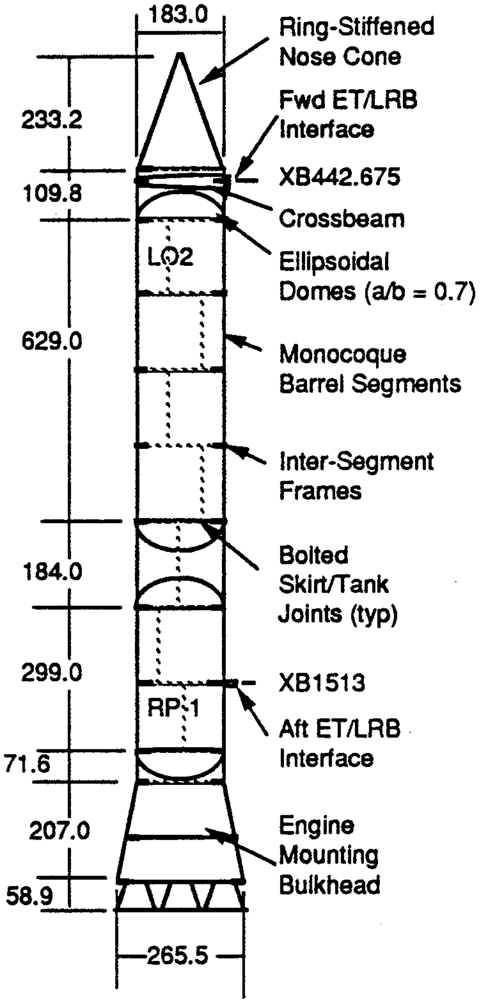


Figure 6.1.2-1 Pump-Fed Structural Arrangements

Table 6.1.3-1 Pump-Fed Dry Weight Mass Properties

Item	Weight (lb)	Center of Gravity (in.)			Radius of Gyration (in.)		
		x	y	z	kx	ky	kz
Nose Cone	1,900	345.0	0.0	0.0	65.4	80.2	80.2
Forward Skirt	4,310	474.2	11.6	0.0	85.5	64.8	68.6
Forward Tank - LO2	20,870	860.7	0.0	0.0	88.7	216.4	216.4
Intertank	5,110	1261.0	0.0	0.0	91.3	80.6	80.6
Aft Tank - LH2	11,970	1507.0	0.4	0.2	86.4	125.2	125.2
Aft Skirt	26,600	1823.9	0.0	0.0	108.3	103.5	103.5
Structure	70,760	1323.6	0.8	0.0	95.7	504.3	504.4
Propulsion System	32,710	1834.4	0.0	0.0	87.1	145.2	145.2
TVC System	720	1759.1	0.0	0.0	80.6	94.8	87.3
Thermal/Acoustical Protection	2,070	1170.8	0.0	0.0	93.6	632.0	632.0
Separation System	1,220	1046.0	0.0	75.8	15.8	596.2	596.0
Avionics	3,150	1576.3	-8.0	8.0	82.5	377.5	377.5
I/F Attach	1,320	977.8	110.0	0.0	0.1	535.2	535.2
Range Safety	150	1289.0	0.0	0.0	0.1	0.1	0.1
Contingency (10%)	11,210	1472.6	1.6	1.1	0.0	0.0	0.0
Total Dry Weight	123,310	1472.6	1.6	1.1	88.4	472.0	472.1

Table 6.1.3-2 Pump-Fed Weight Summary

	Weight (lb)			
Item	LRB (2)	ET	Orbiter	P/L
Dry Weight	246,620	66,620	176,210	70,500
Management Reserve				2,000
Usable Implulse Propellant	1,959,080	1,590,060		
Propellant Residual		4,630	2,380	
Pressurant	27,220	420		
Propellant - Reserve		2,220	2,780	
Other		490	26,860	
Lift-Off Weight	2,232,920	1,664,440	208,230	72,500
Total Vehicle GLOW		4,178,090		

Table 6.1.3-3 NSTS/LRB Pump-Fed Launch Vehicle Properties

NSTS/LRB
At Liftoff

Total Weight	Propellant	Weight	Level
4,130,870			
	Fuel	229,638	1,081.98
	Oxydizer	1,367,983	458.14

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,357.94	.28	422.51
	40,448,257.69	273,095,211.74	300,619,771.64
	40,967.91	10,213,374.48	46,745.96
	.09	2.24	.01

NSTS/LRB
At 10 sec

Total Weight	Propellant	Weight	Level
3,944,212			
	Fuel	225,062	1,105.69
	Oxydizer	1,340,567	482.88

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,364.82	.29	423.57
	38,091,381.85	264,368,058.73	289,578,932.59
	40,701.66	10,075,315.46	45,026.62
	.09	2.29	.01

NSTS/LRB
At 20 sec

Total Weight	Propellant	Weight	Level
3,757,082			
	Fuel	220,421	1,127.41
	Oxydizer	1,312,718	502.79

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,370.35	.31	424.75
	35,732,711.85	255,919,809.56	278,819,144.38
	40,408.18	9,964,476.25	43,646.26
	.1	2.34	.01

NSTS/LRB
At 30 sec

Total Weight	Propellant	Weight	Level
3,569,952			
	Fuel	215,780	1,148.62
	Oxydizer	1,284,869	519.78

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,374.36	.32	426.05
	33,371,570.95	247,751,868.73	268,342,134.64
	40,083.94	9,883,925.60	42,643.11
	.11	2.40	.01

Table 6.1.3-3 NSTS/LRB Pump-Fed Launch Vehicles Properties

NSTS/LRB
At 40 sec

Total Weight	Propellant	Weight	Level
3,382,822			
	Fuel	211,139	1,169.76
	Oxydizer	1,257,020	534.87

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,376.55	.34	427.49
	31,007,549.10	239,680,976.14	257,964,707.87
	39,723.82	9,840,049.34	42,096.69
	.12	2.48	.01

NSTS/LRB
At 50 sec

Total Weight	Propellant	Weight	Level
3,195,692			
	Fuel	206,498	1,190.90
	Oxydizer	1,229,171	548.62

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,376.61	.36	429.10
	28,640,140.21	231,565,734.89	247,546,706.94
	39,321.53	9,838,707.65	42,079.98
	.14	2.57	.01

NSTS/LRB
At 60 sec

Total Weight	Propellant	Weight	Level
3,016,294			
	Fuel	201,857	1,212.04
	Oxydizer	1,201,322	561.35

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,374.77	.38	430.83
	26,387,057.56	223,477,273.45	237,274,582.57
	38,888.99	9,875,616.65	42,539.64
	.16	2.68	.01

NSTS/LRB
At 70 sec

Total Weight	Propellant	Weight	Level
2,848,977			
	Fuel	197,216	1,233.18
	Oxydizer	1,173,473	573.29

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,371.43	.41	432.64
	24,314,797.40	215,449,183.13	227,246,901.45
	38,436.49	9,942,744.88	43,375.63
	.19	2.80	.01

Table 6.1.3-3 NSTS/LRB Pump-Fed Launch Vehicles Properties

NSTS/LRB
At 80 sec

Total Weight	Propellant	Weight	Level
2,673,445			
	Fuel	192,575	1,254.32
	Oxydizer	1,145,624	584.58

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,364.56	.43	434.78
	22,111,815.36	206,739,765.79	216,420,516.23
	37,900.90	10,080,682.45	45,093.46
	.22	2.96	.01

NSTS/LRB
At 90 sec

Total Weight	Propellant	Weight	Level
2,487,765			
	Fuel	187,934	1,275.46
	Oxydizer	1,117,775	595.36

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,352.64	.47	437.38
	19,746,502.89	196,940,031.67	204,359,667.38
	37,252.07	10,319,887.97	48,072.45
	.29	3.19	.02

NSTS/LRB
At 100 sec

Total Weight	Propellant	Weight	Level
2,300,635			
	Fuel	183,293	1,296.61
	Oxydizer	1,089,926	605.69

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,335.33	.50	440.42
	17,350,378.46	185,981,598.29	191,127,180.94
	36,492.22	10,667,303.94	52,399.06
	.41	3.50	.02

NSTS/LRB
At 110 sec

Total Weight	Propellant	Weight	Level
2,116,713			
	Fuel	178,652	1,317.75
	Oxydizer	1,062,077	615.66

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,312.18	.55	443.93
	14,993,227.92	173,735,213.09	176,664,562.66
	35,614.49	11,131,807.23	58,183.83
	.70	3.92	.02

Table 6.1.3-3 NSTS/LRB Pump-Fed Launch Vehicles Properties

NSTS/LRB
At 120 sec

Total Weight	Propellant	Weight	Level
1,945,184			
	Fuel	174,011	1,338.89
	Oxydizer	1,034,228	625.31

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,284.62	.60	447.80
	12,815,951.28	160,600,845.23	161,508,446.40
	34,646.31	11,684,989.02	65,072.98
	2.18	4.47	.03

NSTS/LRB
At 130 sec

Total Weight	Propellant	Weight	Level
1,786,616			
	Fuel	169,370	1,360.03
	Oxydizer	1,006,379	634.68

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,251.39	.65	452.04
	10,826,983.59	146,232,374.07	145,321,257.65
	33,585.92	12,351,815.15	73,377.42
	-2.11	5.20	.03

NSTS/LRB
At 131.5 sec

Total Weight	Propellant	Weight	Level
1,764,174			
	Fuel	168,681	1,363.17
	Oxydizer	1,002,244	636.05

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,242.41	.66	452.71
	10,547,658.35	141,739,973.40	140,576,106.10
	33,420.44	12,532,071.40	75,622.27
	-1.64	5.46	.03

NSTS/LRB
Jettisoned

Total Weight	Propellant	Weight	Level
1,520,174			
	Fuel	168,681	1,363.17
	Oxydizer	1,002,244	636.05

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,121.05	.76	461.17
	6,299,661.58	94,775,177.38	90,096,092.42
	31,306.00	14,967,677.62	105,954.53
	-.38	9.83	.07

Table 6.1.3-3 NSTS/LRB Pump-Fed Launch Vehicles Properties

ET at
LRB Ignition

Total Weight
1,665,159

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	875.70	.60	402.10
	441,294.00	48,865,586.77	48,804,503.98
	34,720.00	585,345.00	132,558.00
	-24.33	.69	.16

Orbiter at
LRB Ignition

Total Weight
208,229

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,867.40	-.20	714.10
	932,071.00	7,051,976.06	7,335,525.41
	-1,416.00	241,639.00	9,996.00
	-.29	2.16	.09

6.2 STRUCTURES

6.2.1 Nosecone

The nose cone serves to provide an aerodynamic shape and support avionics equipment and the separation motor package. It is a mechanically fastened skin and stringer assembly reinforced with ring frames, measures 251.3 ins. long and weighs 1900 lb.. The skin is brake formed and the ring frames are formed extrusions. Skin thickness increases from 0.09 in. at the cone apex to 0.24 in. at the cone base and the ring cross-section areas increase from 1.56 sq. ins. to 2.16 sq. ins. in like fashion. Frames divide the structure into eight bays capped with a nose cap. It is fabricated in two, fore and aft, conical sections. The separation package, which delivers an aft and outward acting thrust relative to the External Tank, is mounted on the aft three ring locations of the nose cone.

6.2.2 Fwd Skirt & Crossbeam

The fwd skirt serves to connect the nose cone to the oxidizer tank, and to transfer the forward ET/LRB interface loads to the LRB. The structure consists of a monocoque shell reinforced with built-up I-section frames and a tapered built-up box section crossbeam. It has a length of 109.8 ins., an outside diameter of 183.0 ins. and weighs 4310 lb.. The 0.50 in. shell is divided into three bays by two intermediate frames. Flanges are attached at the fwd and aft ends for connection to the nose cone and oxidizer tank. Direct loads are reacted by a tapered thrust panel and reinforced by longitudinal stiffeners. The crossbeam reacts the moment longitudinally from the forward ET/LRB interface and transverse loads caused by the offset of the load transfer point from the LRB shell wall. The 27.0 ins. wide crossbeam tapers from 8.5 ins. to 28.0 ins. high where it attaches to the thrust panel. The thrust panel measures 88.0 ins. wide by 80.0 ins. high and tapers from 0.5 in. to 2.0 ins at the fitting. The fwd intermediate frame, which lies in the same plane as the crossbeam, assists in distributing interface loads to the shell. From experience with the ET Intertank, the crossbeam/thrust panel configuration was chosen over the alternative longeron/barrel concept because it better distributes load into the shell and is lower in weight.

6.2.3 Oxidizer Tank

The tank consists of two 0.7 ratio elliptical domes, three intermediate ring frames and four rolled plate barrel sections. It is designed to hold over 701,000 lb. of oxidizer, has a length of 757 ins., an outside diameter of 183.0 ins., a volume of 10,750 cu. ft. and has an empty weight of 20,870 lb. Fabrication of the fwd dome begins with a spin formed and chemical milled 80 in. diameter dome cap. Six 60 degree dome gore panels, stretch formed and chemical milled to a minimum of 0.12 in. thick, are welded together and to the dome cap assembly. A manhole assembly and necessary penetrations are welded to the dome cap and dome gore panels. Interface flanges, which are integrally machined roll ring forgings, are welded to the dome. Interior ring frames are mechanically assembled to the interface flanges. Weld lands in the domes are approximately twice as thick as the membrane, as dictated by parent and weld metal strengths. Fabrication of the aft dome is similar except that no manhole is needed. The barrel sections consist of three 120 degree segments, roll formed and welded from 0.50 in. mill stock material. Intermediate ring frames, which are integrally machined roll ring forgings, are welded between the four barrel sections.

6.2.4 Intertank

The intertank is a welded monocoque structure made up of three 120 degree segments rolled from 0.50 in. mill stock plate. It is 183 ins. in diameter, 184 ins. long and weighs 5110 lb. Attachment flanges are welded at the fore and aft ends. No additional weld joint thickness is required as the design driver of the pump-fed shell is stiffness rather than strength. Penetrations and the local reinforcing around the access panel cutouts are provided.

6.2.5 Fuel Tank

The tank consists of two 0.7 ratio elliptical domes, one intermediate frame and two rolled plate barrel sections. It is designed to hold 268,700 lb. of fuel, has a length of 427 ins., a diameter of 183.0 ins., a volume of 5792 cu. ft. and has an empty weight of 11,970 lb.. Fabrication of the forward dome begins with a spin formed and chemical milled 80 in. diameter dome cap. Six 60 degree dome gore panels, stretch formed and chemical milled to a minimum of 0.12 in. thick, are welded together and to the dome cap assembly. A manhole assembly and necessary penetrations are welded to the dome cap and dome gore panels. Weld lands in the domes are approximately twice as thick as the membrane, as dictated by parent and weld metal strengths. Interface flanges, which are integrally machined roll ring forgings, are welded to the dome. Interior ring frames are mechanically assembled to the interface flanges. Fabrication of the aft dome is similar except that no manhole is needed. The barrel sections consist of three 120 degree segments roll formed from stock mill material. Thicknesses of the fwd and aft barrels are 0.50 in. and 0.55 in. respectively. An intermediate ring frame is welded between the barrels at the aft ET attach point.

6.2.6 Aft Skirt/Thrust Structure

The Aft Skirt/Thrust Structure is a welded and mechanically fastened structure. The overall length is 278.6 ins., which includes a 71.6 in. long, 183 in. diameter cylinder at top, flaring out into a cone with a base diameter of 265.5 ins.. It is fabricated in quarter sections, each consisting of four cone panels and one hold down post. The engine mount platform is 89.3 ins. forward of the base. Frames are located at the top, the cylinder/cone transition, the engine mount platform at mid-cone and the base. Four tapered and forged longerons are attached to the shell equally spaced between the posts. The thickness of the upper cylinder is 0.65 in. and the cone is 0.7 in. for a total skirt weight of 26,600 lb..

6.2.7 Structural Interface

This section describes the various structural interfaces that the pump-fed LRB is required to meet. Section 6.2.7.1 describes the forward LRB/ET attach point interface, Section 6.2.7.2 describes the aft LRB/ET attach points, and Section 6.2.7.3, the LRB/MLP hold down supports.

6.2.7.1 Forward LRB/ET Attach

The forward end of the LRB is attached to the ET intertank using the existing ET/SRB attachment fitting. The existing ET fitting mates with an LRB fitting of similar design to the SRB forward fitting. Axial thrust of approximately 1680K lb (limit) is transmitted to the ET at this location.

6.2.7.2 Aft LRB/ET Attach

The Aft LRB/ET interface consists of two attach fittings points spaced circumferentially 114 ins. apart. The ET/LRB fittings are of similar design to the current ET/SRB aft fittings. This allows attachment to the ET without modification to the ET side of the interface. Only lateral Y and vertical Z loads are transmitted to the ET at these locations.

6.2.7.3 MLP Hold Down Supports

The STS is supported by hold down fittings on the aft face of the LRB aft skirt. The weight of the entire STS is supported off the two LRB's while in this position.

Explosive bolts attach the LRB aft skirt to the MLP at four hold down posts spaced equally around the circumference (± 45° off the Y- axis) which are simultaneously fired approximately six seconds after SSME ignition.

6.2.8 Cable Trays, Fairings and Fittings

The external wiring and cables are enclosed in faired aluminum cable trays that protect them from flight aerodynamic loads, thermodynamic heating, and lightning effects. Shielded cables are used in the cable trays to provide further lightning protection. Cable trays have removable covers for servicing and are protected by a thermal protection system applied to external surfaces.

Propulsion system feed and pressurization lines and cable trays require forward end fairings at the entry points to the LRB interior. These fairings provide aerodynamic shaping to reduce aerodynamic loads and heating in addition to controlling the compartment venting and outside air injection during both prelaunch and ascent mission phases.

All lines and cable trays are mechanically attached to the LRB with appropriate fittings. Fitting designs and locations depend on structural and aerodynamic loads.

6.2.9 Thermal Protection

The thermal protection system is designed to maintain the quality of the propellants and protect the primary structure and its subsystem components within design temperature limits during prelaunch and ascent phases. Approximately 1.0 in. of SOFI is applied to the oxidizer tank and 0.5 in. of SLA ablator to the nosecone and aft skirt. (Figure 6.2.9-1).

6.2.10 Acoustic Protection

Acoustic insulation is provided in the aft skirt region to dampen out the engine acoustics. The acoustic dampening material will be used to provide acceptable sound pressure levels by either protecting individual components or enclosed compartments.

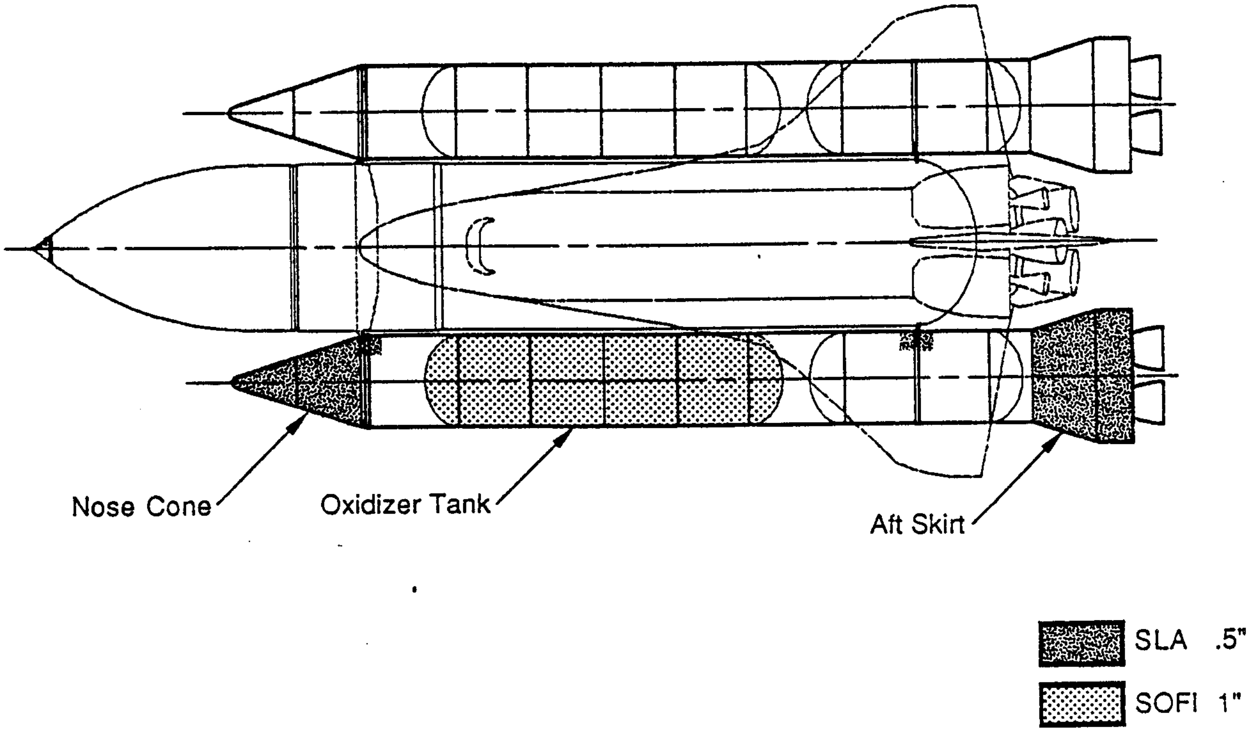


Figure 6.2.9-1 LRB TPS

6.2.11 Major Ground Tests

Testing of the LRB is accomplished in several phases, beginning with component testing and progressing to a full duration simulation. The tests will verify structural integrity for all operational conditions. Both limit and ultimate loads will be applied during the tests. The limit load tests will verify that the structure does not experience unacceptable deformation. Ultimate load tests will verify that the structure does not rupture or collapse.

Component Testing—Subassemblies are tested for strength using design pressures, concentrated loads, heating, etc., to ensure structural integrity. The structural components tested are shown in Figure 6.2.11-1 and include :

- Intertank
- Engine Mount Structure
- Aft Skirt
- Interface Hardware
- Nose cone
- Fuel and Oxidizer Tank
- Fwd Skirt
- Separation System

Major engine components testing include:

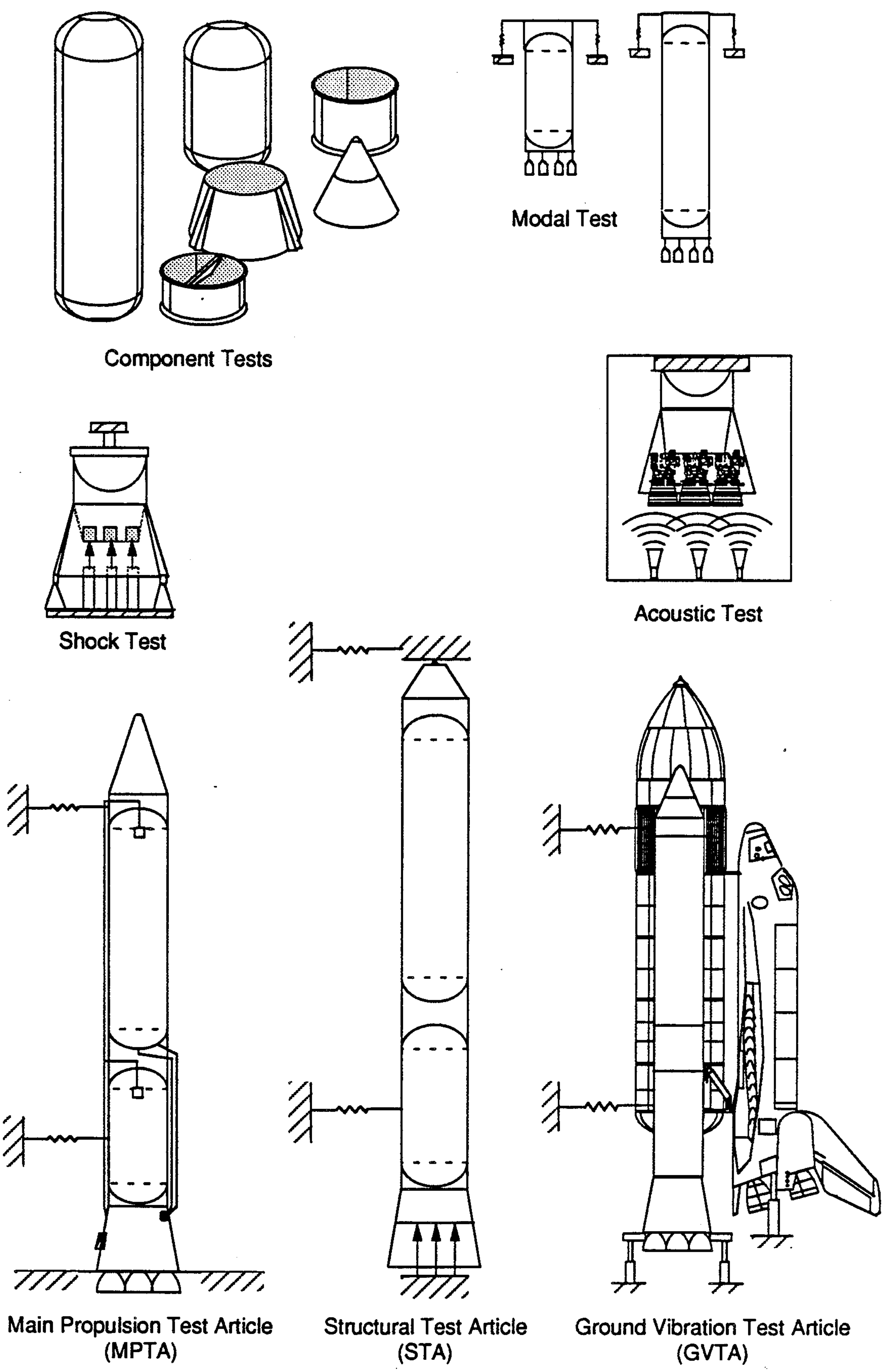
- Thrust Chamber Assemblies
- Turbo Pumps
- Gas Generators/Heat Exchangers

Single Engine Test Article (SETA)— Duration and start-up testing is performed on the liquid propellant engines to verify design definition & analysis and ensure quality, safety, performance and reliability.

Shock Test—Objectives of the shock test are: 1) assess requirements for shock design; 2) measure shock response spectra; and, 3) obtain vibration response. The test setup includes a flight skirt and engine support thrust structure, a dummy aft dome, and weights simulating the liquid engines. This setup is mounted on a support structure simulating the holddown posts on the MLP. Loads are applied at the engine gimbal points from below, and at the dome tangency point from above.

Acoustic Test—Objectives of the acoustic test are: 1) obtain acoustic spectrum shape: 2) obtain random vibration response; 3) predict random loads; and, 4) test acoustic insulation. The test configuration consists of the same hardware as the shock test. Actual engines or mockups with the same acoustic response are used in place of the weights and noise insulation is applied. The structure is attached at the forward end and acoustic energy is applied by horns near the aft end.

Modal Test—Objectives of the modal test are: 1) identify mode shapes; 2) estimate structural damping; 3) identify natural frequencies; and, 4) verify hydroelastic properties in support of math model analysis. The test configuration consists of flight tanks and dummy fwd and aft skirts for use in supporting the tanks. The load is applied at the fwd end and the response measured at the aft end.



Component Tests

Modal Test

Shock Test

Acoustic Test

Main Propulsion Test Article
(MPTA)

Structural Test Article
(STA)

Ground Vibration Test Article
(GVTA)

Figure 6.2.11-1 Major Ground Tests

Main Propulsion Test Article (MPTA)—This test configuration consists of a full duration simulation to test the propulsion system performance: The MPTA will test LRB ground interface, component purging, propellant fill and drain, pressurization system, engine start sequence, and engine shut-down sequence. Test hardware includes flight tanks, intertank and skirts, and all propulsion components, i.e. engines, feedlines , umbilicals, etc.

Structural Test Article (STA)—This test consists of flight tanks and an intertank. Skirts are used to support the tanks and attach load cells. No engines or feedlines are needed. The structure is supported at the actual attachment points, i.e. ET forward and aft interfaces. Point loads and pressures are applied at appropriate locations. Various flight loading conditions including, tank pressurization, pre-launch, lift-off, max acceleration, and engine gimbal are applied.

Ground Vibration Test Article (GVTA)—Objectives include obtaining frequency modes and damping characteristics of the launch vehicle and feedline systems to verify design and analysis. The test configuration consists of all components of the STS system including one LRB, one dummy LRB, the ET and a dummy Orbiter. The system is supported at the MLP holddown posts and the orbiter aft thrust structure. Vibration measurements are taken at key locations including major interface points.

6.3 PROPULSION/MECHANICAL

6.3.1 Turbopump Fed (TF) Engines

The major engine components are shown in the schematic of the Turbopump Fed rocket engine system, Figure 6.3.1-1. Liquid oxygen enters the engine at the LO2 pump inlet. After leaving the LO2 pump, high pressure oxidizer is delivered to the main injector, to the gas generator, and to the heat exchanger mounted in the turbine exhaust where a small fraction of the LO2 is heated to the gaseous state for autogenous oxidizer tank pressurization. Fuel enters the engine at the fuel pump inlet. Fuel leaving the pump is delivered, at very high pressure (5022 psia at EPL), to the main chamber coolant manifold, through the chamber coolant passages, and into the main injector. The schematic shows that the hottest, highest pressure GG flow goes first to the most highly loaded turbine, i.e. the fuel pump-driving turbine. A small fraction of the fuel flow is tapped off at the pump discharge, routed through the fuel tank pressurant gas cooler, and returned to pump suction. Fuel flow is also delivered to the gas generator from the pump discharge. The gas generator flow passes through the fuel turbopump turbine, then the oxidizer turbopump turbine, and finally into the main engine exhaust. A portion of the gas generator flow is used to pressurize the fuel tank after having passed through the fuel tank pressurant gas cooler.

The LRB TF engine is shown in Figure 6.3.1-2 along with the NPL/EPL descriptors. A preliminary design layout is shown in Figure 6.3.1-3 with one suggested configuration of turbopumps and cross-feed lines. Complete descriptions of the LRB turbo pump engine is presented in the Aerojet report (Appendix L).

6.3.1.1 Fuel Cooled Thrust Chamber Assembly (TCA)

The RP-1 flow to the nozzle coolant manifold proceeds through the coolant passages, picking up heat at high heat flux levels, especially at the throat region of the thrust chamber. As it enters the injector manifold the relatively hot fuel provides correspondingly low viscosity values for excellent atomization at the injector nozzles. The high fuel pump outlet pressure (5022 psia) is required because of the relatively poor thermal transport properties of RP-1. RP-1 cooling presents the need for a 3722 psia pressure drop through the chamber cooling channels at EPL. This assumes no coking. This valve may change slightly during detail design to gain a little Isp or accommodate some choking in an expendable engine application. The small associated improvement in Isp and the specific pressure levels, etc., are details beyond the scope of current preliminary design tasks.

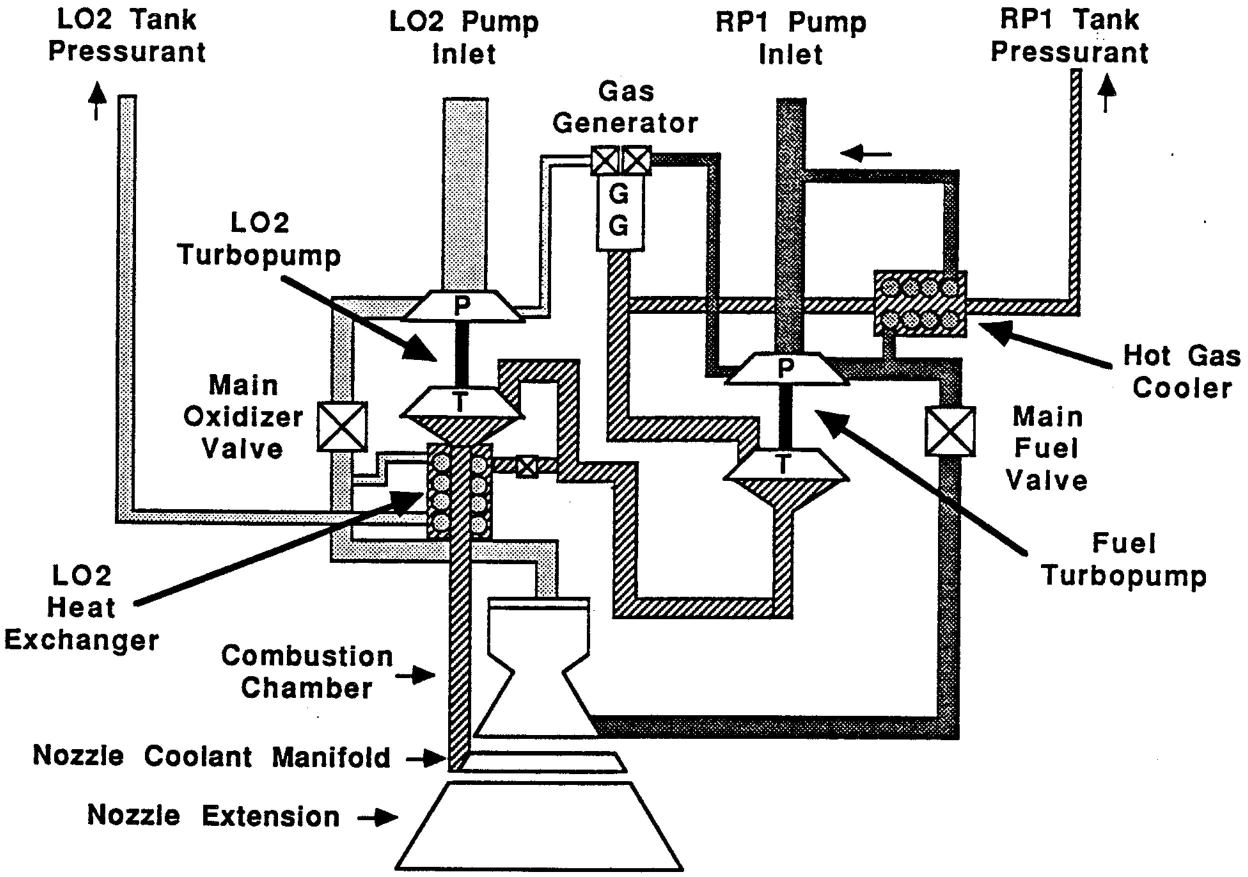
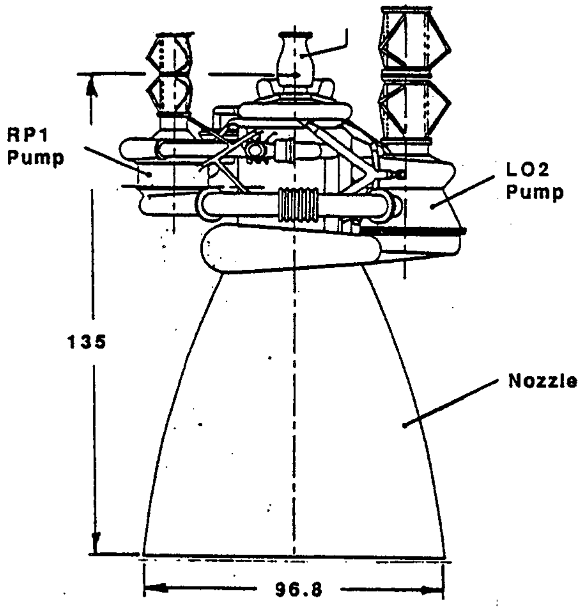


Figure 6.3.1-1 LO2/RP1 Pump-Fed Engine Schematic



	NPL	EPL
Thrust, S.L. klbs	513	685
Thrust, Vac. kbs	623	788
ISP, S.L. sec	265	277
ISP, Vac, sec	322	318
Mixture Ratio	2.6	2.5
Total Flow Rate, lb/sec	1933	2473
Chamber Pressure, Psia	1033	1300
Exit Pressure, Psia	5.9	7.7
Expansion Ratio	21.2	
Nozzle Type	Carbon-Carbon	
Weight, Dry, lbs	6807	
Engine Cycle	Gas Gen	
Propellants	LO2/RP1	
Gimbal Type	Head End	
Gimbal Angle	±6°	
Throttle Range	65 - 100%	

Figure 6.3.1-2 LO2/RP1 LRB Pump-Fed Engine

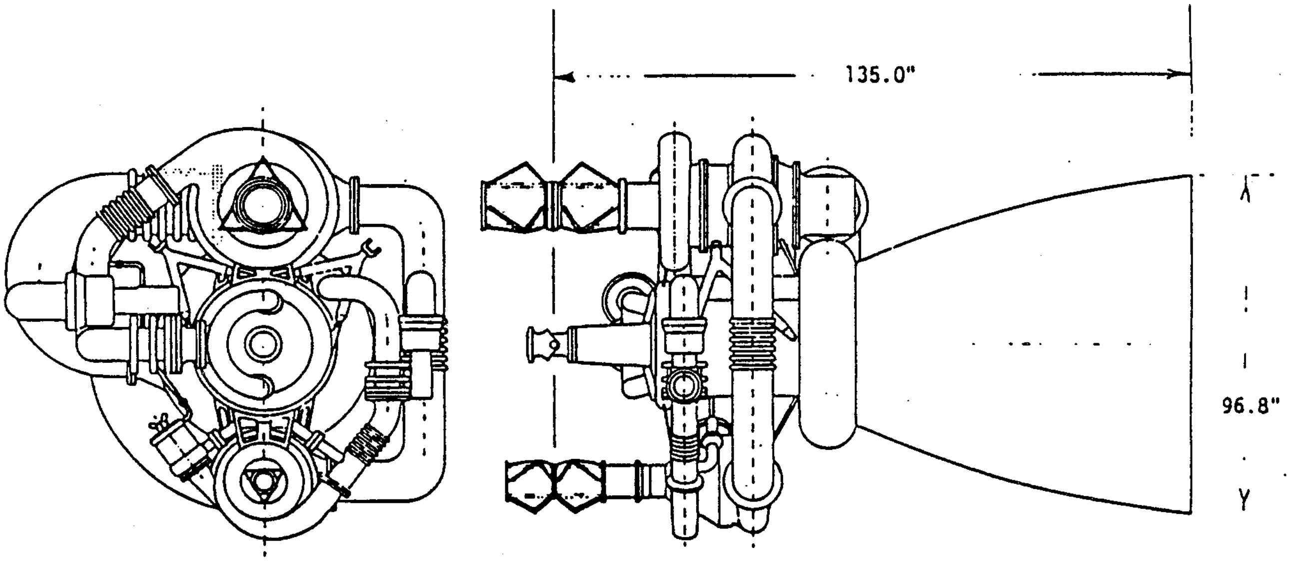


Figure 6.3.1-3 LRB for STS Turbopump Fed Rocket Engine Configuration

6.3.1.2 Injector

The turbopump fed LRB main injector design provides high performance and good design compatibility with low cost. The oxidizer-fuel-oxidizer, (OFO), triplet injector core element type was selected. This injector design embodies 225 elements with 0.20" orifice diameters for both fuel and oxidizer. At EPL conditions the oxidizer and fuel inlet pressures are 1942 and 1739 psia respectively. The corresponding pressure drops across the injector elements are 384 and 534 psia.. About 5% of the TCA fuel is injected at 118 peripheral showerhead injectors, each 0.060" orifice diameter, resulting in a throat wall mixture ratio of 1.67. This provides for fuel film cooling at the TCA wall. Table 6.3.1.2-1 summaries the principal descriptors of this injector.

6.3.1.3 Turbopumps

Preliminary designs were conducted for both RP-1 turbopump, and LO2 turbopump requirements. Both designs are based on engine power balance results at EPL; see the LRB Turbopump Requirements summarized in Table 6.3.1.3-1. The LRB turbopump design objectives focused on achieving high component efficiencies, avoiding boost pumps to enhance reliability, and low cost design features with extensive use of castings.

The turbopump designs (Figures 6.3.1.3-1 & 2) are well within the current start of the art, offer high reliability potential, excellent overall TPA efficiencies, and should afford relatively low cost via the extensive use of castings.

6.3.1.4 Gas Generator

The TF LRB gas generator design is similar to the Aerojet gas generator still in production for Titan IV. The injector incorporates the latest technology improvements of the Oxygen/Hydrocarbon Injector Characterization contract for the Air Force Astronautics Lab and will utilize existing designs and test data. Both 18" and 8" diameter injectors and chambers have been designed and built for LO2/RP-1 propellants.

The gas generator will be designed to operate at 0.33 mixture ratio to provide 1235 psia, 1400° F gas to the drive turbopump turbine. This gas generator design will include design features for assuring excellent combustion performance and operational reliability.

Table 6.3.1.2-1 Principal Descriptors of the LRB Main Injector Design

Core Element Type	OFO Triplet
# Elements	225
OX Orifice Diameter	0.20 in
Fuel Orifice Diameter	0.20 in
OX Injector Inlet Pressure*	1942 psia
Fuel Injector Inlet Pressure	1739 psia
OX Injection ΔP	384 psia
Fuel Injection ΔP	534 psia
FFC (5% Of TCA Fuel)	118 Showerheads
FFC Orifice Diameter	0.060 in
Throat Wall Mixture Ratio	1.67

* All Pressures At EPL

Table 6.3.1.3-1 LRB Turbopump Requirements

	MPL		NPL		EPL*	
	RP1	LO2	RP1	LO2	RP1	LO2
Engine Flowrate, lb/sec	402	1049	536	1398	706	1767
Pump Inlet Pressure, psia	35	60	35	60	35	60
Pump Discharge Pressure, psia	1982	891	3178	1240	5022	1631
Propellant Temperature, °R	528	163	528	163	528	163
Propellant Density, lb/cu. ft.	49.9	71.0	49.9	71.0	49.9	71.0

* Turbopump Design Point

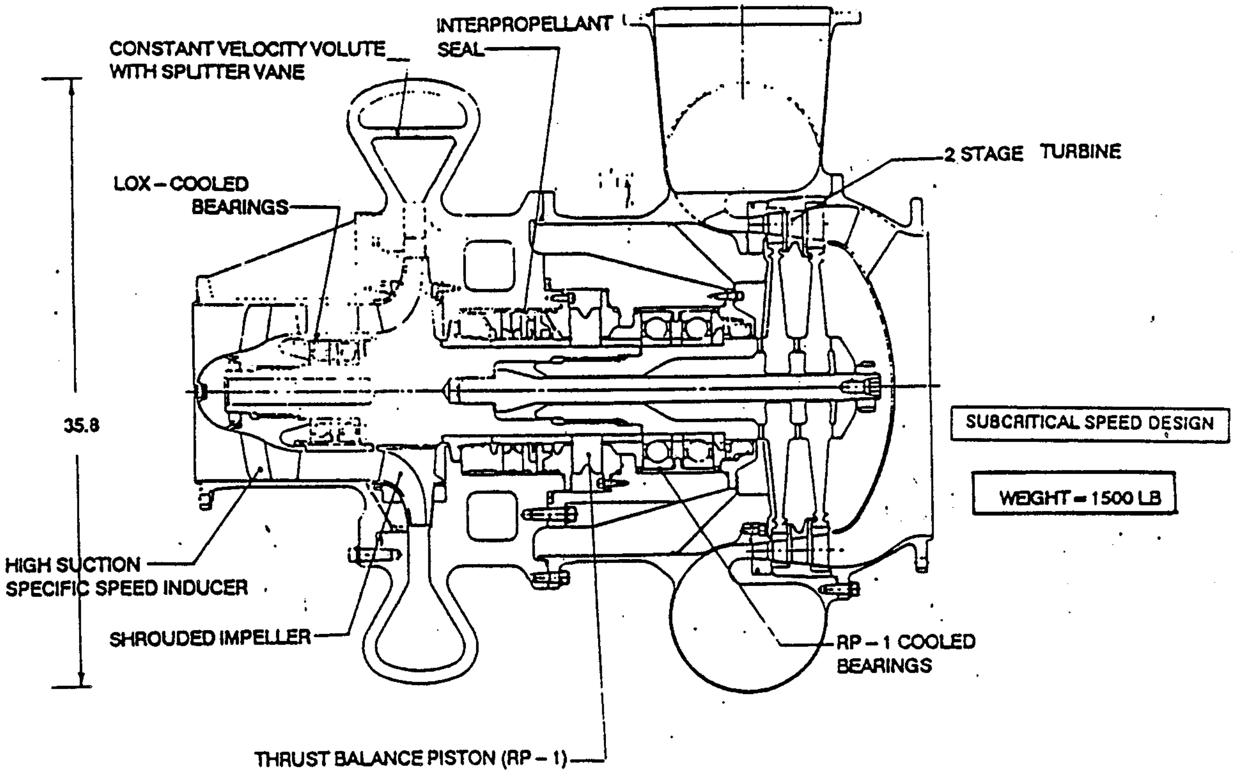


Figure 6.3.1.3-1 LRB Oxidizer TPA Design Features

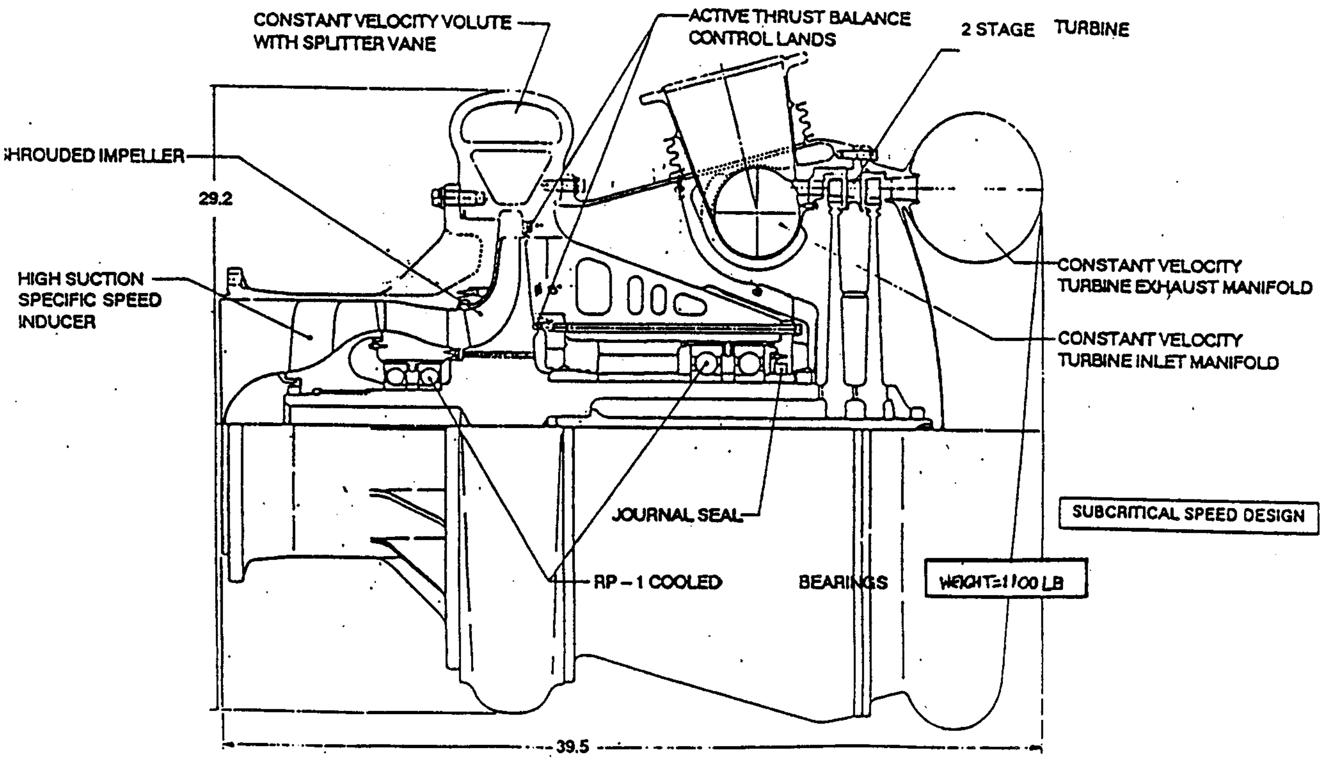


Figure 6.3.1.3-2 LRB Fuel TPA Design Features

6.3.1.5 Main Propellant Throttling Valves

The design features anticipated for the LRB main propellant throttling valves are illustrated in Figure 6.3.1.5-1. The high speed electric motor has an excellent power to weight ratio. By driving the valve through a very light weight harmonic drive assembly, the high torque and slow speed is achieved with the lightest possible motor assembly.

6.3.1.6 Silica Phenolic Nozzle Extension

A rugged design, employing silica phenolic material technology, will provide a suitable nozzle extension, sufficiently strong to perform in the extreme vibrational and acoustic environment at lift-off. Silica phenolic is much less expensive than the carbon-carbon material candidate which would provide slightly superior weight performance.

6.3.1.7 Heat Exchangers

The heat exchangers for cooling the autogenous fuel tank pressurization gas flow and vaporizing and superheating the LO2 flow allocated for pressurizing the LO2 tank ullage will be proven Aerojet designs. Table 6.3.1.7-1 presents the results of a preliminary design analysis for a heat exchanger to cool the GG gas to 800° R for use to pressurize the RP-1 tank.

6.3.1.8 Engine Controller

Engine thrust, mixture ratio control, and health monitoring are managed by the engine-mounted controller which actively utilizes chamber pressure in the feedback loop while processing input signals from the LRB avionics.

6.3.2 Pressurization System

The pump-fed engine schematic, Figure 6.3.1-1 illustrates the sources for the oxidizer and fuel tanks pressurization gas. The LO2 tank is pressurized with heated GO2 from the LO2 heat exchanger. The GO2 is heated by the GG gas after it exists the LO2 turbopump. The RP-1 tank is pressurized with GG gas cooled by fuel in the hot gas cooler.

Figure 6.3.2-1 illustrates the pressurization system manifolds and lines in the LRB aft skirt.

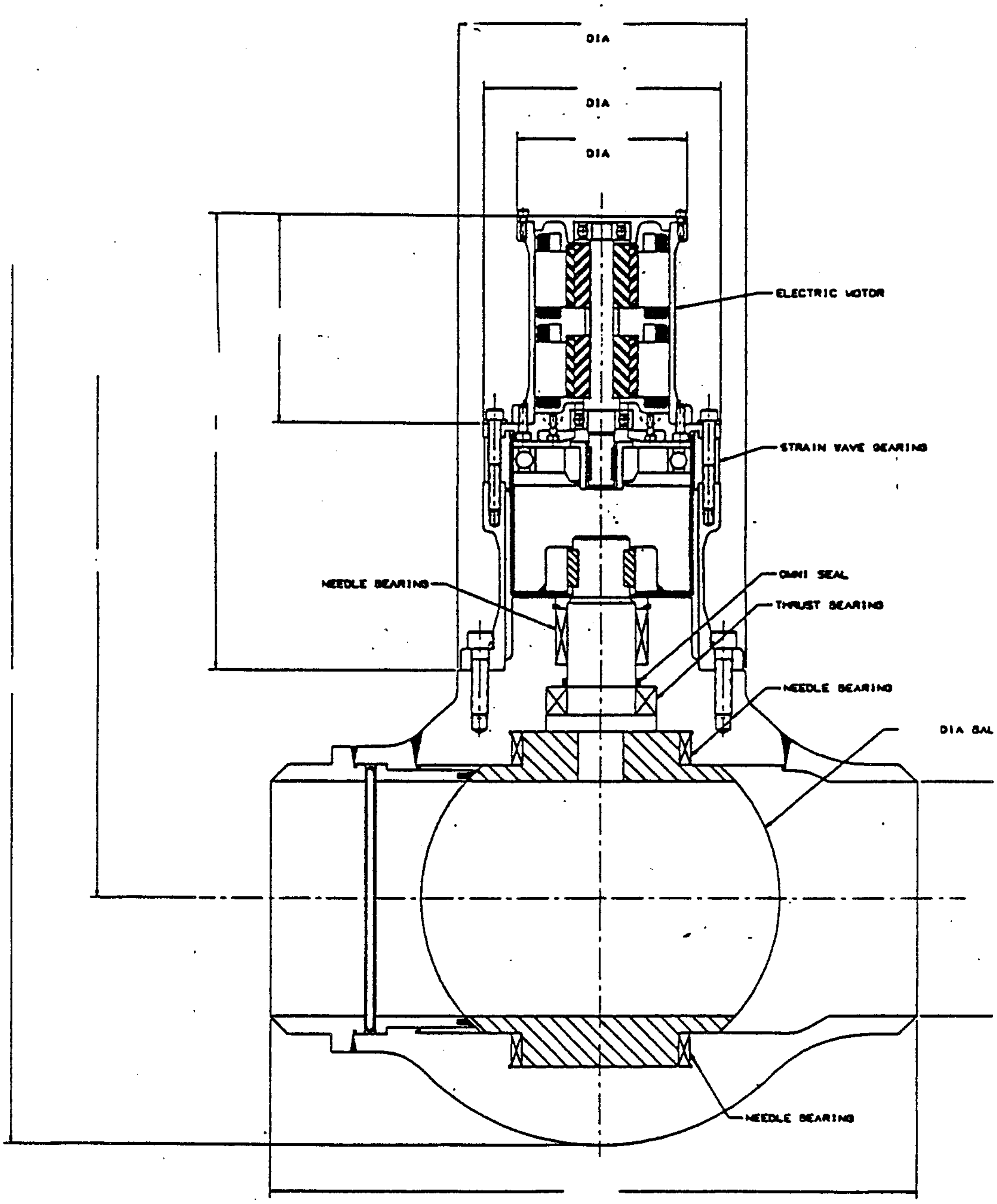


Figure 6.3.1.5-1 LRB Main Propellant Throttling Valves

Table 6.3.1.7-1 Results of the Preliminary Design of the Heat Exchanger

Heated Inlet Temperature, R	T1 = 560.000
Heated Outlet Temperature, R	T2 = 660.000
Heated Flow Rate, Lb/Sec	WHE = 16.2000
Heated Density, Lb/Cu. Ft.	DENHE = 49.3000
Heated CP, BTU/Lb. F.	CPHE = 0.550000
Heated Coefficient, BTU/Sec. Ft2. Deg.	HHE = 0.416000E-01
Heat Transfer Rate, BTU/Sec.	Q = 891.000
Hot Flow Rate, Lb/Sec	W = 1.63000
Hot Inlet Temperature, R	TA = 2000.00
Hot Density, Lb/Cu. Ft.	DEN = 0.113000
Hot Specific Heat, BTU/Lb. Deg.	CP = 0.456000
Heating Exit Temperature, R	TB = 800.000
Hot Coefficient, BTU/Sec. Ft2. Deg.	HH = 0.111000E-01
LMTD, F	TLMTD = 639.614
Metal Conductivity, BTU/Sec. Ft. Deg.	COND = 0.300000E-02
Metal Thickness, Ft.	THICK = 0.208333E-02
Metal Density, Lb/Cu. Ft.	DENMET = 523.000
U, BTU/Sec. Ft2. F.	U = 0.870906E-02
A, Ft2	A = 159.952
HXR Approximate Weight, Lb.	WEIGHT = 174.281

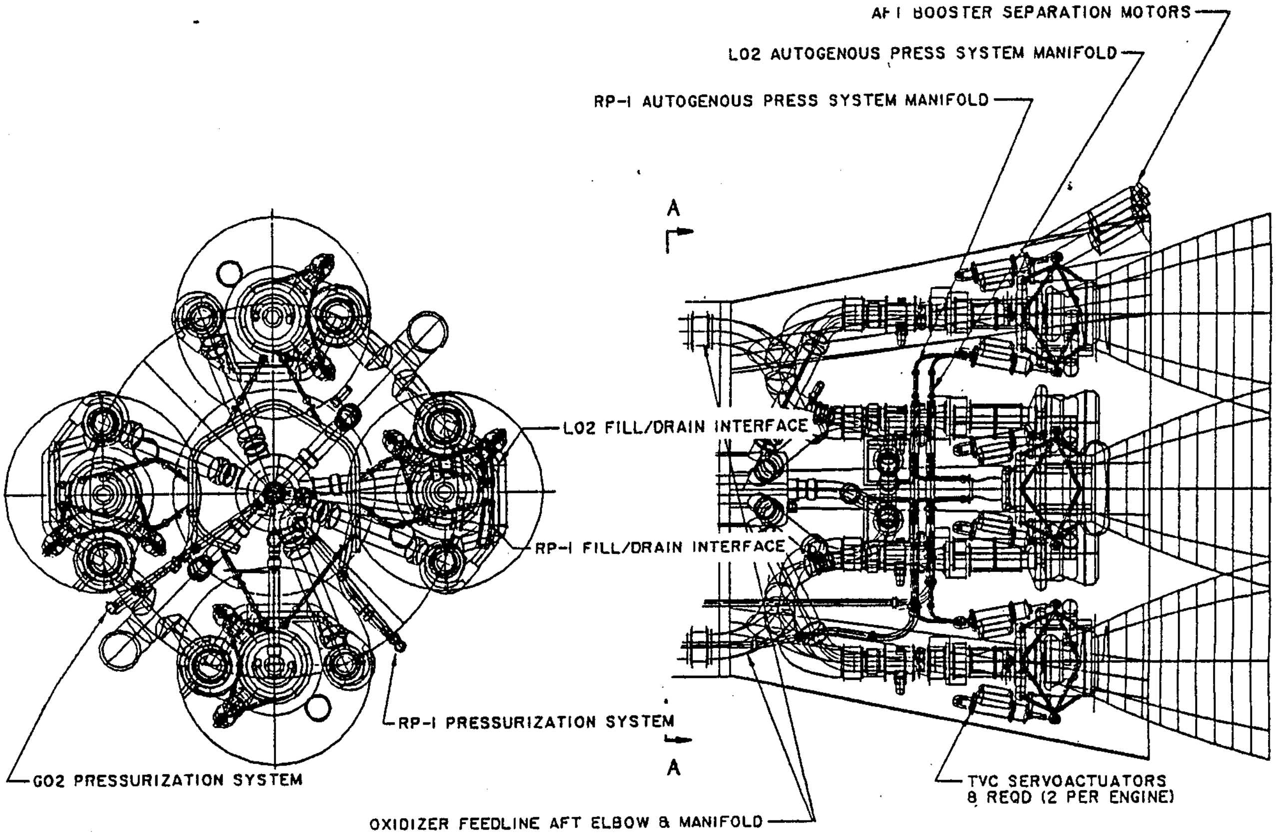


Figure 6.3.2-1 Pump-Fed Pressurization System Layout

6.3.3 Fill, Feed, Drain and Vent Subsystems

The LO2 feedline, Figure 6.3.3-1, consists of three major component subassemblies. The LO2 tank outlet, is a 24.3 in. dia assembly of solution aged INCO 718 nickel base alloy. The feedline then splits into two 17" dia. lines down either side of the RP-1 tank. The forward flex sections contain three internally gimballed flex joints to accommodate both cryogenic and flight induced motions. The straight sections, external to the RP-1 tank are fabricated from Al-Li (Weldalite ™049) or 2219 aluminum alloy. The aft flex section/engine inlet manifold is manufactured from solution aged INCO 718 nickel base alloy, each of the four branches being 12.5 in./dia. and including three internal gimballed flex joints. All segments of the LO2 feedline assembly are coated with TPS to insulate the lines. The RP-1 engine outlet manifold assembly is manufactured from solution aged INCO 718 nickel based alloy, each of the four branches being 9.7 in./dia. with three internal gimballed flex joints.

Fill /Drain rain lines assemblies interface with the low points in both the RP-1 and LO2 feedline subsystems through the external umbilical carrier plates. Fill/drain line assemblies are manufactured from solution aged INCO 718 nickel base alloy with two flex joints assemblies in each line. The LO2 fill/drain line assembly will have TPS as appropriate to prevent LO2 boiloff. Additionally, GHe injection thru the LO2 fill subsystem will be utilized for anti-geyser protection during LO2 fill.

Vent system lines assemblies are solution aged INCO 728 nickel alloy each with two flex joint assemblies. The LO2 vent valve and line will have TPS as appropriate. Figure 6.3.3-2 illustrates the major components of the LRB fill, drain, feed and vent system.

6.3.4 Hazardous Gas Detection and Compartment Purge Requirements

Safety and environmental concerns associated with LO2/RP-1 as the propellant combination for the LRB have established the hazardous gas/purge requirements are as follows:

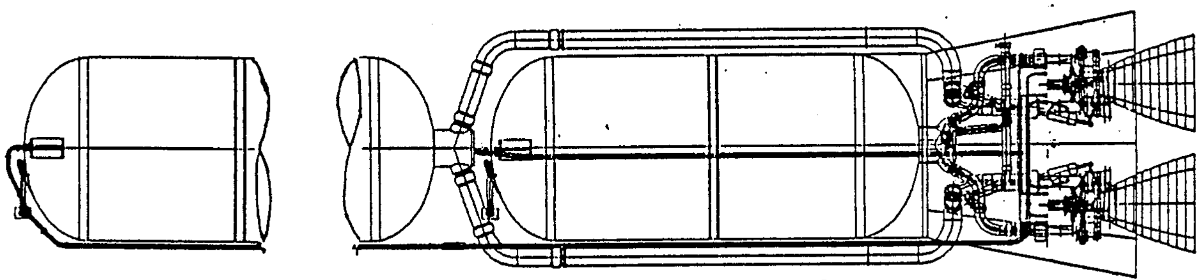
Hazardous Gases

The maximum compartments concentrations of propellant gases during flight are:

- LO2: 40,000 PPM
- RP-1: 10,000 PPM

Compartment Purges

- Purging gas: dry nitrogen
- Purge flow rate; 100 lbm/min
- Purging gas temperature: 300 deg. F



<u>Oxidizer Feed System</u>

Oxidizer : LO2
Diameter : 2 X 17 in. ID
Materials : Fwd Flex Sections -
Sol. Aged Inco 718
Mid Straight Sections -
AL 2219 (Weldalite)
Aft Flex Sections -
Sol. Aged Inco 718
No. Flex Joints -
Fwd = 3
Aft = 12
Pogo Accumulations = 4
Pre-Valves = 4
Weight : 4134 lb

<u>Fuel Feed System</u>

Fuel : RP-1
Diameter : 9.7 In.x4
Materials : Sol. Aged Inco 718
No. Flex Joints = 12
Pogo Accumulators = 4
Pre-Valves = 4
Weight : 2026 lbs

Figure 6.3.3-1 Pump-Fed Propellant Feed System

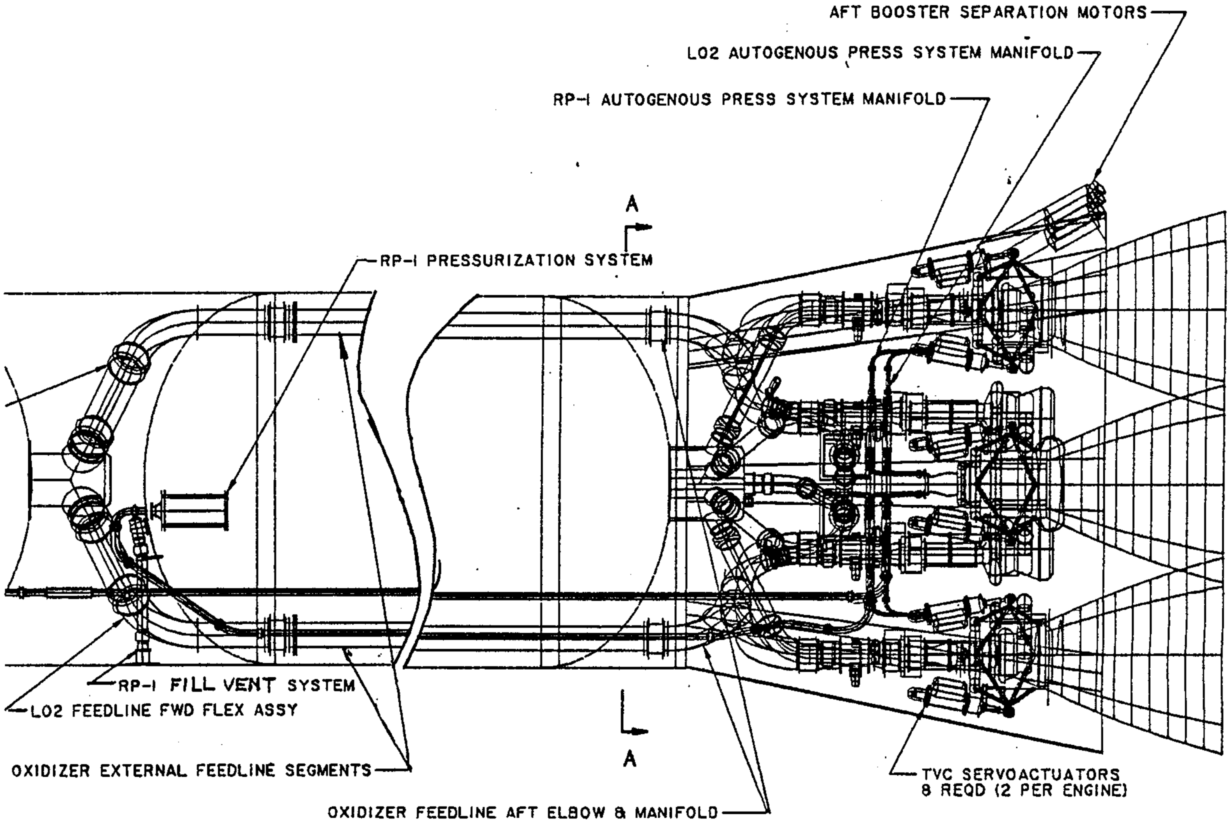


Figure 6.3.3-2 Pump-Fed Propellant Fill/Vent/Relief

Compartment vent areas will be designed to maintain adequate differential pressure during flight so as not to exceed LRB structural limits and assure propellant gas concentrations are not violated. Figure 6.3.4-1 presents the LRB purge and HGDS system schematic.

6.3.5 Separation System

Separation motors are installed in the LRB nose cone and the aft skirt. USBI solid-fueled motors (BSM's) currently used in the SRB are baselined for the LRB. Three BSM's per cluster are required for the pump-fed configuration. The angles corresponding to thrust vector and LRB centerline rotation with respect to the Z axis are TBD, as well as the pitch angles with respect to the Y-Z plane along the rotated LRB centerline.

6.3.6 Thrust Vector Control

The selected baseline thrust vector control (TVC) concept utilizes head end gimballed engines actuated by two electromechanical actuators positioned on engine rock and engine tilt axes. Each actuator has the capability to gimbal the engine ±6° in its appropriate axis. Sufficient power is provided by batteries to drive the actuators at an engine gimbal rate of 10°/sec. Figure 6.3.6-1 shows actuator installation for each engine providing adequate clearance between all engines in the event one engine fails in the gimbal null position. Additional discussion on the TVC system is presented in Section 6.4.4.

6.3.7 Umbilicals

Two LRB/MLP umbilicals (Figure 6.3.7-1&2) are located on the LRB aft skirt. These umbilicals provide fluid and electrical interfaces for the following subsystems: compartment purges, hazardous gas detection, propellant tank pre-pressurization, propellant fill and drain, helium - inject antigeyser system, and electrical.

The umbilical carrier assemblies are integral structural parts of the aft skirt wall containing quick disconnects for the propulsion and electrical systems.

Separation of the ground and flight umbilical carrier assemblies is achieved through the activation of pressure cartridges in a pyrotechnics locking device. Figure 6.3.7-3 illustrates the umbilical locations in the LRB.

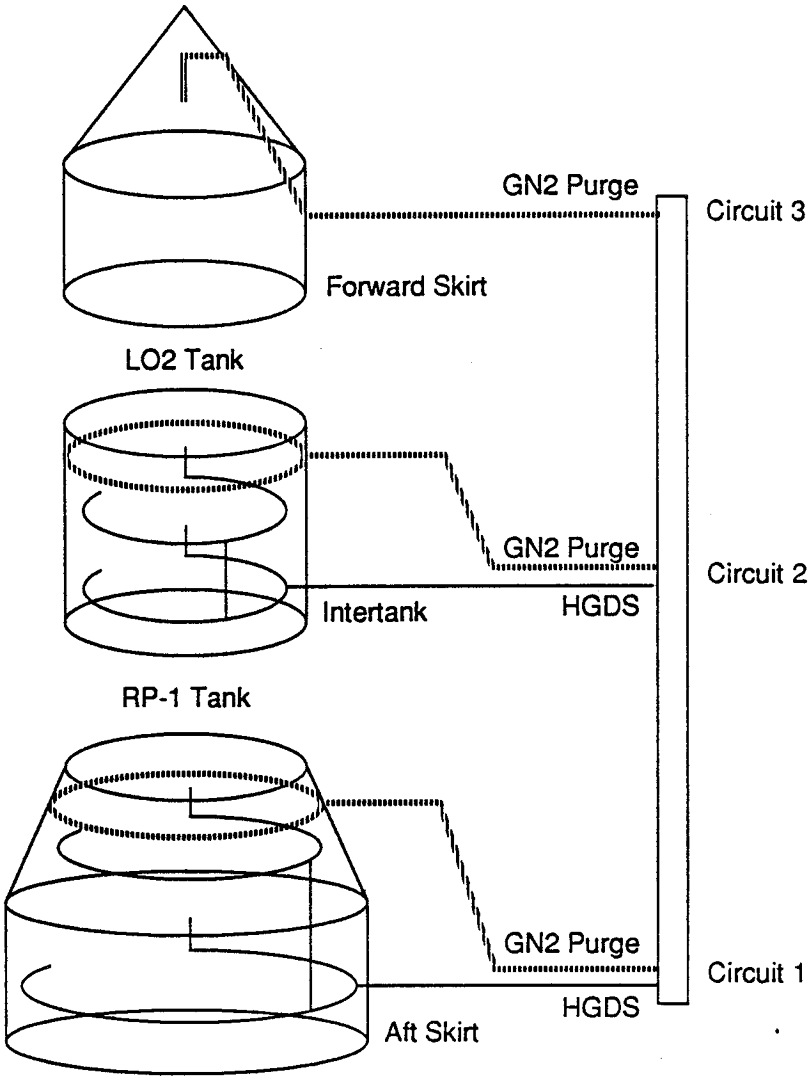


Figure 6.3.4-1 LRB Purge and HGDS Schematic

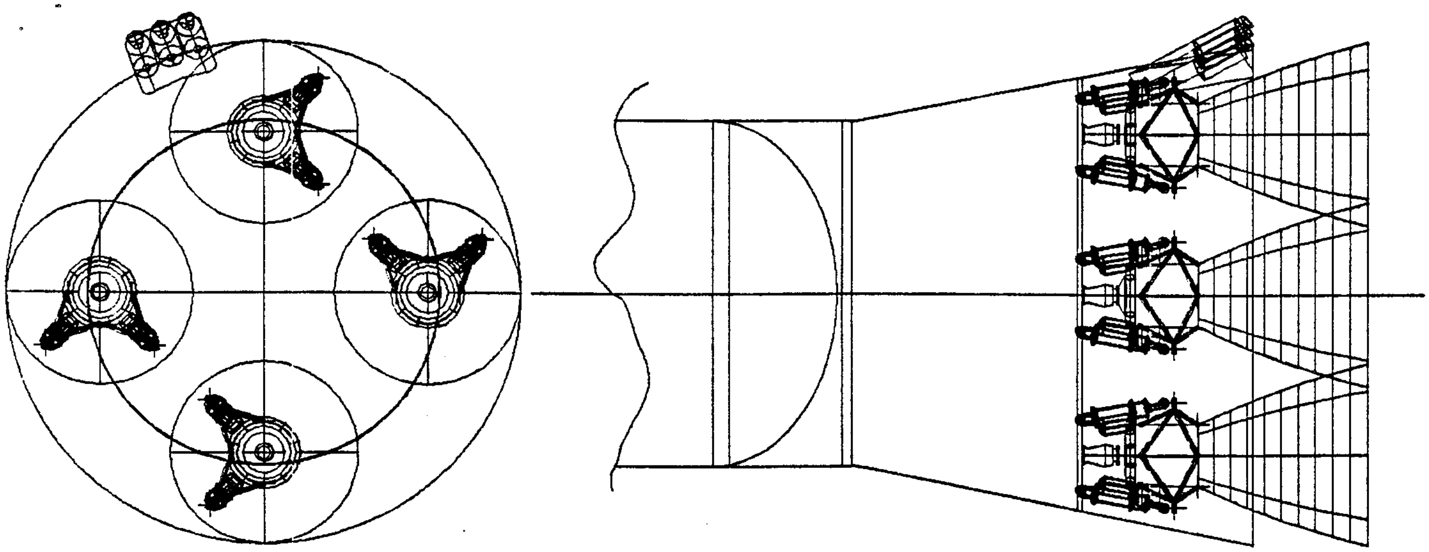
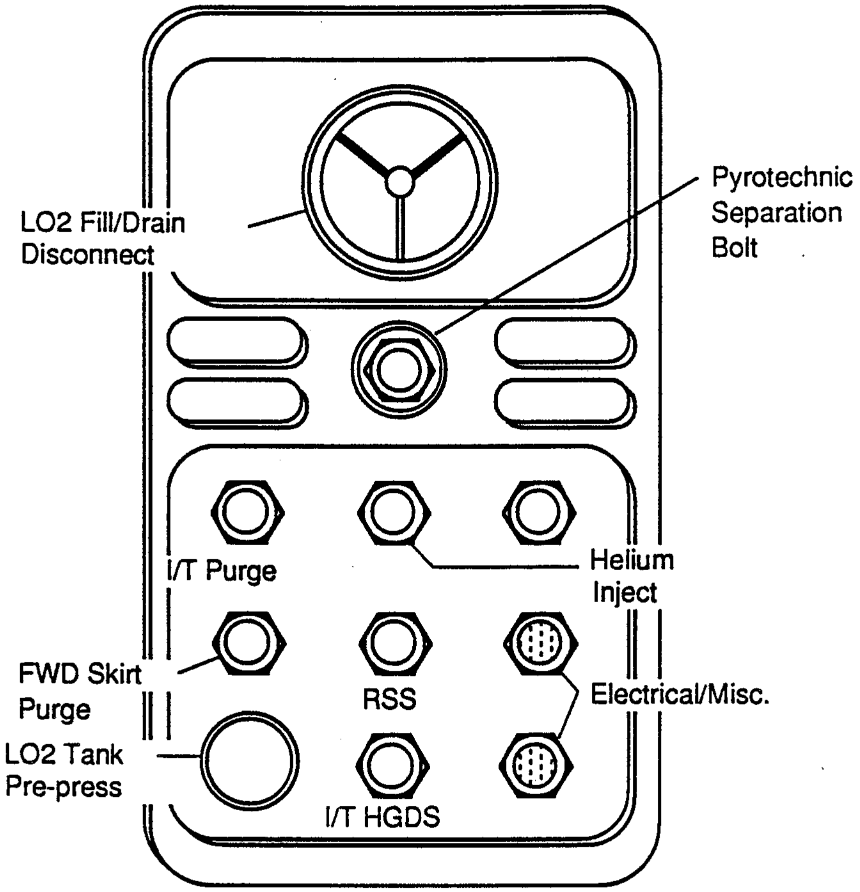


Figure 6.3.6-1 TVC Actuators



(Pump-Fed Configuration/LO2 UCP)

Figure 6.3.7-1 Pump-Fed Vehicle Umbilicals LO2 UCP

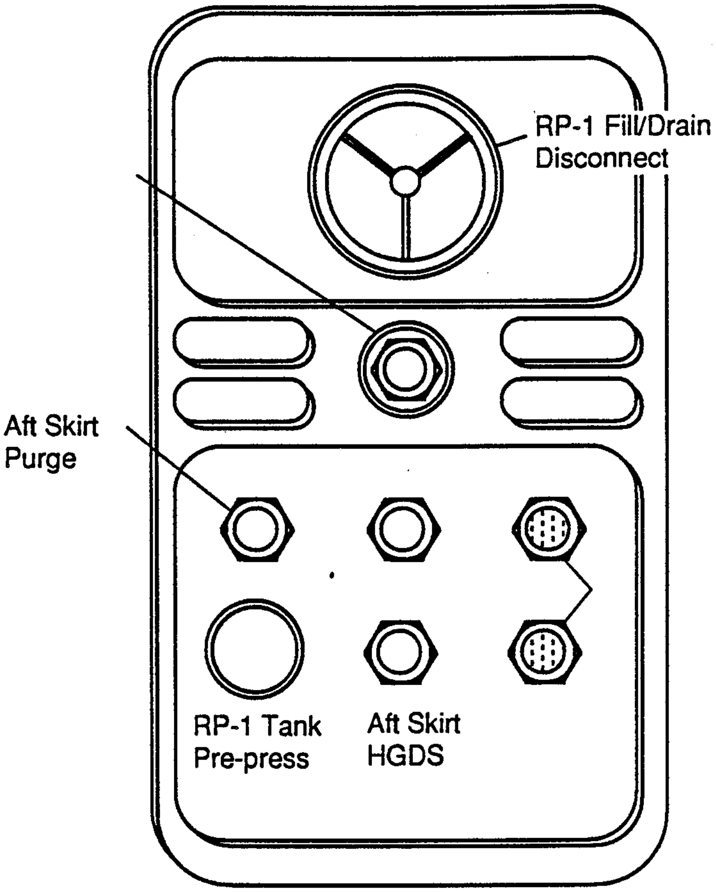


Figure 6.3.7-2 Pump-Fed Vehicle Umbilicals RP-1 UCP

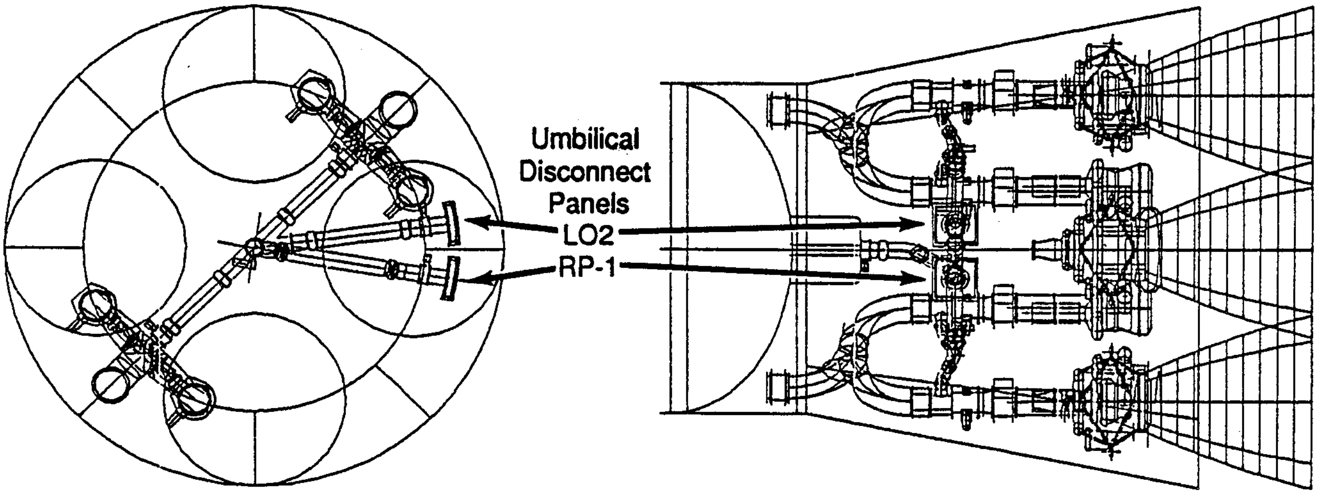


Figure 6.3.7-3 LRB Umbilical Locations

6.4 ELECTRICAL/AVIONICS

6.4.1 General Configuration

Trade studies led to the avionics architecture shown in Figure 6.4.1-1. Electrical power, engine control and thrust vector control are provided within the LRB. Other functions common with the SRBs will remain unchanged.

New avionics units added for LRB control will be mechanized within the centralized architecture to minimize impacts to Orbiter interface wiring. Actuator Control Units (ACU) and Motor Control Units (MCU) mechanize the Electromechanical Actuator system. An Engine Controller (EC) is used to control each LRB engine. These units are discussed further in the following paragraphs. An Orbiter Interface Adapter (OIA) provides the serial data bus compatibility between the orbiter and the LRB. Figure 6.4.1-2 shows the general location of major LRB avionics components. Note that a majority of the components are located in the aft skirt area, in close proximity to the engines themselves. A list of these components, together with their locations and weights, is given in Table 6.4.1-1.

6.4.2 Engine Controller

The LRB Engine Controller (EC) is a new unit, based on the Orbiter SSME controller. It will be man-rated and will incorporate both dual redundancy and Class S piece parts to maximize its reliability. A functional diagram of the controller is shown in Figure 6.4.2-1.

6.4.3 Software Language

Ada has been chosen as the programming language for the LRB software. Although HAL/S is the language used in the STS program, it has very little useage outside of STS. Therefore there are very few software development tools and few trained software engineers available for HAL/S programming. Ada has been selected by NASA for the Space Station program and is the DoD mandatory software language. Software engineers and software development tools are available throughout industry, along with a growing set of documentation tools, standards and common software modules. Since the interface between the Orbiter and LRB is via data busses, the fact that two different software languages are used is transparent.

OIA = Orbiter Interface Adapter
ACU = Actuator Control Unit
MCU = Motor Control Unit
EC = Engine Controller

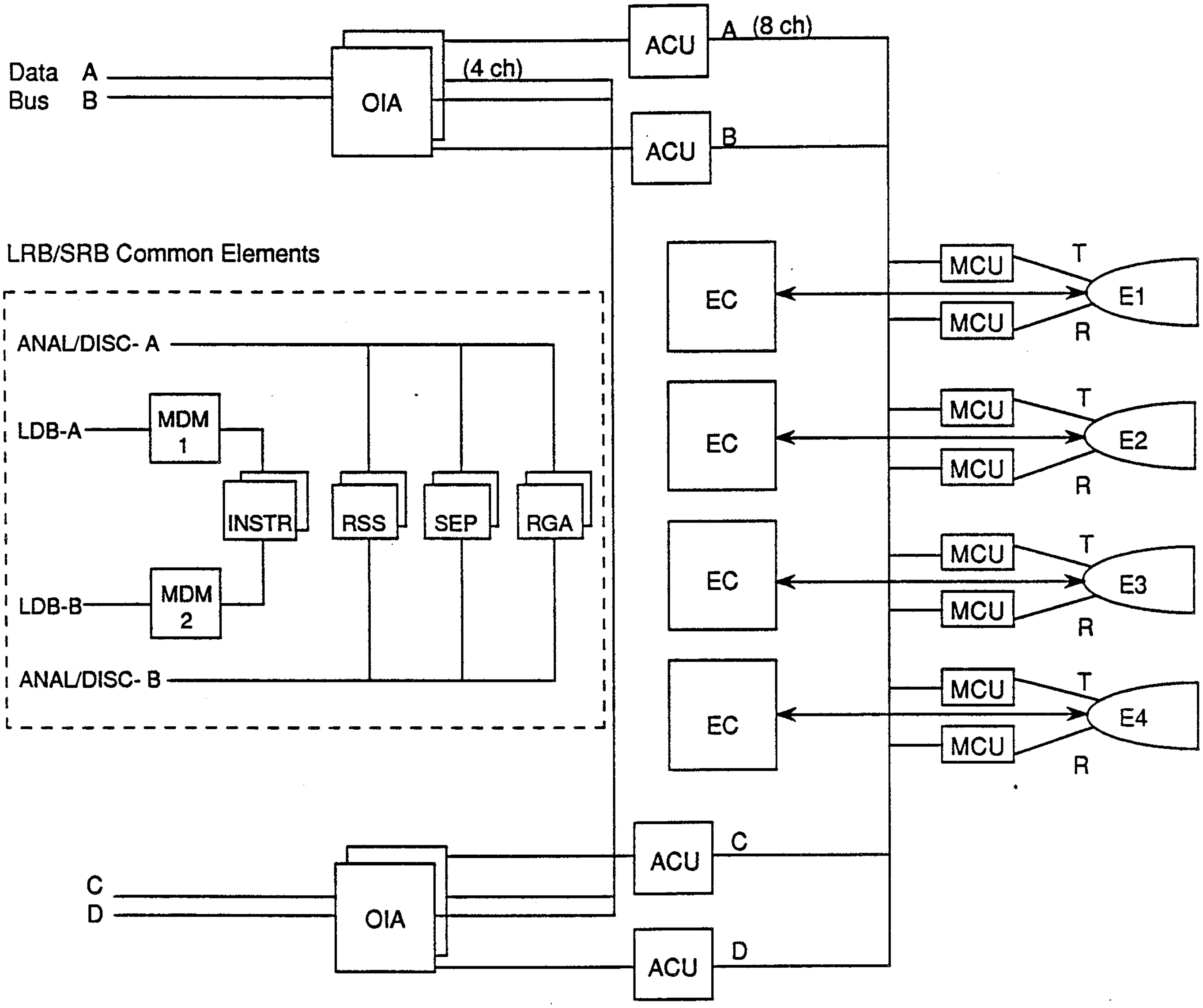


Figure 6.4.1-1 Avionics Architecture

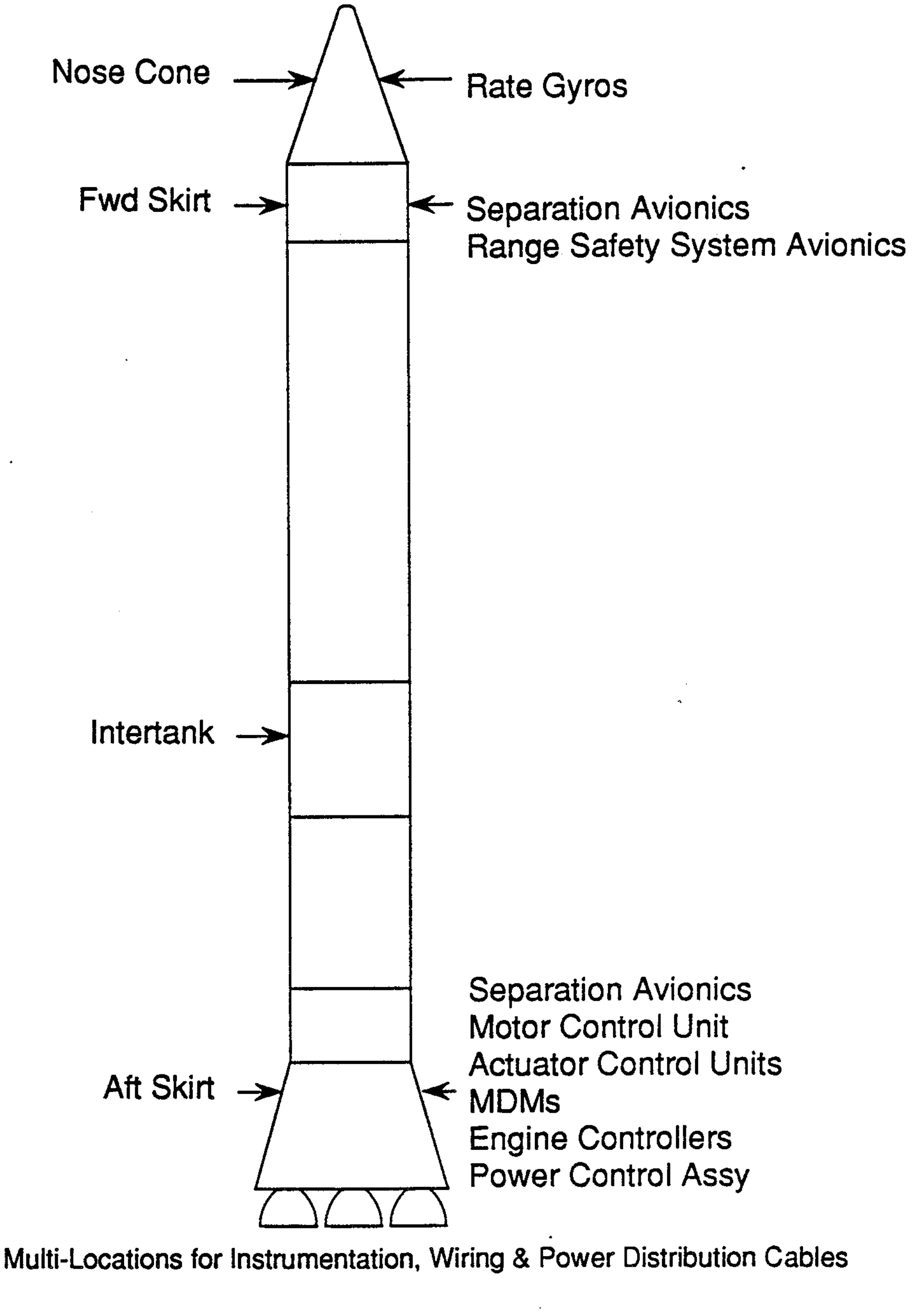


Figure 6.4.1-2 Avionics Subsystems Locations

Table 6.4.1-1 LRB Avionics

Unit	Weight	Envelope (WxLxH)	Location	Qty
GN&C				
Engine Controller				
(Pressure)	160 lb	14.5x18/5x16.5	On Engine	4
(Pump)	187 lb	14.5x20.9x16.5		
Orbiter Interface Assembly	30 lb	11.6x13x6.6	Aft Skirt	4
Rate Gyro Assy.	22 lb	(730 in.)^3	Fwd Skirt	2
Actuator Contr. Unit	55 lb	10.1x32x7.6	Aft Skirt	4
Motor Control Unit	46 lb	10.1x27x6	Aft Skirt	8
Instrumentation				
MDM	38 lb	11.6x13x6.6	Aft Skirt	2
Electric Power				
Power Control Assy	70 lb	15x20x10	Aft Skirt	3
EM Battery	93 lb	7.25x17.1x8.25	Aft Skirt	3
AV Battery	45 lb	7.25x12.2x8.25	Aft Skirt	3
Separation				
Separation Elec.	15 lb	5x10x10	Mid Skirt	2
Range Safety				
RSS Distribution			Mid Skirt	1
RSS Integrated Receiver Decoder			Fwd Skirt	2
RSS Battery			Mid Skirt	2
RSS Antenna			Fwd Skirt	2
RSS Directional Coupler			Fwd Skirt	1
RSS Hybrid Coupler			Fwd Skirt	1
RSS Safe and Arm Device			Mid Skirt	1

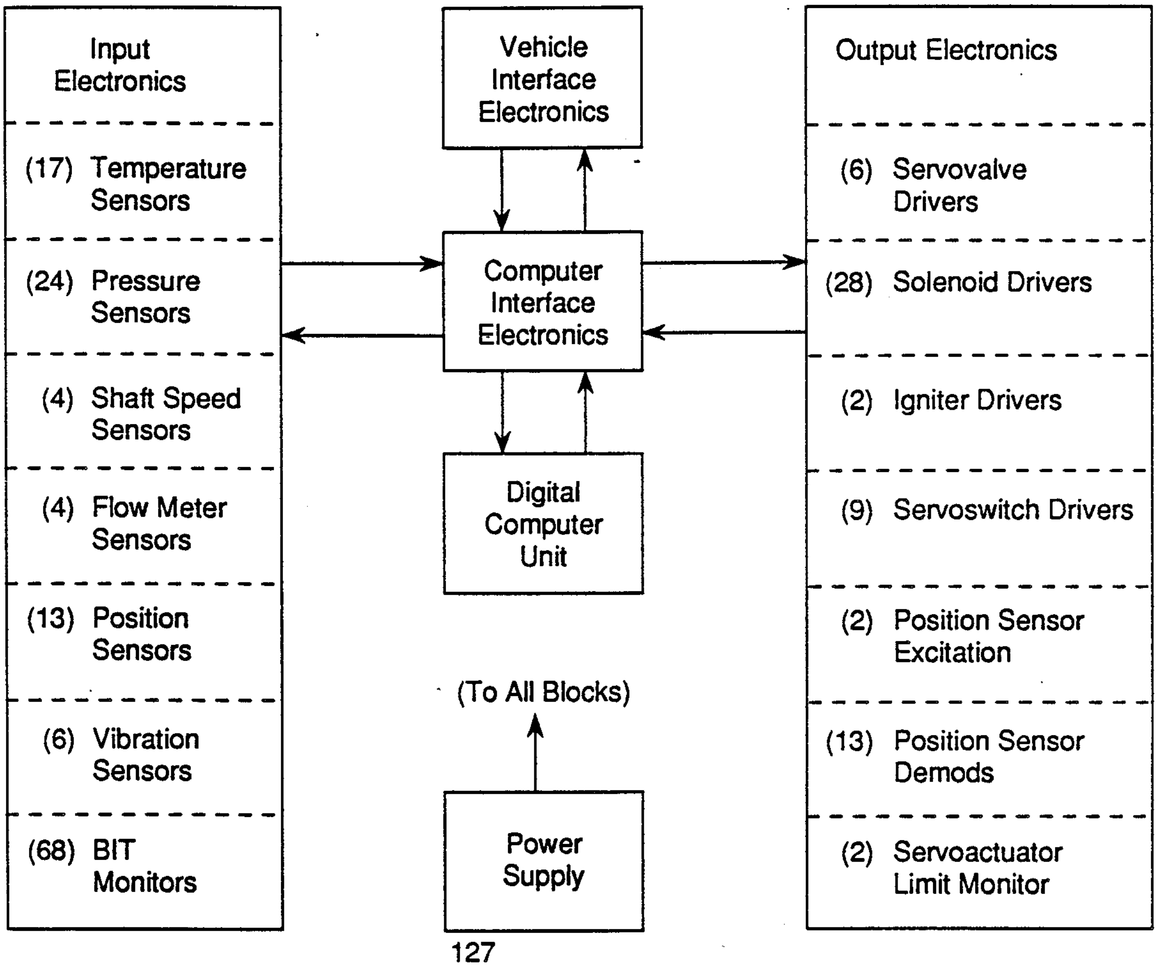


Figure 6.4.2-1 Pump-Fed LRB Engine Control

6.4.4 Thrust Vector Control

Several differences between LRBs and SRBs were identified during Phase 1 and are listed below:

1. Thrust profile of the LRBs is different from that of the SRBs (each LRB is normally throttled to 75% due to the redundant engine configuration).
2. Thrust mismatch between LRBs will be lower than between the existing SRBs during normal flight, due to the multiplicity of engines used in each LRB.
3. An 'Engine Out' condition will lead to a thrust mismatch until thrust balance can be re-established by the control system (3 sec. max)
4. The vehicle mass is approximately the same as the current STS/SRB.
5. LRB propellent slosh will affect vehicle dynamics and control.

The actual TVC requirements will be developed during Phase 2, as the vehicle dynamics and overall control system requirements are determined. During Phase 1, requirements pertaining to TVC for STS/SRB were reviewed, and those used for TVC sizing are listed below:

1. Engine is gimballed at head end.
2. Gimbal actuators are positioned in pitch and yaw.
3. 8 actuators are used for each LRB (2 per engine, 4 engines per LRB).
4. Gimbal angle is ± 6 degrees in pitch and yaw.
5. Gimbal rate is ≥10 deg/sec.
6. 3 sigma wind conditions.

These requirements were used as a part of a trade study that considered fluid injection, hydraulic actuators and electromechanical actuators as means to achieve thrust vector control. While hydraulic actuators are used on the SRB and are the most commonly used on other vehicles, their main drawback is the need for the entire hydraulic system; power supply, pumps, lines, etc. Fluid injection is not new, but is an infrequently used technique, and it is questionable whether or not the required thrust vector angle can be achieved. Electromagnetic actuators eliminate the requirement for the hydraulic system, but require more development, particularly in the motor and motor controller area. A strong desire to eliminate the hydraulics and the associated hardware and fluids led to a decision to baseline the electromechanical actuator system.

The ascent thrust vector control function is mechanized in two separate hardware units. The ACU is analogous to the input portion of the Orbiter ATVC, receiving position and velocity commands and providing feedback data and status to the orbiter. The control signals are then passed on to the MCU which contains the high power motor drive circuits for the electromechanal actuators. This physically separates the high currents of the MCU from the lower level signals of the ACU.

6.4.5 Power

Electrical power for the LRB is supplied by on-board batteries, as opposed to the STS system in which the orbiter provides all of the power for the SRB This approach was chosen in order to minimize the impact on the orbiter.

Power requirements for TVC are dealt with in the report enclosed in Appendix C. This report resulted from a brief study by NASA and other personnel. It was recommended that a series string of nine 30 volt silver-zinc batteries be used to provide the 270 volts necessary for typical electromechanical actuators. Seven such strings are required to provide the 37KW average (165 KW peak) power for the 3 minutes of the LRB engine burns. Two additional strings are added to provided two fault tolerance, bringing the total to nine strings.

Separate batteries provide the +28vdc for the remainder of the avionics.

6.4.6 Electrical Interfaces

Orbiter to LRB interface problems are minimized by the centralized LRB avionics architecture and the use of independent LRB on-board power. This eliminates the need for the 72 wires presently used to transport six quad redundant functions between the orbiter and the SRB for TVC. For the Orbiter interface, isolated taps into the Orbiter flight critical data busses are required to provide the new interface to the LRB. While this will require minor modifications to the orbiter harnessing and to the orbiter software IOP routines, this approach will avoid the transport delays that would result from simply using the existing MDMs for those interfaces.

Interfaces between the Orbiter and LRB for such functions as the RGAs, RSS, and SEP will be identical to those existing between the Orbiter and the SRB.

6.4.7. Range Safety System

The Range Safety System will utilize the same components as are used on the present SRB.

6.5 SYSTEMS ANALYSES

6.5.1 Structural Analyses

This section presents analysis for the Pump-Fed LRB structural systems. Included in the discussion are: Loads and Dynamics Analysis, Stress Analysis and Materials properties.

6.5.1.1 Loads/Dynamics Analysis

Rigid Body ET Interface Loads - Ultimate–Calculation of rigid body loads for LRB design is discussed in Section 5.2.

Launch Transient Response Analysis–Launch transient is a condition which results in many of the critical design loads cases for launch vehicles. As structural definition of LRBs developed, a launch transient response analysis was conducted.

Launch transient response analysis, in addition to generating launch loads, helps quantify the motion of the vehicle during SSME ignition. SSME ignition on the pad causes the vehicle to bend and build up strain energy in the vehicle. Excursions of the vehicle on the pad resulting from this motion are important for launch facility design. Minimizing this strain energy at lift off is critical to the Shuttle lift off loads. Ideally, MLP bolt release should be at the bucket of the base bending Y moment when strain energy in the vehicle is a minimum. Thus timing of LRB ignition and bolt release are determined by this base Y bending moment curve.

Use of LRBs instead of SRBs will cause launch transient response to be different from a normal STS case. Some contributing factors are :

1. SRB ignition pressurizes the casing, whereas the LRBs produce point loads at the engines. This total load is taken to ground by a short stiff load path - the skirt. When the bolts are fired this load ripples to the front giving a jolt to ET forward fitting.
2. As the LRB's build up thrust, the bolts (and the MLP) are put into tension. On firing the bolts this tension is relieved and the vehicle leaps away cleanly from the pad.

Transient Response Models—Some of the important details of LRB models generated for transient response analysis are given below:

a) Right hand LRB's were modelled as centerline equivalent beam sticks using NASTRAN.
b) LRB skirts were modelled as plates, reinforced by beams at the holddown pads.
c) Propellents were represented by elastic axial elements to simulate the approximate primary bulge effects.
d) Secondary structure, e.g. engines, was modelled as mass elements only.
e) LRB-ET interface hardware were simulated by NASTRAN multipoint constraints.

f) As generated, the LRB model size had 624 degrees of freedom.
g) For transient response analysis, the LRB models were reduced to 22 modes and 21 discrete freedoms (3 engines, 6 ET attach, 12 MLP interface).

Results presented at the mid-term review (March , 1988) were for a strength designed Pump-Fed LRB. The skin-stringer concept was subsequently changed to monocoque to increase stiffness, and new baseline was formed. The two Pump-Fed configurations are compared later in this Section to show the changes and to highlight the effect of LRB stiffness on vehicle response.

Model mass and c.g. data for pressure fed and monocoque pump fed LRBs is given in Table 6.5.1.1-1.

Transient Response Vehicle Models–Vehicle models were created from the main STS components :

Right and left SRBs/LRBs
Empty Orbiter model (wt = 202300 lbf)
Hydroelastic ET (wt = 1668000 lbf)

Three vehicle models were generated : a) Baseline STS vehicle using SRB's, this would verify the transient response method and provide a reference for LRB response; b) Pressure fed LRB vehicle; and c) Monocoque Pump fed LRB vehicle. Mass and c.g. information for the three vehicles is given in Table 6.5.1.1-2.

Note that the dynamics models are created relative to the Dynamics coordinate system. The definition of this system is :

Origin at ET aft LH2 dome;
+X forwards;
+Y towards the right SRB/LRB;
+Z away from the Orbiter.

Following relationships convert dynamics coordinates to ET stations :

ET X STA = 2173.025 - X DYNAMICS
ET Y STA = Y DYNAMICS
ET Z STA = -Z DYNAMICS.

It must be emphasized that the LRB models were stick models based on very preliminary information They had no radial (or hoop) flexibility.

Comments On Transient Response Analysis–Although the LRB modelling was kept as simple as possible at this stage of the design and development process,the transient response analysis was fairly complex. Some of the salient features are detailed below.

ET cryo loads were simulated by applying loads to the tank which cause it to shrink. This method automatically simulates the relief due to structural elasticity. Cryo loads were assumed to be the same as for STS.

Table 6.5.1.1-1 As-Modeled Mass and CG

	Pressure-Fed	Monocoque Pump-Fed
Weight	1,387,000 lbf	1,090,000 lbf
X C.G.	575 in. (ET STA 1598)	542 in. (ahead of ET aft LH2 dome) (ET STA 1631)

Table 6.5.1.1-2 Vehicle Mass and CG

	SRB	Press-Fed	Pump-Fed
Weight lbf	4453000	4705000	4050000
X CG in	768.6	809.8	843.2
Y CG in	0.0	0.0	0.0
Z CG in	-14.1	-13.3	-15.4

A second order follower force effect, an additional moment caused by z deflection of the offset c.g. of the vehicle, was also simulated in the transient analysis.

Nominal SSME and SRB forcing functions for the SRB vehicle were generated based on the MSFC launch analysis condition L0941.

A completely nominal launch was simulated - there were no winds, or thrust mismatch/misalignment.

There were no changes to the MLP mass or stiffness between the SRB and LRB configurations.

MLP bolt release was assumed to be instantaneous.

LRB thrust rise curves were developed from the SSME center engine X force by suitable scaling and time shifting. LRB thrust was assumed to be axial only.

Four LRB engines were replaced by a single equivalent engine.

On - Pad SSME Ignition Results–For this analysis the vehicle was bolted to the pad while the SSMEs were lit simulating an FRF type of event. Results for base Y bending moments and cg Z excursions are shown plotted in Figure 6.5.1.1-1.

First bending mode frequencies of the three vehicles bolted to the MLP were calculated to be :

0.27 Hz. for STS (SRB vehicle),
0.28 Hz. for the LRB Pressure Fed vehicle,
and 0.29 Hz. for the LRB monocoque Pump fed vehicle.

These are the frequencies of the plots in Figure 6.5.1.1-1.

The base Y bending moment bucket determines the optimum bolt release time. The graph on the top shows the results for the three vehicles - namely the SRB, pressure fed, and monocoque pump fed. It can be seen that the LRB's are very similar to the baseline SRB vehicle.

From the base Y bending moment curves the optimum bolt release time for the SRB vehicle is at 7.1 sec; it is actually at 6.7 sec. in the forcing functions database to allow for any variations in the system. LRB vehicle bolt release times were assumed to be at the moment bucket (7.0 sec). SSME ignition in all cases was at 1.9 sec., with time t=0 being at SSME ignition command.

The second graph in Figure 6.5.1.1-1 shows vehicle cg Z excursion on the pad under the action of SSME's. Max excursions for the three vehicles are :

12 in. for the SRB vehicle,
10 in for the LRB Pressure Fed vehicle,
and 11 in. for the LRB Pump Fed vehicle.

LRB Engine Forcing Functions–In order to determine the launch transient it was also required to define LRB forcing functions. LRB engine forcing functions were derived from the SSME center engine axial thrust build-up by suitable scaling and time shifting.

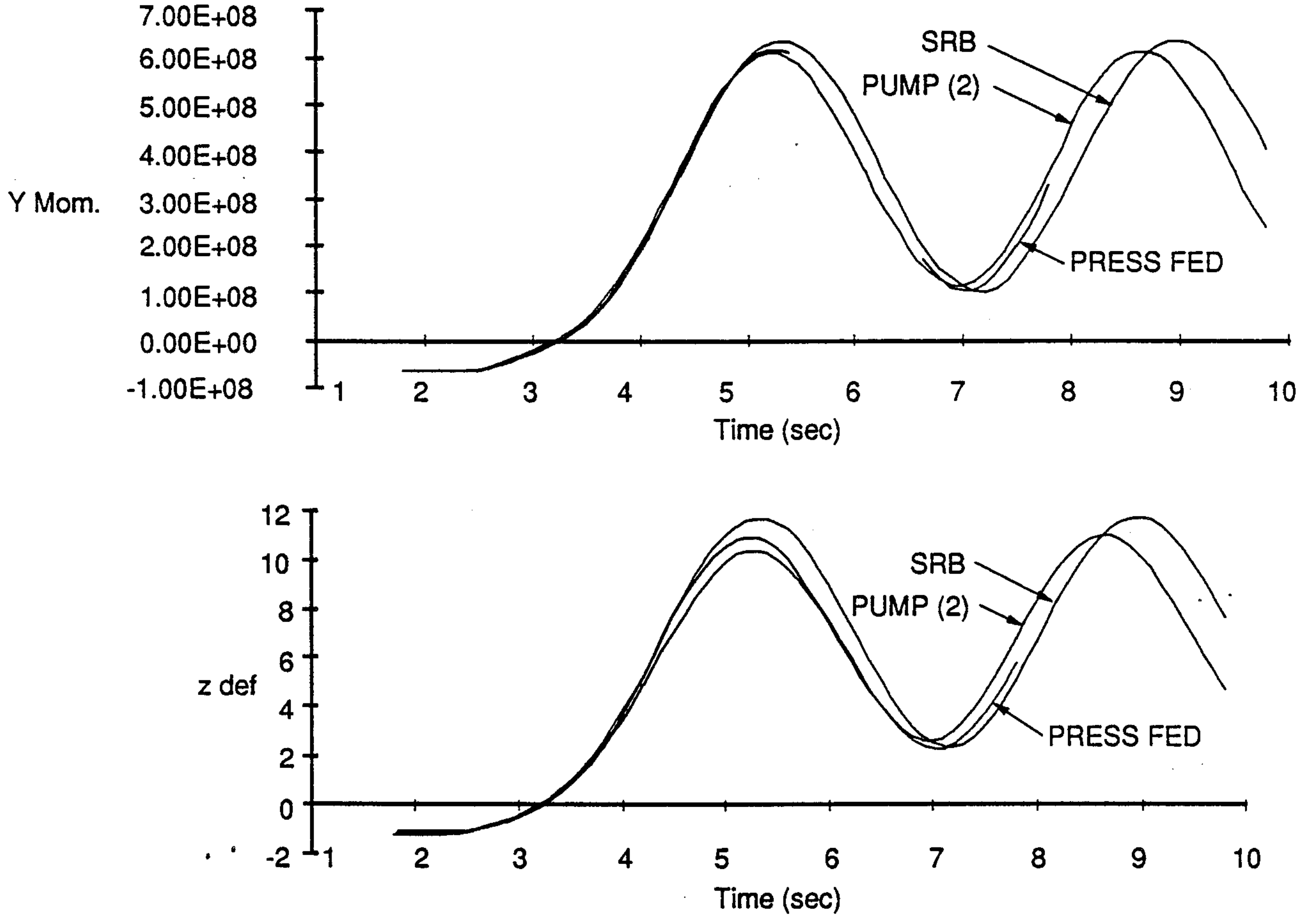


Figure 6.5.1.1-1 On-Pad SSME Firing Results

For the Pressure-Fed case, the plateau in the SSME curve, assumed to be from turbo-pump spin-up, was removed as shown by dashed line in Figure 6.5.1.1-2. The curve was scaled and time shifted giving a peak thrust of 2912 kips at 7.0 sec. Bolt release was also at 7.0 sec as determined from on-pad results.

For the monocoque Pump-Fed case, the SSME curve was used unchanged but the amplitude was scaled to give a peak thrust of 2052 kips. Peak thrust and bolt release were also at 7.0 sec.

LRB Ignition Sequence–The arguments for selecting the LRB ignition sequence for transient loads analysis are detailed in this section.

STS bolt release is at base Y bending moment bucket to alleviate lift-off loads. LRB loads will have to be alleviated similarly, by launching when strain energy in the vehicle is a minimum.

Base bending moment oscillation is primarily governed by the LRB stiffness. This oscillation will take place as the SSME's build up thrust, with a period of 4-5 sec.

Time for SSME thrust build-up is approximately 2.6 sec. If 1 sec is allocated for the pre-launch engine checks, the SSMEs need at least 3.6 sec before bolt firing signal can be issued. By this time the twang motion is half way through its cycle, and strain energy in the vehicle is near its maximum value (Figure 6.5.1.1-3). SSMEs are maintained at full power as the vehicle swings back towards the moment bucket.

Considering the inevitability of twang, and the desire to launch when all engines are up to 100% power level, the time of the moment bucket becomes the driver for bolt release.

To minimize fuel burn on pad, bolt release should be just before the first moment bucket (approx 0.33 sec before the bucket for SRB's). This allows for a tolerance for any dispersions such that the vehicle is moving towards the minimum strain energy condition.

Hence LRB ignition time has to be backed off from the base bending moment bucket such that:

LRB's are at 100% + time for pre-launch checks + time for dispersions.

Assuming 1 sec for engine checks and 0.33 sec for dispersions then if LRB's take 2 sec to reach 100% thrust the SSME's have to be lit first. If this time is 20 sec, the LRB's have to be lit first. Since LRB engine thrust curve was based on SSME (with a thrust build-up time of 2.6 sec), using the above arguments the SSMEs were lit first (at 1.9 sec) with LRBs being ignited at 3.1 sec.

ET Loads Due To Launch Transient–Table 6.5.1.1-3 shows the results of launch transient response analyses carried out for LRB design support. ET loads are shown because, being a complete set, any impacts to the Orbiter interface loads would also show up. The loads are in KIPS; they are in the dynamics coordinate system (see section 6.5.1.1 for definition), and are max-mins for simulation time from 1.8 sec to 20.0 sec.

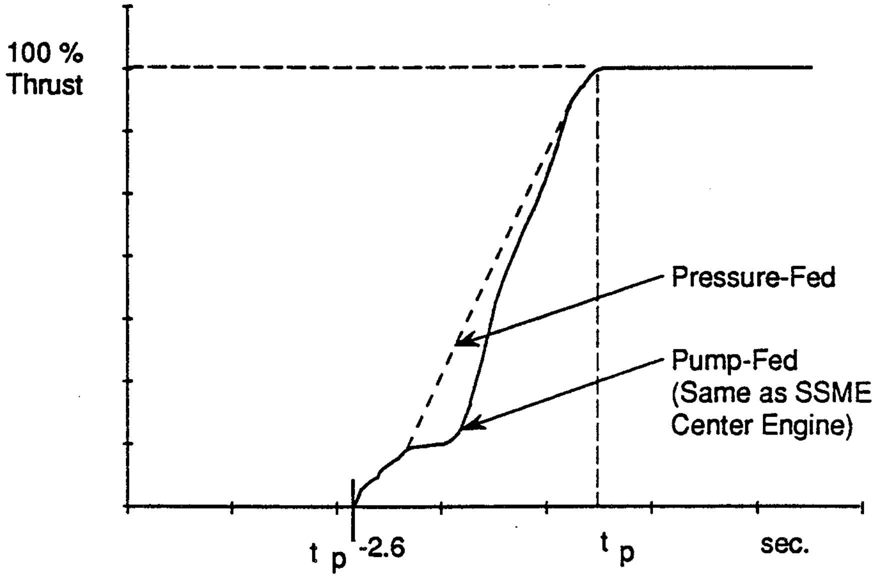
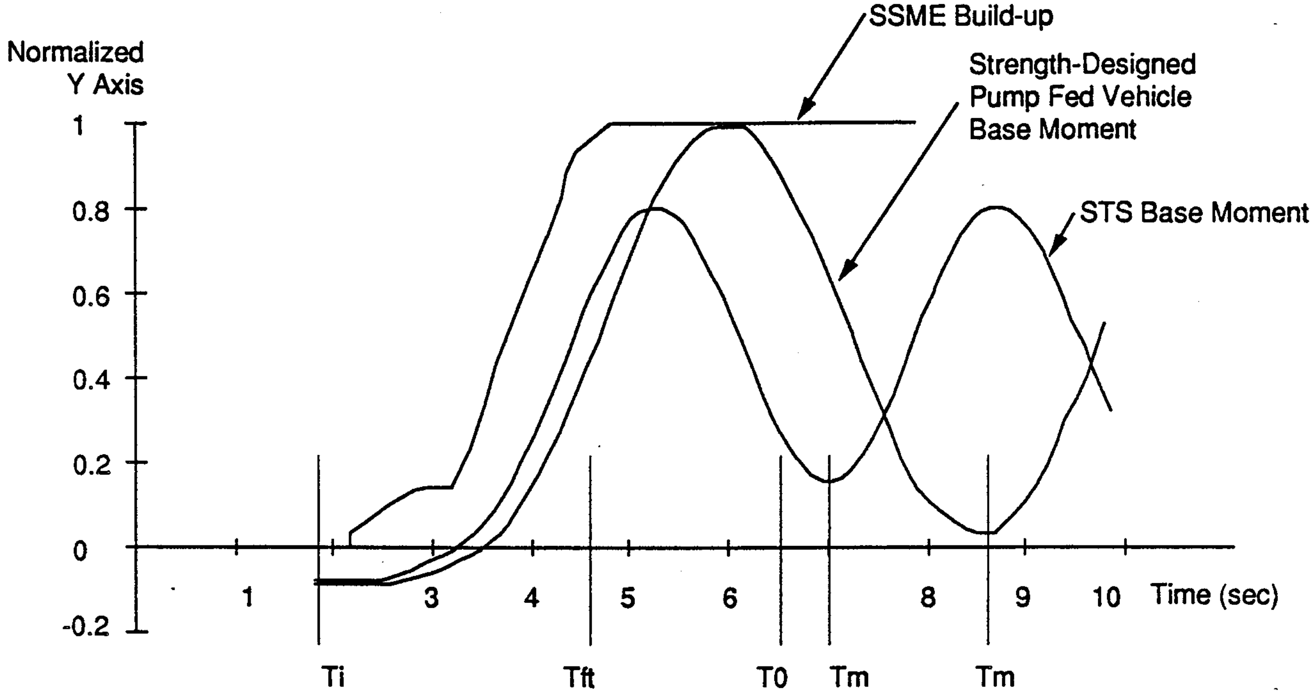


Figure 6.5.1.1-2 LRB Engine Forcing Functions



Ti	-	SSME ignition (1.9 sec., engines staggered by 0.182 sec)
Tft	-	SSMEs at 100% thrust (4.8 sec)
T0	-	Nominal SRB ignition (6.68 sec)
Tm	-	Moment bucket times

Figure 6.5.1.1-3 LRB Ignition Sequence

K-18/jer

Table 6.5.1.1-3 ET Loads Due to the Launch Transient

			SRB		Press-Fed		Monocoque Pump-Fed	
			Max	Min	Max	Min	Max	Min
ET-ORB:	Fwd Bipod	X	2	-9	2	-10	2	-9
		Y	7	-8	2	-5	5	-6
		Z	101	-24	113	-23	105	-23
	Aft Linkage R	X	471	-104	482	-105	497	-105
		Y	51	12	87	-30	79	-17
		Z	126	11	138	11	142	11
	Aft Linkage L	X	478	-100	497	-99	499	-99
		Y	-11	-43	-12	-48	-12	-45
		Z	122	11	141	11	130	11
R SRB: (LRB)	Fwd	X	1126	356	1119	383	935	373
		Y	2	-140	77	-203	80	-212
		Z	31	-192	30	-184	30	-187
	Aft	Y	136	-178	176	-257	185	-246
		Z	36	-86	70	-116	69	-113
		Y	164	-6	223	-30	173	-23
L SRB: (LRB)	Fwd	X	1126	356	1123	376	935	368
		Y	142	-3	204	-78	214	-84
		Z	36	-191	30	-184	30	-186
	Aft	Y	162	-128	214	-175	220	-156
		Z	44	-75	73	-110	83	-89
		Y	-3	-154	28	-221	20	-159

Column 1 shows the loads obtained for the baseline STS vehicle (with SRB's); they were calculated to establish a baseline response.

Column 2 shows loads for the PRESSURE-FED LRB vehicle. These loads are generally very similar to the SRB vehicle loads, except for the LRB-ET lateral loads. These are judged to be too conservative because of the lack of any radial (or hoop) flexibility in the LRB stick models.

The monocoque PUMP-FED LRB's also have stiffness characteristics very similar to the SRB's, as was shown earlier for the on-pad response results. However the launch g-level is lower (1.2 g's) because of their lower sea-level thrust. Hence the launch transient loads shown in column 3 of Table 6.5.1.1-3 for a nominal launch are also smaller. Pump fed LRB lateral loads are also conservative, being obtained from stick models without any radial flexibility. Pressure Fed and Pump Fed LRB lateral loads are very similar.

Steady state values of loads (after the launch transient has decayed) are very similar to the rigid body loads discussed in para 6.5.1.1.

Max Accelerations Allowable, ET LO2 Dome–One of the ET loads constraints is that the pressure at STA 852 is restricted to 58.84 psia, which translates to a dome limit of 70 .68 psia. Pressure at ET LO2 aft dome (Pa) is given by :

$$\mathbf{Pa = dl * g * h + Pu + cp}$$

where: dl = LO2 density (71.19 lbf/cu.ft),

h = LOX head pressure,

cp is a correction term to allow for lag in ET nose cone venting,

and Pu = ullage pressure (23 psia nominal).

Assuming cp = 5 psia for 25-75 sec, and using LOX head from a typical STS mission (61C) the dome static equivalent g limit can be calculated. This is shown plotted as DOME LIMIT in Figure 6.5.1.14. Also shown are the g levels for a nominal STS mission, and the g levels for LRB mission profiles. It can be seen that mission g levels are less than the dome static g level allowables.

However the DOME LIMIT g levels shown in Figure 6.5.1.1-4 are static equivalents. The launch transient also causes dynamic dome pressure variations as discussed below.

ET LO2 Tank Dome Pressure : SRB Vehicle Lift-Off–Figure 6.5.1.1-5 shows the ET LO2 tank aft dome pressure response caused by the transient from a nominal STS (SRB vehicle) launch. Critical area in the ET LO2 tank is the barrel at STA 852 (strength critical). The limit pressure of 58.84 psia translates to a dome pressure limit of 70.68 psia. Peak pressure from

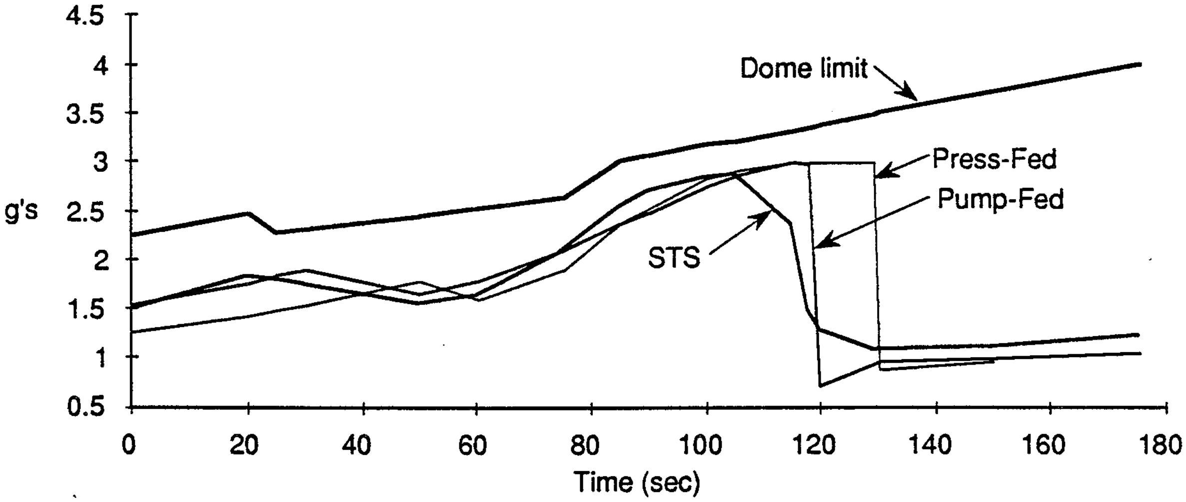


Figure 6.5.1.1-4 Max Accelerations Allowable, ET LO2 Dome

the launch transient (assuming 23 psia ET ullage pressure) is obtained as 63.7 psia, which is below the 70.68 psia design limit.

ET LO2 Tank Dome Pressure : Pressure-Fed Vehicle Lift Off– Figure 6.5.1.1-6 shows the ET LO2 tank aft dome pressure response caused by the transient from a pressure fed LRB vehicle launch. Peak pressure from the launch transient (assuming a 23 psia ET ullage pressure) is obtained as 63.7 psia. The peak value is similar to the nominal STS pressure response, although the actual time history is different.

ET LO2 Tank Dome Pressure : Pump-Fed Vehicle Lift-Off–Figure 6.5.1.1-7 shows the ET LO2 tank aft dome pressure response caused by the transient from a monocoque pump fed LRB vehicle nominal launch. Peak pressure from a launch transient (assuming a 23 psia ullage) is obtained as 57.1 psia, which is lower than the STS and the pressure fed vehicle values because of the lower launch g level.

Pump-Fed LRB Stiffness Issues–Monocoque Pump fed LRB was developed to increase stiffness of the LRB because of the following concerns:

a) Original strength designed Pump fed LRB vehicle had excessive on-pad c.g. z excursions - (28 in). This translated to ET LOX tank motion of approx. 40 in. Such a large "tipping" motion was not acceptable to the ET as it could cause off-design loading conditions for the tanks.

b) Clearance problems with launch pad umbilicals.

c) Nominal transient response results were very different from STS nominal results. This, coupled with the greater dynamic swing of loads for the original strength designed Pump Fed vehicle, could result in ET I/F loads exceedances once the dispersions were taken into account.

d) Strength designed Pump Fed LRB had strong low frequency modes (15-20 dB stronger than with SRB's), leading to insufficient flex stability margins. This would require major changes to Flight Controls System software.

Z Deflection At ET1 Intertank Umbilical–ICD-2-0A002 Section 3.1.3 gives the max allowable deflection at the ET1 (ET intertank) umbilical during SSME build-up as 23 in. Launch pad positioning tolerance is given in the ICD as 0.9 in. From aft cargo carrier launch analysis studies (1983), deflection allowance for gusts is estimated to be 2 in. This leaves a total allowable deflection during SSME build-up of 20 in.

The upper graph in Figure 6.5.1.1-8 shows the z deflection obtained during a nominal FRF (no winds) at SRB/ET forward fitting (which is 18 in. forward of the umbilical). Maximum deflections obtained were :

SRB VEHICLE: 17 in.
LRB PRESS FED: 14 in.

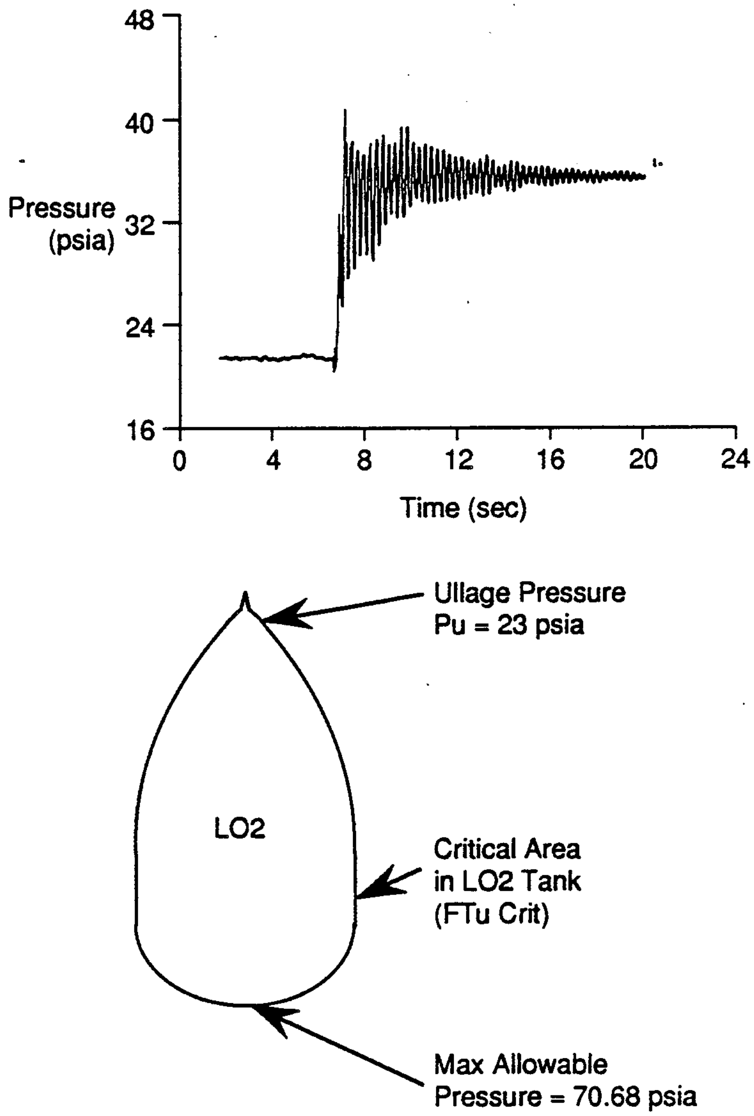


Figure 6.5.1.1-5 ET LO2 Tank Dome Pressure
SRB - Nominal Lift-off

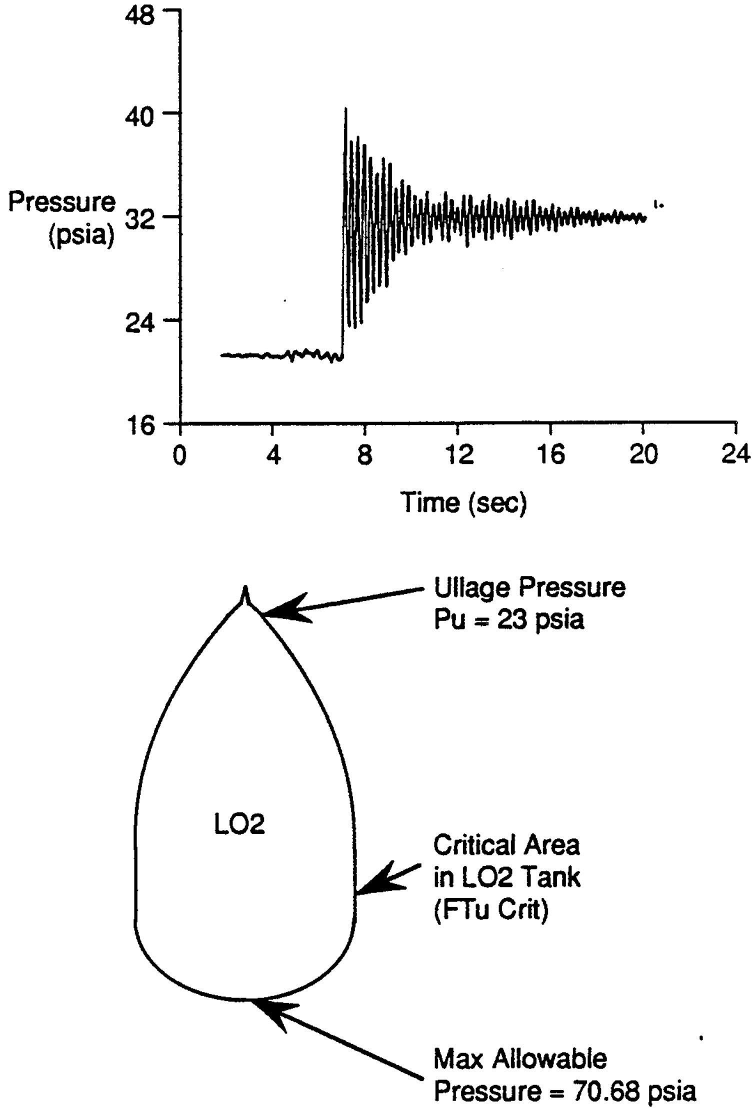


Figure 6.5.1.1-6 ET LO2 Tank Dome Pressure
Pressure-Fed LRB - Nominal Lift-off

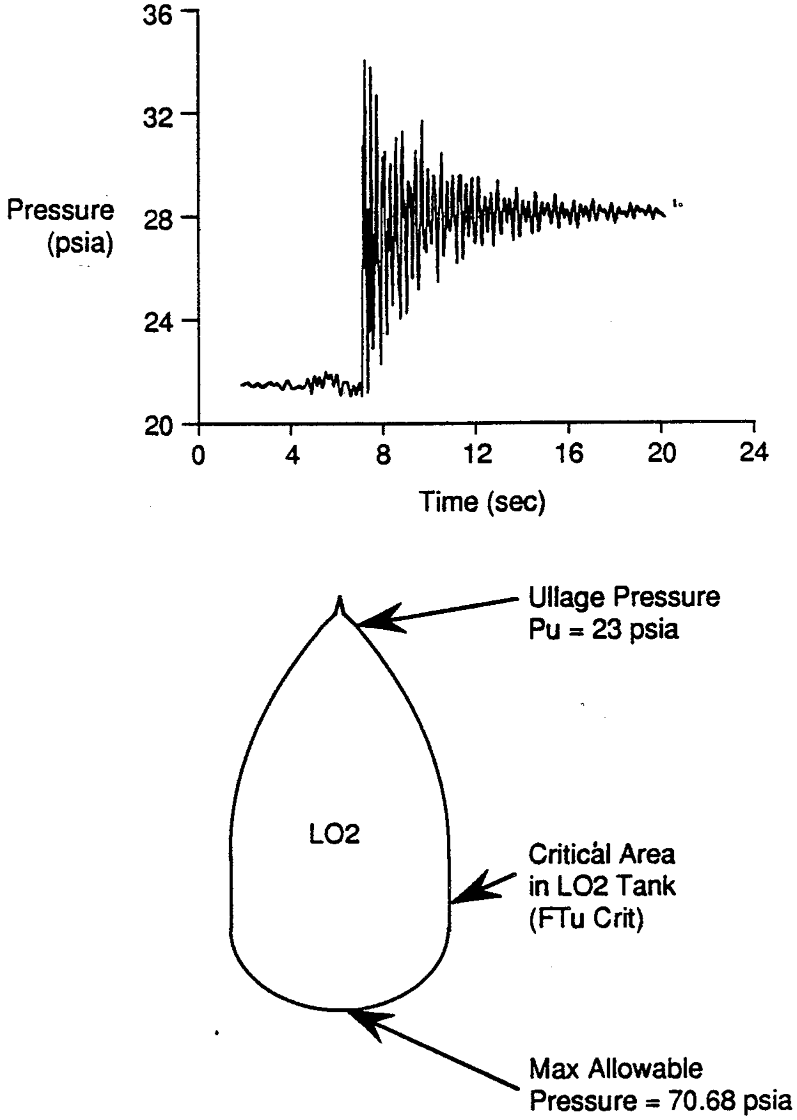
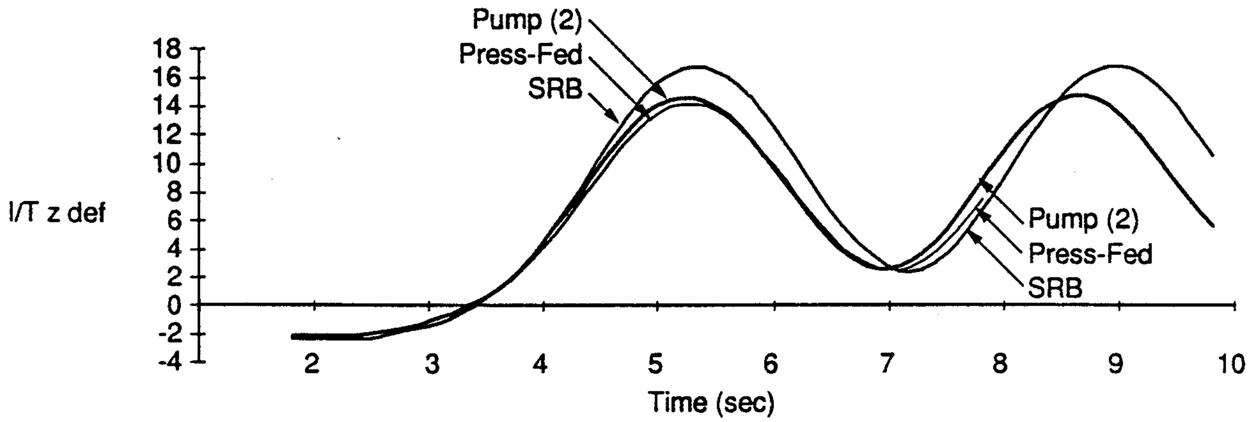


Figure 6.5.1.1-7 ET LO2 Tank Dome Pressure
Monocoque Pump-Fed LRB - Nominal Lift-off



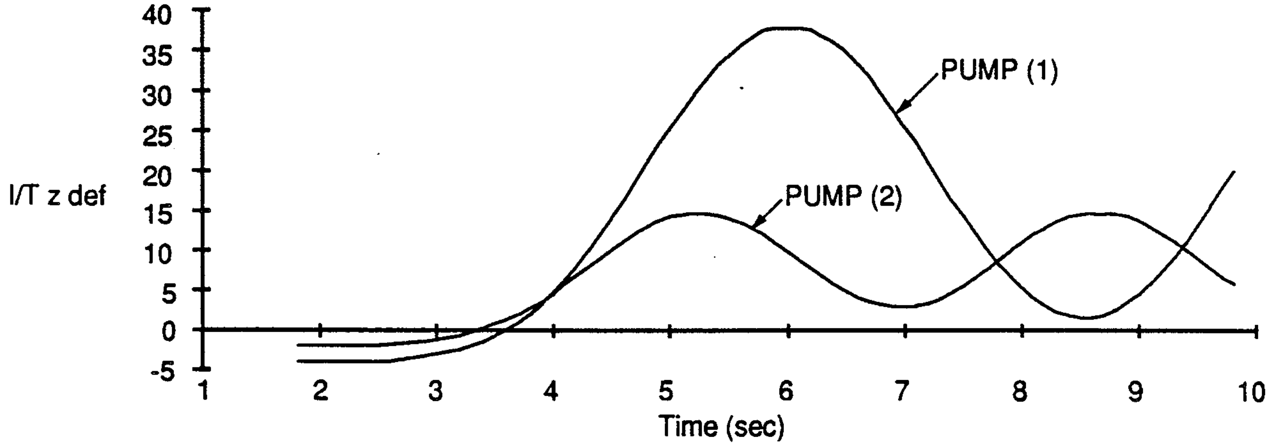


Figure 6.5.1.1-8 Z Deflection at ET Intertank Umbilical

LRB MONOCOQUE PUMP FED: 15 in.

It can be seen that all three vehicles meet the deflection criteria.

The lower graph in Fig 6.5.1.1-8 compares the intertank deflections for the two Pump Fed vehicles. Strength designed Pump fed LRB vehicle deflection (38 in.) was unacceptable, and was one of the reasons for increasing the stiffness (leading to the monocoque concept). Also the greater period of the strength designed concept would lead to a longer SSME burn time on the pad and a requirement for significantly more fuel volume.

Strength Designed Pump-Fed - Launch Loads Table 6.5.1.1-5 shows ET loads for the original strength designed Pump-fed LRB for an optimum launch (bolt release at 8.5 sec), and loads from a non-optimum launch (MLP hold-down bolts fired at 7.0 sec). Non-optimum loads are generally larger and show a greater dynamic range.

The optimum launch loads shown in Table 6.5.1.1-5 are greater than those shown earlier for the monocoque Pump-fed LRB, mainly because of the greater launch g-level.The comments made earlier in para. 6.5.1.1.7 about the lateral loads apply here also. The lateral loads are conservative because of a lack of radial flexibility in the LRB beam models.

Figure 6.5.1.1-9 shows the ET LO2 tank aft dome pressure responses caused by the launch transient of a strength designed pump fed LRB vehicle. The upper curve shows that the peak pressure from the nominal launch transient (assuming a 23 psia ullage pressure) is 70.2 psia, which is very close to the 70.68 psia design limit. The lower curve shows that the peak pressure from the off-nominal launch transient (assuming a 23 psia ET ullage pressure) is obtained as 63.5 psia, which is similar to the nominal STS result. However, the pressure swing is much larger, with a minimum pressure of only 33 psia.

Conclusions - Results from this preliminary transient response analysis indicate that the current LRB configurations both pressure-fed and pump-fed are similar to the SRB baseline vehicle.

There do not seem to be any loads that are show-stoppers. The predicted aft LRB attach loads will be reduced to acceptable levels when a more detailed model accounts for radial stiffness at these points.

LRB stiffness must be maintained near SRB values in order that ET interface loads are not exceeded. Strength designed pump fed vehicle stiffness was very low. This caused sufficient variations from a baseline STS response that this vehicle could give rise to unforeseen problems.

Monocoque pump fed vehicle stiffness approximates the SRB and pressure-fed LRB values.

LRB models used were simple stick models believed adequate for this phase of development.

Table 6.5.1.1-5 Strength-Designed Pump-Fed LRB: Loads for Optimum and Non-Optimum Launch

			Optimum Launch		Non-Optimum Launch	
			Max	Min	Max	Min
ET-ORB:	Fwd Bipod	X	2	-11	2	-15
		Y	4	-5	7	-10
		Z	126	-24	177	-24
	Aft Linkage R	X	494	-105	499	-105
		Y	62	1	84	-21
		Z	127	11	159	-16
	Aft Linkage L	X	504	-100	514	-100
		Y	-11	-42	4	-51
		Z	119	11	145	-6
ET-R LRB:	Fwd	X	1351	362	1152	44
		Y	153	-238	92	-214
		Z	32	-228	109	-240
	Aft	Y	123	-107	128	-271
		Z	44	-76	201	-212
		Y	198	-34	228	-145
ET-L LRB:	Fwd	X	1352	370	1143	53
		Y	247	-155	240	-91
		Z	32	-229	103	-237
	Aft	Y	108	-116	271	-111
		Z	31	-73	200	-200
		Y	34	-202	132	-241

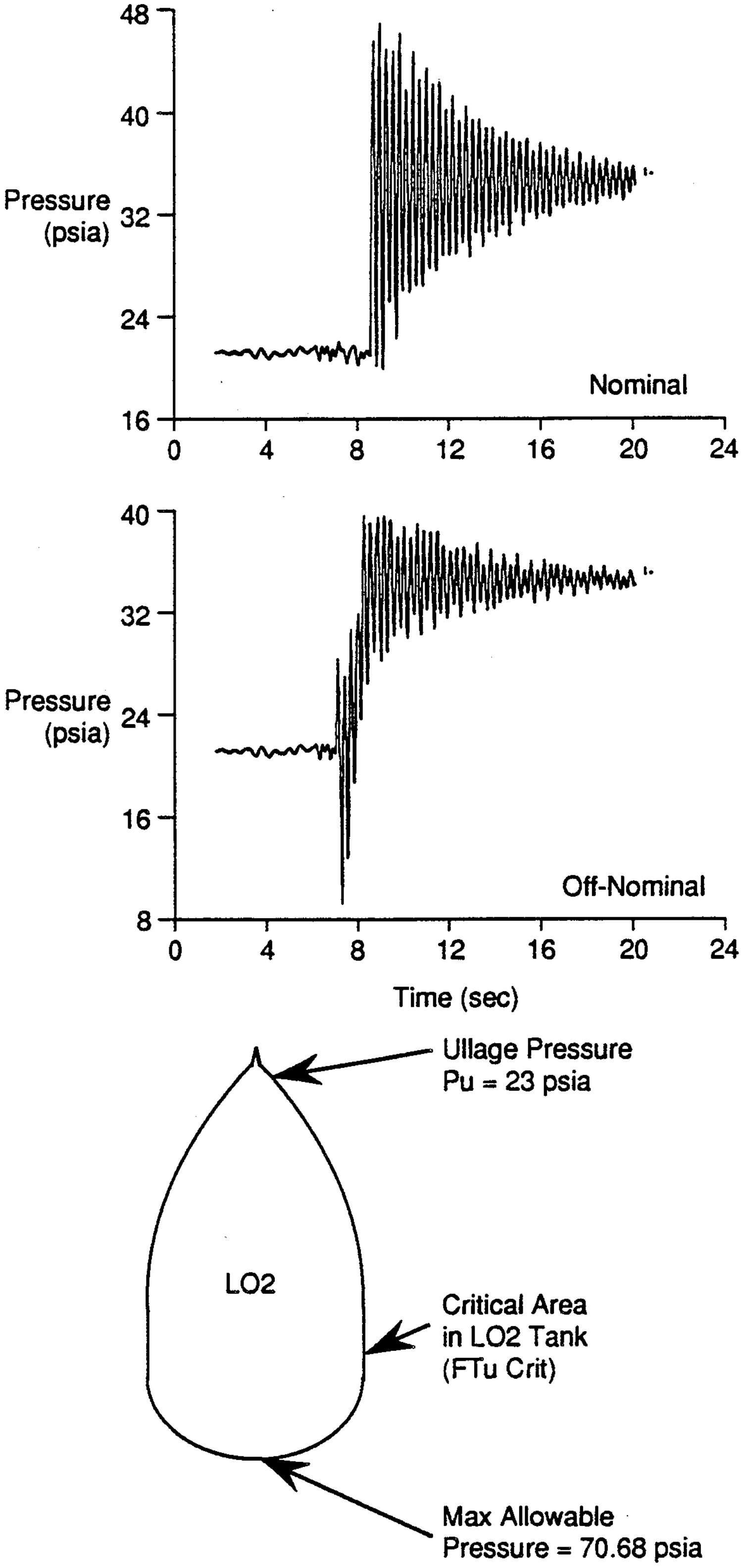


Figure 6.5.1.1-9 ET LO2 Tank Dome Pressure for Strength Designed Pump-Fed LRB

6.5.1.2 Stress Analysis

A separate report entitled Liquid Rocket Booster (LRB) for the Space Transportation System (STS), Stress Analysis Report for Pump-Fed and Pressure-Fed LRB, Jan. 15, 1989 is included as Appendix A. This report presents a preliminary design stress analysis of the pump-fed and pressure-fed configurations using the structural design requirements specified in the LRB CEI Specification, Rev. 1 April 1988. These requirements meet those specified in MSFC-HDBK-505A, Structural Strength Program Requirements.

The stress report utilizes vehicle static and dynamic loads presented in section 6.5.1.1 and material properties outlined in section 6.5.1.3. On-pad Max-pitchover, Lift-Off, Max Q and Boost Ascent loading cases along with proof pressure loading conditions are presented.

6.5.1.3 Materials Properties

Trade Studies-Trade studies were conducted during Part 1 of the LRB program in order to determine the material best suited for LRB and the goals of the LRB program. The approach taken to perform the trade studies was to first establish material requirements for a booster design, establish a candidate material list, screen the candidates for the most promising, determine design and cost data for the most promising, and then perform structural sizing and weight analysis for concept evaluation. Structural weight data was then provided as one input to the system trade study for the pump-fed configuration along with performance, manufacturing complexity, safety, technical and schedule risks, and cost data. The system trade study results and supporting rationale is described in Section 4.0.

Certain material requirements and characteristics were necessary in order to build a viable, low cost, safe booster to replace the SRB. It was determined early in the program that material strength properties had to be high to keep structural weight of the booster reasonably low. Materials used in the tankage had to be readily welded and develop good weld efficiencies. The material had to be compatible chemically with the propellants and if the propellants were cryogenic, the material also had to be able to perform satisfactorily at cryo temperatures.

Other factors which had significant influence in screening the materials were the fracture characteristics and fracture toughness of welds. Fracture toughness was considered important to the tank design to the extent that welds could be classified as "leak before burst" welds. Otherwise additional weld thickness, weight, and cost would be required to make a safe condition at the welds.

Formability and machinability were also important for manufacturing costs. General corrosion resistance and stress corrosion properties were of lesser importance.

Materials considered for possible LRB use were: weldable high strength aluminum alloy 2219 used in many launch vehicles including ET; 5456, an excellent marine alloy with high weld efficiency; 2090 aluminum-lithium, a new high strength alloy currently under development; Weldalite™049, a higher strength aluminum lithium alloy also under development; D6AC, the high heat-treated steel used for SRB's, 18N1-T200 &T250 maraging steels with very high heat-treat strength, HP9-4-20 & - 30 high nickel content heat treatable steel with high weld efficiency considered for ASRM, 300 series stainless steel in the hardened condition, and two composite materials, graphite-epoxy (GR-EB) used in filament would tanks and graphite polyether etherketone (GR-PEEK), a high temperature themosplastic composite with high strength capabilities.

These materials and their mechanical properties are shown in Tables 6.5.1.3-1 & 2 for sheet and plate respectively. Also listed in the properties are the specific strength, FTU/DENSITY and FTY/DENSITY, and the specific modulus, E/DENSITY, values.

Structure design by strength considerations is most efficient if the specific strength is the highest. Structure designed by stiffness is most efficient if the specific modulus is the highest.

Figures 6.5.1.3-1 graphically shows the specific strength and modulus values for the materials in plate thicknesses at room temperature. The as-welded strengths of the aluminums are also shown. The two composite materials shown, GR-EP and GR-PEEK provide the highest specific strength and modulus. Weldalite™049 achieves the highest parent metal specific strength of the alloys shown and the highest as-welded strength. 2090-T8E41 has the highest specific modulus of the alloys. Welded properties of the steel alloys were not shown as D6AC steel is not considered to be a good weldable alloy and the 18NI maraging steels should be heat-treated after welding.

Specific strength and modulus of the candidate materials at -320°F is shown in Figure 6.5.1.3-2. This cryo temperature covers the use of LO2 at -297°F. The highest values for specific strength and modulus in the aluminum alloys are achieved by Weldalite™049. The specific modulus of the GR-EP composite is high but the strength values of all the composites are reduced at cryo temperatures.

The steel alloys are considered unsuitable for cryogenic applications because of their brittle behavior. Therefore, no data was shown.

Results- At the conclusion of the structural weight study of the candidate materials, Weldalite™049 was shown to result in the lowest weight for the pump-fed vehicle. Table 6.5.1.3-3 shows the difference in total structural weight for each material except the composites. Composite filament wound tanks were sized and weights determined under a separate trade study, S-10, described in Section 4.0. The results were not included in this table because tank liner development had not progressed far enough for filament-wound tanks to be considered for

Table 6.5.1.3-1 LRB Trade Study (Materials) - Sheet

Material	Density lb/in3	FTU ksi	FTY ksi	Modulus E x10 3 ksi	FTU / Density	FTY / Density	E / Den
2219-787	.103	68	55	10.5	660	534	102
5456-H321	.096	51	37	10.4	552	385	108
2090-T8E41	.093	77.3	70.5	11.0	831	758	118
T8 Weldalite™ 049	.097	100	95	11.3	1031	928	116
18NI-T250	.286	250	240	27.5	874	839	96
18NI-T200	.286	190	190	27.5	682	664	96
9-4-20	.283	190	180	27.5	671	636	97
9-4-30	.28	215	190	27.5	768	679	98
D6AC	.29	210	180	29.0	724	621	100
301 ST-ST	.286	185	98	27.0	647	343	94
GR-Epoxy(FW) (±30,90)	.058	51/37		9.15	879/638		158
GR-Peek(FW)	.058	84/59		7.15	1448/1017		123

Table 6.5.1.3-2 LRB Trade Study (Materials) - Plate

Material	Thickness (in.)	Density lb/in3	FTU ksi	FTY ksi	Ductility e o/o	Modulus E x10 3 ksi	FTU / Density	FTY / Density	E / Den
(B) 2219-787	2-3	.103	65	52	6	10.5	631	505	102
(S) 5456-H321	1.5-3	.096	41	29	12	10.2	427	302	106
(E) 2090-T8E41	2-3	.093	77.3	70.5	6	11.0	831	758	118
T8 (E) Weldalite™ 049	2-3	.097	100	95	5	11.3	1031	979	117
T4 (E) Weldalite™ 049	2-3	.097	90.2	69	16.3	11.3	930	711	117
(S) 18NI-T250	>.250	.286	255	245	6	26.5	892	857	93
(E) 18NI-T200	.5-1	.286	195	190	7	26.0	682	664	91
(S) 9-4-20	.5-1	.283	190	180	10	28.8	671	636	102
(S) 9-4-30	≥.250	.28	220	190	10	28.5	786	679	102
(E) D6AC	.5-1	.29	210	180	8	29.0	724	621	100
301 ST-ST	≤.25	.286	185	98	11	27.0	647	343	94

B -Basis Allowable MIL-HDBK-SE
S-Basis Allowable MIL-HDBK-SE
E-Estimated From Existing Data to be Comparable to an S Basis Allowable

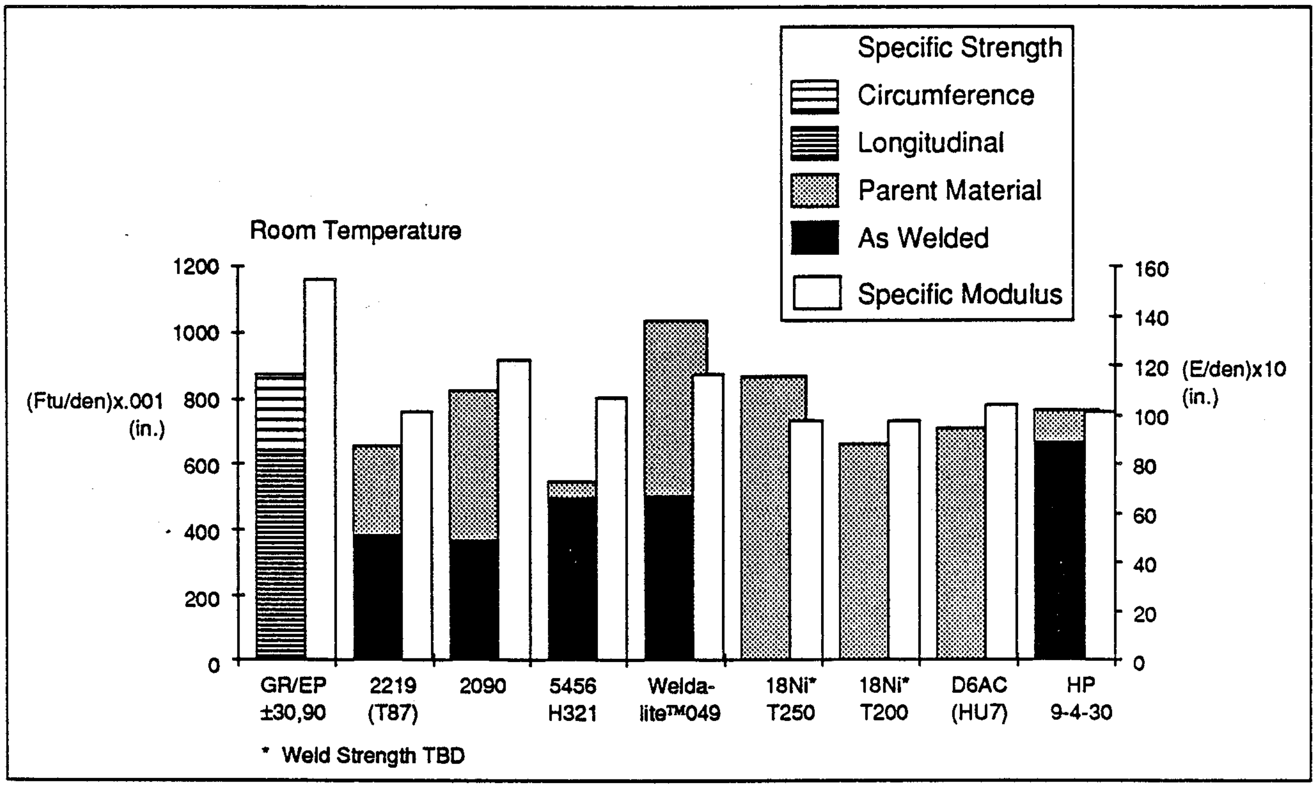


Figure 6.5.1.3-1 Material Properties (Plate)

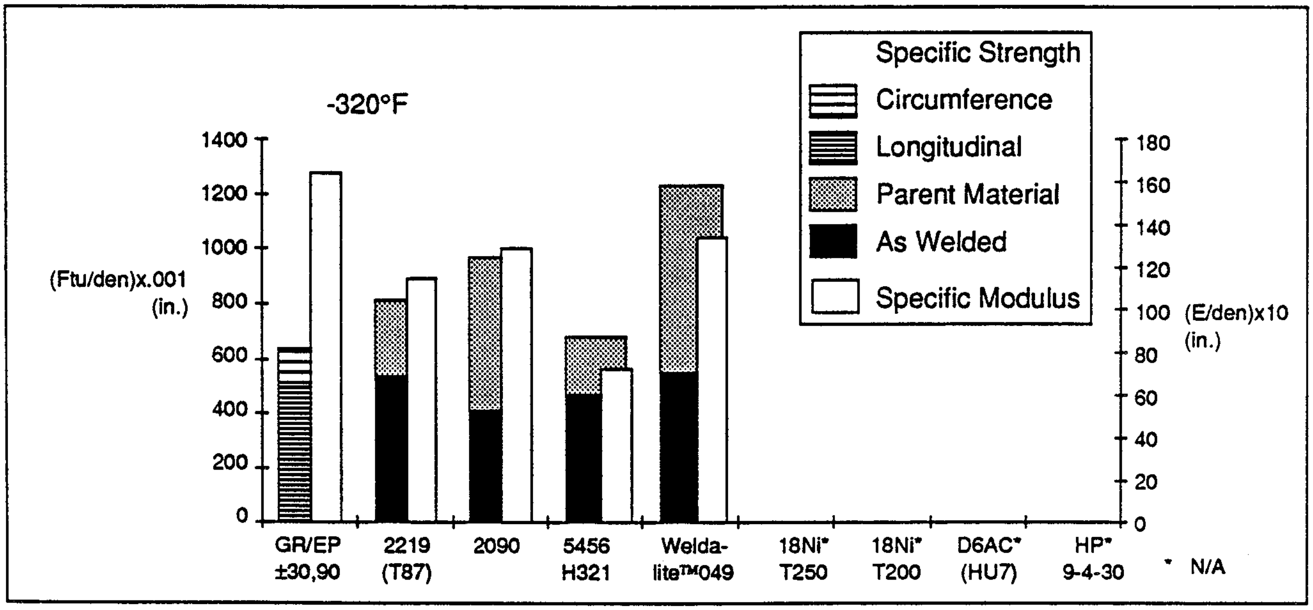


Figure 6.5.1.3-2 Material Properties

Table 6.5.1.3-3 Structural Weight Comparison Estimates for Selected Materials

Material	Nose Cone	Fwd Skirt	Fwd Tank	Inter tank	Aft Tank	Aft Skirt	Total (lb)	Δw
2219 Al	760	6710	11020	4530	9370	16940	49330	+8300
5456 Al	720	7130	10660	4270	9790	15490	48060	+7030
2090 Al-Li	660	6250	9450	3910	7890	15100	43260	+2230
Weldalite™049	670	5910	9450	3980	7650	13370	41030	-
18 Ni-T250	810	7360	17670	6250	15820	14720	62630	+21600
18 Ni-T200	810	7810	17670	6250	15820	16660	65020	+23990
Hp 9-4-20	805	7870	17490	6180	15660	16800	64805	+23775
Hp 9-4-30	795	7680	17310	6120	15500	15700	63105	+22075
D6AC ST	780	7830	16970	6000	15190	16290	63060	+22030
301 St-St	830	8440	18050	6380	16160	17110	66970	+25940

cryogenic applications. At that time, composite tankage was dropped from the LRB study. Structural weights for the steel alloys, as shown in the Table, were completed while the baseline propellants were storable N204/MMH. When the cryogenic LO2/RP-1 propellant combination was the propellant trade study, consideration of the steel alloy materials was also stopped.

From the total weights, the Weldalite™049 was clearly the lowest weight but 2090 AL-LI & 2219 aluminum were close behind. When subsequent design definition was completed, weight of the vehicle had increased. Review of the materials showed that all the materials had proportional weight increases and Weldalite™049 was still the winner.

Additional work in the Part 3 extension showed that the 2219 aluminum alloy could be optimized to a sufficient degree that mission requirements would be met, but payload reserve was less than Weldalite™049. The final choice for the pump-fed vehicle was the Weldalite ™049 with the 2219 as a backup. Use of Weldalite™049 enhances the pump-fed vehicle performance.

Although a new alloy and early in its development phase, Weldalite™049 has raised considerable interest in the aluminum and aerospace industries. At this time, it appears that all development and testing on this material will be completed by the time that pump-fed vehicle construction begins. If the alloy is not ready, 2219 can be substituted.

6.5.2 Thermal Analysis and TPS

LRB TPS—The Thermal Protection System (TPS) for the LRB must prevent ice formation, maintain propellant quality while on the pad and protect the vehicle structure against aeroheating and base heating during ascent. LRB thermal environments were discussed in Section 5.1.2. Analysis gave a baseline TPS configuration of 0.5" SLA (Super Light Ablator) in the high aerodynamic heating regions and 1.0" SOFI (Spray-on Foam Insulation) on the cryogenic tankage to prevent icing and maintain propellant quality. The high heating regions are the nosecone, the forward and aft interface attachment areas, and the aft skirt. Baseline TPS for LRB's is shown in Figure 6.2.9-1.

STS Impact—As discussed in Section 5.1.2, the bow shock wave from LRBs will impinge on the ET LO2 tank (Figure 6.5.2-1) amplifying the heating tiles. Impact of this to ET TPS will have to be addressed in the next phase.

6.5.3 Propulsion Analysis

Propulsion Analyses were performed to support propulsion system trade studies (Section 4.3) and pump-fed propulsion system design (Section 6.3).

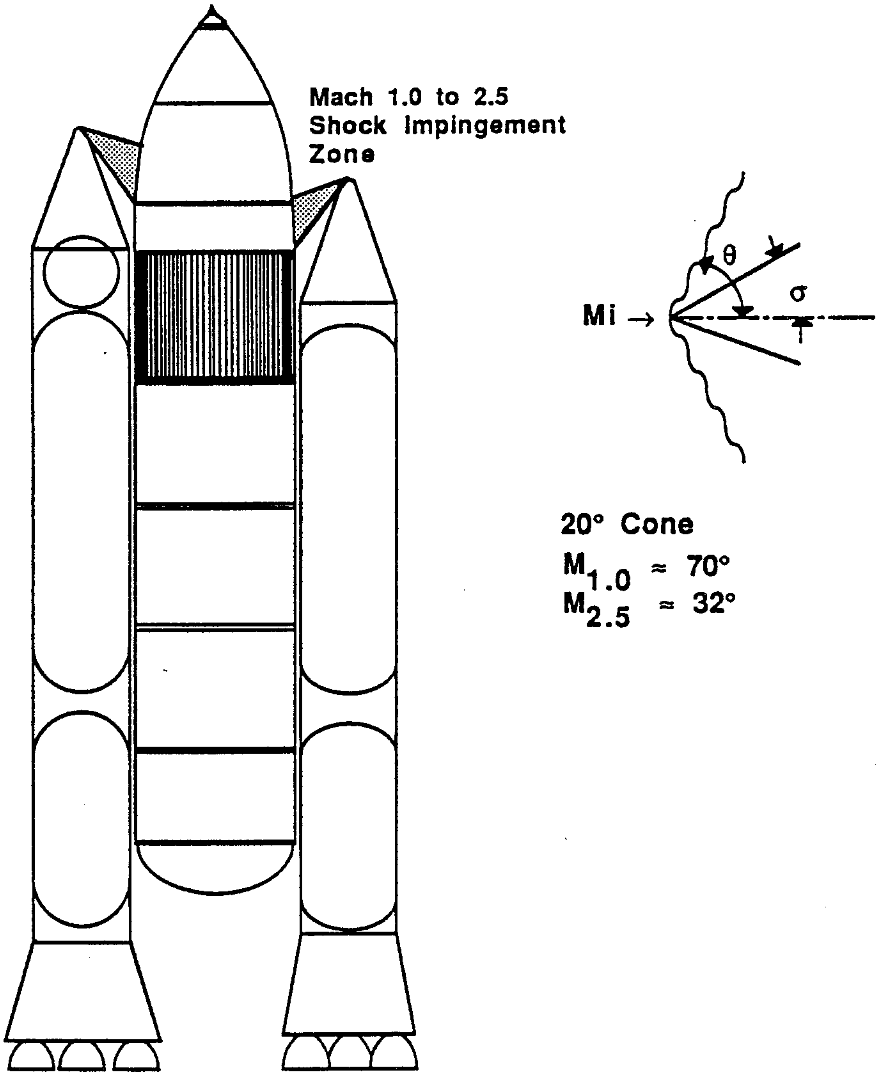


Figure 6.5.2-1 LRB Shock Impingement Zones on ET

Analyses for the pump-fed engine requirements and design is summarized in Section 6.3.1, Turbopump-Fed (TF) Engine. Complete documentation of the engine analyses and design is contained in Appendix L, LRB Engine Status, Aerojet Tech Systems.

The system requirements for the other propulsion subsystems, i.e. pressurization, TVC, fluid and gas interfaces, separation, etc., are presented with their designs in Sections 6.3.2 through 6.3.8.

7.0 LRB DESCRIPTION - PRESSURE-FED

7.1 GENERAL CONFIGURATION

7.1.1 Shuttle/LRB Vehicle Pressure-Fed

The STS with a pressure-fed liquid rocket booster is presented in Figure 7.1.1-1. The solid rocket boosters are replaced with liquid boosters which have four 750K pound thrust engines that use LO2 and RP-1 as propellants. This configuration was selected as the optimum pressure-fed design to meet the requirements specified in the LRB for the STS definition study.

7.1.2 LRB

The optimum pressure-fed liquid rocket booster for the STS is defined in detail in the following paragraphs. Figure 7.1.2-1 presents an overview of the pressure-fed structural arrangement. The booster is approximately 162.7 feet in length and 16.2 feet in diameter. The aft skirt flares to 25.8 feet at the STS mobile launch pad structural interface. Appendix J contains the detailed engineering drawings for the pressure-fed LRB.

7.1.3 Mass Properties

Mass Properties are presented for the Pressure-Fed Liquid Rocket Booster (LRB) and the NSTS/LRB launch vehicle system configuration in this section. Table 7.1.3-1 presents the LRB dry weight mass properties and Table 7.1.3-2 shows how the NSTS/LRB (GLOW) was developed. The reference coordinate system is shown in Section 2, Figure 2.1.1-1.

Mass properties data presented in Table 7.1.3-3 are the complete NSTS/LRB launch vehicle system properties from light-off through LRB separation taken in 10 sec intervals. The data shows the propellant usage schedule for the shuttle system which was used the performance and trajectory analysis. Although only the ET fuel and oxidizer propellant weights are shown in Table 7.1.3-3, the total weight shown includes the usage of LRB propellant.

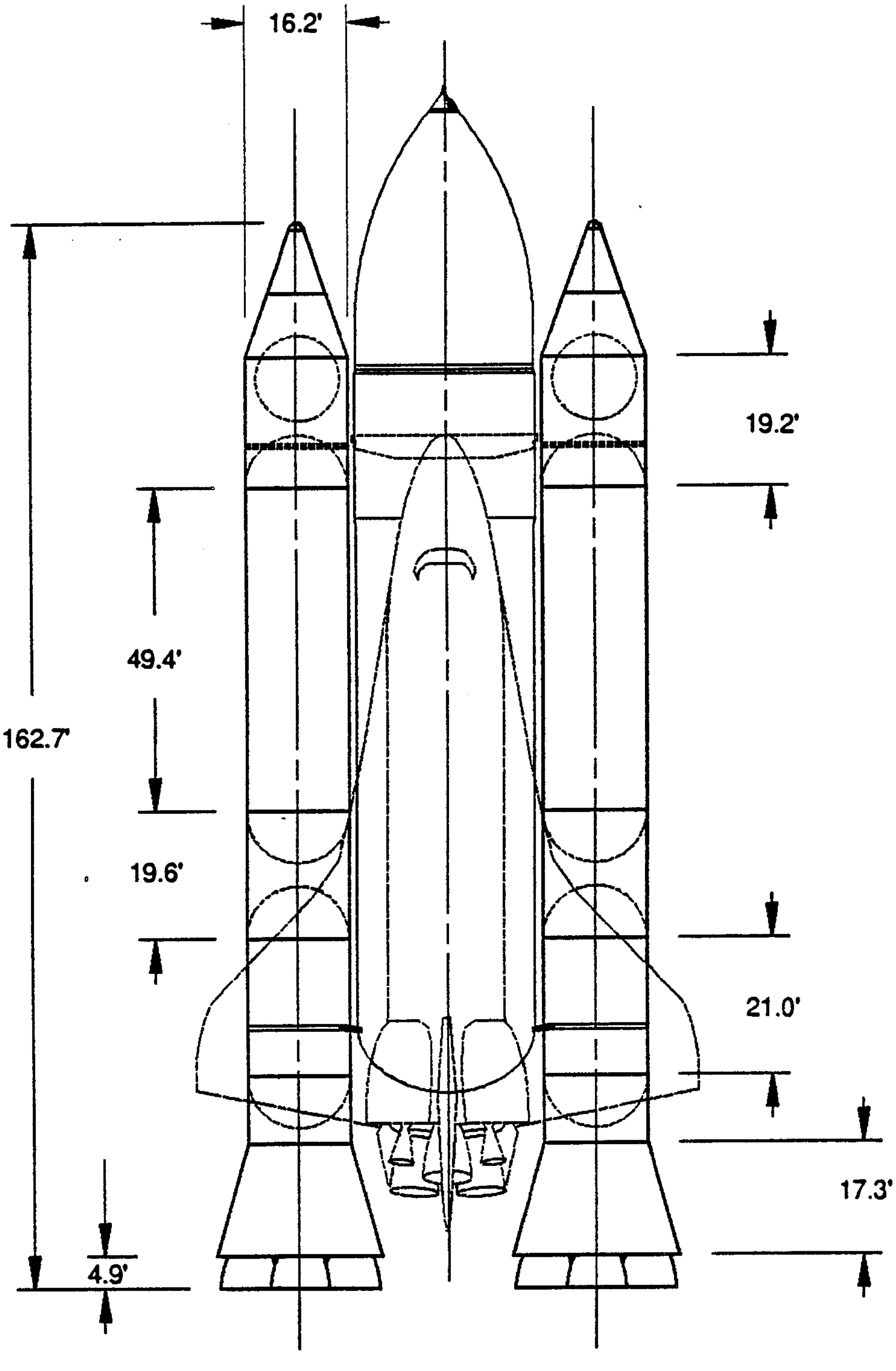


Figure 7.1.1-1 STS with Pressure-Fed Liquid Rocket Booster

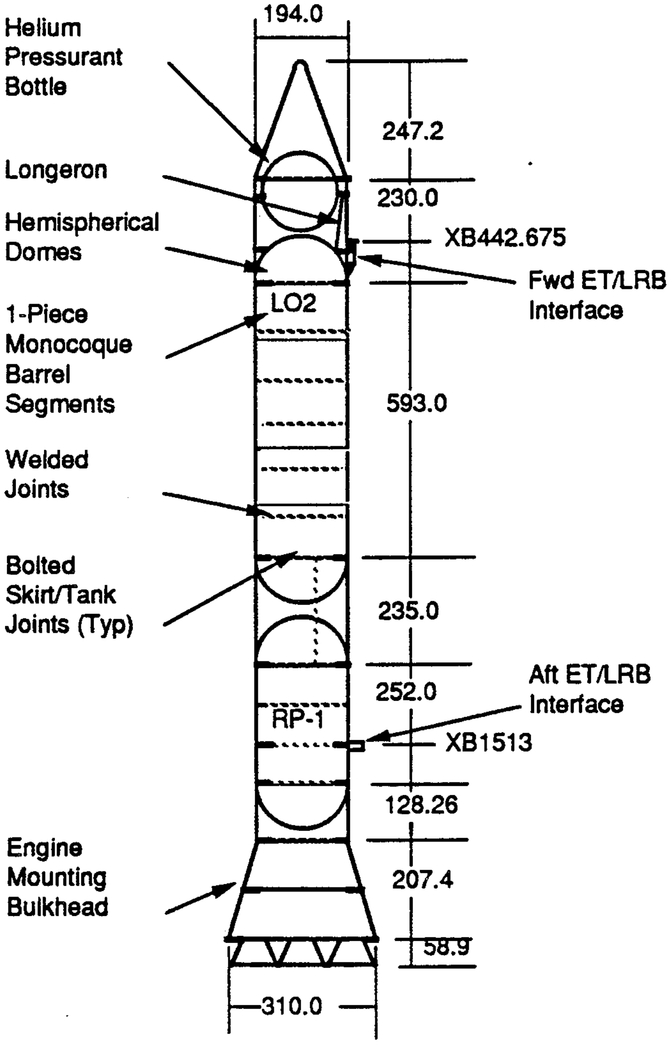


Figure 7.1.2-1 Pressure-Fed Structural Arrangements

Table 7.1.3-1 Pressure-Fed Dry Weight Material Properties

Item	Weight (lb)	Center of Gravity (in.)			Radius of Gyration (in.)		
		x	y	z	kx	ky	kz
Nose Cone	2,010	199.3	0.0	0.0	68.8	80.6	80.6
Forward Skirt	9,900	393.3	10.3	0.0	94.5	90.4	94.9
Forward Tank - LO2	62,220	813.3	0.0	0.0	93.6	228.5	228.5
Intertank	6,780	1225.5	0.0	0.0	96.1	90.8	90.8
Aft Tank - LH2	37,250	1471.7	0.0	0.0	90.7	134.3	134.3
Aft Skirt	31,990	1809.6	0.0	0.0	120.4	119.1	119.1
Structure	150,150	1171.6	0.7	0.0	99.2	495.1	495.2
Propulsion System	40,450	1321,0	-4.6	-4.6	84.4	695.0	695.0
TVC System	720	1732.5	0.0	0.0	86.7	119.7	119.7
Thermal/Acoustical Protection	2,420	1348.8	0.0	0.0	109.5	607.9	607.9
Separation System	1,520	970.0	0.0	97.0	17.7	730.1	730.3
Avionics	3,170	1109.4	-8.0	8.0	97.0	479.4	479.4
I/F Attach	1,450	977.8	97.0	0.0	4.1	535.2	535.2
Range Safety	150	1285.0	0.0	0.0	8.2	8.2	8.2
Contingency (10%)	20,000	1202.1	0.2	-0.1	0.0	0.0	0.0
Total Dry Weight	220,030	1202.1	0.2	-0.1	92.0	523.8	523.9

Table 7.1.3-2 Pressure-Fed Weight Summary

Item	Weight (lb)			
	LRB (2)	ET	Orbiter	P/L
Dry Weight	440,460	66,620	176,210	70,500
Management Reserve				2,350
Usable Implulse Propellant	2,196,000	1,590,060		
Propellant - Usable Press System	49,440			
Propellant Residual	11,820	4,630	2,380	
Pressurant	21,200	420		
Propellant - Reserve		2,220	2,780	
Other		490	26,860	
Lift-Off Weight	2,718,520	1,664,440	208,230	72,850
Vehicle Lift-Off Weight		4,664,040		

Table 7.1.3-3 NSTS/LRB Pressure-Fed Launch Vehicle System Properties

NSTS/LRB
At Liftoff

Total Weight	Propellant	Weight	Level
4,530,757			
	Fuel	229,638	1,081.98
	Oxydizer	1,367,983	458.14

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,346.22	.26	420.90
	49,865,136.48	276,575,242.64	312,915,856.63
	42,267.70	10,635,446.13	51,163.98
	.07	2.31	.01

NSTS/LRB
At 10 sec

Total Weight	Propellant	Weight	Level
4,275,712			
	Fuel	225,075	1,105.62
	Oxydizer	1,340,479	482.95

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,354.07	.27	422.14
	46,217,192.40	266,003,786.96	298,747,782.03
	42,267.70	10,635,446.13	51,163.98
	.07	2.31	.01

NSTS/LRB
At 20 sec

Total Weight	Propellant	Weight	Level
4,020,486			
	Fuel	220,437	1,127.34
	Oxydizer	1,312,551	502.90

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,359.49	.29	423.55
	42,565,965.48	256,006,674.20	285,156,901.25
	41,597.24	10,364,224.19	47,809.32
	.08	2.44	.01

NSTS/LRB
At 30 sec

Total Weight	Propellant	Weight	Level
3,765,260			
	Fuel	215,800	1,148.53
	Oxydizer	1,284,624	519.92

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,361.99	.31	425.15
	38,910,843.16	246,371,175.05	271,931,096.61
	41,193.84	10,313,099.51	47,177.16
	.09	2.53	.01

Table 7.1.3-3 NSTS/LRB Pressure-Fed Launch Vehicle System Properties

NSTS/LRB
At 40 sec

Total Weight	Propellant	Weight	Level
3,565358			
	Fuel	211,163	1,169.65
	Oxydizer	1,256,696	535.04

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,363.30	.33	426.56
	36,159,299.73	238,097,406.23	260,963,844.67
	40,837.56	10,286,345.64	46,846.35
	.10	2.61	.01

NSTS/LRB
At 50 sec

Total Weight	Propellant	Weight	Level
3,376,245			
	Fuel	206,525	1,190.78
	Oxydizer	1,228,768	548.81

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,363.04	.35	428.04
	33,581,638.54	230,033,449.16	250,383,026.41
	40,461.66	10,291,660.11	46,912.07
	.11	2.71	.01

NSTS/LRB
At 60 sec

Total Weight	Propellant	Weight	Level
3,198,664			
	Fuel	201,888	1,211.90
	Oxydizer	1,200,840	561.56

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,361.33	.37	429.60
	31,190,110.41	222,069,216.14	240,090,686.93
	40,068.22	10,326,692.46	47,345.24
	.13	2.82	.01

NSTS/LRB
At 70 sec

Total Weight	Propellant	Weight	Level
2,999,134			
	Fuel	197,251	1,233.02
	Oxydizer	1,172,913	573.52

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,355.46	.39	431.57
	28,433,182.67	213,123,456.03	228,468,492.97
	39,570.57	10,446,631.07	48,828.28
	.15	2.98	.02

Table 7.1.3-3 NSTS/LRB Pressure-Fed Launch Vehicle System Properties

NSTS/LRB
At 80 sec

Total Weight	Propellant	Weight	Level
2,799,232			
	Fuel	192,613	1,254.15
	Oxydizer	1,144,985	584.84

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,345.93	.42	433.83
	25,664,375.24	203,516,377.58	216,184,801.61
	39,000.84	10,641,315.58	51,235.56
	.18	3.19	.02

NSTS/LRB
At 90 sec

Total Weight	Propellant	Weight	Level
2,599,330			
	Fuel	187,976	1,275.27
	Oxydizer	1,117,057	595.63

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,312.29	.49	439.46
	20,103,741.44	181,099,135.29	188,437,291.59
	37,576.60	11,328,965.05	59,738.35
	.29	3.83	.02

NSTS/LRB
At 100 sec

Total Weight	Propellant	Weight	Level
2,399,429			
	Fuel	183,338	1,296.40
	Oxydizer	1,089,129	605.98

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,312.29	.49	439.46
	20,103,741.44	181,099,135.29	188,437,291.59
	37,576.60	11,328,965.05	59,738.35
	.29	3.83	.02

NSTS/LRB
At 110 sec

Total Weight	Propellant	Weight	Level
2,199,691			
	Fuel	178,705	1,317.50
	Oxydizer	1,061,244	615.96

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,285.57	.53	443.04
	17,310,005.11	167,482,835.69	172,173,712.74
	36,671.13	11,875,020.29	66,490.32
	.45	4.36	.03

Table 7.1.3-3 NSTS/LRB Pressure-Fed Launch Vehicle System Properties

NSTS/LRB
At 120 sec

Total Weight	Propellant	Weight	Level
2,012,444			
	Fuel	174,347	1,337.36
	Oxydizer	1,034,977	625.05

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,249.79	.58	447.05
	14,679,373.54	151,642,673.50	153,866,575.80
	35,659.05	12,606,267.04	75,532.19
	.92	5.13	.03

NSTS/LRB
At 120.9 sec

Total Weight	Propellant	Weight	Level
1,996,307			
	Fuel	173,986	1,339.00
	Oxydizer	1,032,806	625.79

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,243.99	.59	447.43
	14,450,219.49	148,519,288.56	150.529,581.82
	35,562.95	12,724,739.38	76,997.10
	1.01	5.30	.03

NSTS/LRB
Jettisoned

Total Weight	Propellant	Weight	Level
1,561,867			
	Fuel	173,986	1,339.00
	Oxydizer	1,032,806	625.79

(in.) CG	X	Y	Z
(slug-sq ft) I	XX	YY	ZZ
(slug-sq ft) P	YZ	XZ	XY
(deg) Alpha	YZ	XZ	XY
	1,114.42	.75	460.62
	6,408,663.77	97,208,802.85	92,420,731.98
	32,229.13	15,372,669.80	109,738.77
	-.39	9.83	.07

Table 7.1.3-3 NSTS/LRB Pressure-Fed Launch Vehicle System Properties

ET at LRB Ignition

	(in.) CG	X	Y	Z
	(slug-sq ft) I	XX	YY	ZZ
Total Weight	(slug-sq ft) P	YZ	XZ	XY
	(deg) Alpha	YZ	XZ	XY
1,665,159		875.70	.60	402.10
		441,294.00	48,865,586.77	48,804,503.98
		34,720.00	585,345.00	132,558.00
		-24.33	.69	.16

Orbiter at LRB Ignition

	(in.) CG	X	Y	Z
	(slug-sq ft) I	XX	YY	ZZ
Total Weight	(slug-sq ft) P	YZ	XZ	XY
	(deg) Alpha	YZ	XZ	XY
208,229		1,867.40	-.20	714.10
		932,071.00	7,051,976.06	7,335,525.41
		-1,416.00	241,639.00	9,996.00
		-.29	2.16	.09

7.2 STRUCTURES

7.2.1 Nosecone

The nose cone serves to provide an aerodynamic shape and support avionics equipment and the separation motor package. It is a mechanically fastened skin and stringer assembly reinforced with ring frames measuring 247.2 ins. long, and weighs 2010 lb.. The skin is brake formed and the ring frames are formed extrusions. Skin thickness increases from 0.09 in. at the cone apex to 0.24 in. at the cone base and the ring cross-section areas increase from 1.56 sq. ins. to 2.22 sq. ins. in like fashion. Frames divide the structure into eight bays capped with a nose cap. It is fabricated in two, fore and aft, conical sections. The separation package, which delivers an aft and outward acting thrust relative to the External Tank, is mounted on the aft three ring locations of the nose cone.

7.2.2 Fwd Skirt & Thrust Beam Assembly

The forward skirt serves to connect the nose cone to the oxidizer tank, house the helium pressurant tank and transfer the forward ET/LRB Interface loads into the LRB. It is 230.0 ins. long, 194.0 ins. in diameter, has a thickness of 0.55 in. and weighs 9900 lb.. Due to the volume occupied by the helium pressurant tank, incorporation of a cross-beam, as in the pump fed forward skirt, was not feasible and a configuration similar to that used in the SRB was adopted. This consists of a ring-stiffened monocoque shell with a longeron spanning two of the rings. The longeron distributes the longitudinal loads into the shell, and acts as a beam to transfer moment, shear and torsion from radial and circumferential loads and moment from the axial load offset from the shell wall, into the supporting frames and thence to the shell. The pressurant tank is trunnion-mounted on support longerons mounted between the frames. The tank is free to slip in the radial direction at one side of the trunnion, thus allowing for thermal expansion differences. The longeron is of built-up box section, and the shell is monocoque. Integrally machined roll-ring forged end flanges allow the skirt to interface the nose cone and oxidizer tank.

7.2.2.1 Helium Pressurant Tank

The helium pressurant tank provides storage for the pressurant mass required to pressurize the oxidizer and fuel tanks. Its 12 ft. diameter hemispherical domes consist of heavy walled, hot spin formed halves. Tank thickness is 1.7 ins. and weld lands are 3.3 ins.. Polar-mounted, bolt-on trunnion fittings mount the pressurant tank to the fwd skirt. External foam insulation is applied to the tank to minimize pressurant conditioning results.

7.2.3 Oxidizer Tank

The tank consists of two hemispherical domes and six flow turned and integrally machined barrel sections. It is designed to hold 773,800 lb. of oxidizer, has a length of 787 ins., an outside diameter of 194.0 ins., a volume of 11,940 cu. ft. and an empty weight of 62,220 lb.. Fabrication of the forward dome is begun with an open die forged and machined 80 in. diameter dome cap. Eight 45 degree dome gore panels, open die forged and contour milled to a minimum of 0.65 in. thick, are welded together and to the dome cap assembly. A manhole assembly is integrally machined in the dome gore panel. Weld lands in the domes are approximately twice as thick as the membrane, as dictated by parent and weld metal strengths. Interface flanges, which are integrally machined roll ring forgings, are welded to the dome. Interior ring frames are mechanically assembled to the interface flanges. Fabrication of the aft dome is similar except that a manhole is not needed. The tank consists of six roll forged turned barrels integrally machined to a thickness of 1.28 ins.. No intermediate frames are required due to the stiffness of the barrel sections.

7.2.4 Intertank

The intertank is a welded monocoque structure made up of three 120 degree segments rolled from mill stock plate. It is 194 ins. in diameter, 235 ins. long and weighs 6780 lb.. The shell thickness is 0.55 in.. Attachment flanges are welded at the fore and aft ends. Weld joint thicknesses are the same as that of the shell since the shell thickness is based on stiffness rather than strength. Penetrations and the local reinforcing around the access panel cutouts are provided.

7.2.5 Fuel Tank

The tank consists of two hemispherical domes, an intermediate frame and roll forged turned and integrally machined barrel sections. It is designed to hold 289,800 lb. of fuel, has a length of 446 ins., an outside diameter of 194.0 ins., a volume of 6300 cu. ft. and has an empty weight of 37,250 lb.. Fabrication of the forward dome is begun with an open die forged and contour machined 80 in. diameter dome cap. A manhole assembly is integrally machined in the dome gore panel. Weld lands in the domes are approximately twice as thick as the membrane, as dictated by parent and weld metal strengths. Interface flanges, which are integrally machined roll ring forgings, are welded to the dome. Interior ring frames are mechanically assembled to the interface flanges. Fabrication of the aft dome is similar except that no manhole fitting is needed. The tank consists of three roll forged barrels integrally machined to a thickness of 1.28 ins.. An intermediate frame is provided at the ET interface.

7.2.6 Aft Skirt/Thrust Structure

The Aft Skirt/Thrust Structure is a welded and mechanically fastened structure. The overall length is 335.6 ins., which includes a 128.3 in. long, 194 in. diameter cylinder at top, flaring out into the cone with a base diameter of 310.0 ins.. It is manufactured in quarter sections, each consisting of four cone panels and one hold down post. The engine mount platform is 106.4 ins. fwd of the base. Frames are located at the top, the cylinder/cone transition, the engine mount platform at mid-cone and the base. Four tapered and forged longerons are attached to the shell equally spaced between the posts. The thickness of the upper cylinder is 0.65 in. and the cone is 0.7 in. for a weight of 31,990 lb..

7.2.7 Structural Interface

See Section 6.2.7

7.2.8 Cable Trays/Fairings

See Section 6.2.8

7.2.9 Thermal Protection

See Section 6.2.9

7.2.10 Acoustic Protection

See Section 6.2.10

7.2.11 Major Ground Test

See Section 6.2.11

7.3 PROPULSION/MECHANICAL

7.3.1 Pressure Fed (PF) Engine

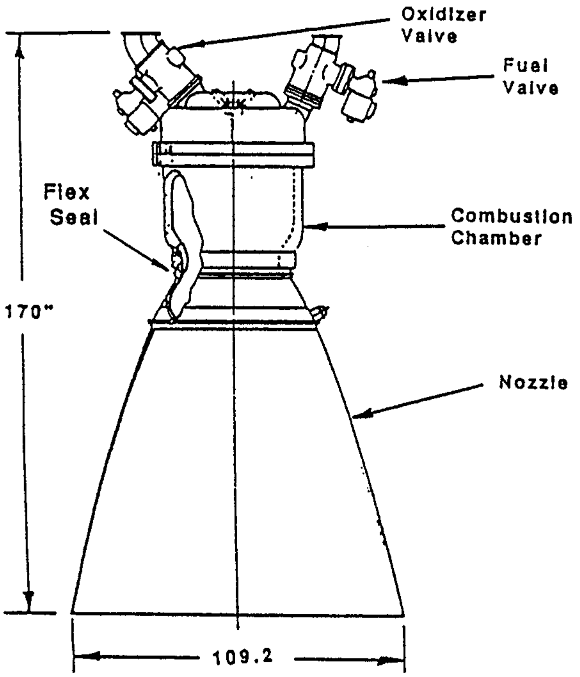
The pressure fed engines develop 750 Klbf thrust at sea level. The engine chamber pressure of 660 psia was selected to minimize engine size, cost, and stability concerns. The 1000 psia inlet pressure for both LO2 and RP-1 is provided by maintaining a corresponding ullage pressure in each tank with gaseous helium. Active thrust chamber cooling is not required because of the use of a silica phenolic ablative thrust chamber. Figure 7.3.1-1 illustrates the LRB PF engine.

7.3.1.1 Ablative Thrust Chamber Assembly (TCA)

The TCA will be similar in construction to the M-1 ablative thrust chamber, Figure 7.3.1.1-1, in baseline material type and configuration. The silica phenolic material is a tape-wrap system based upon the use of silica fiber impregnated with high temperature phenolic resin containing silica fiber.

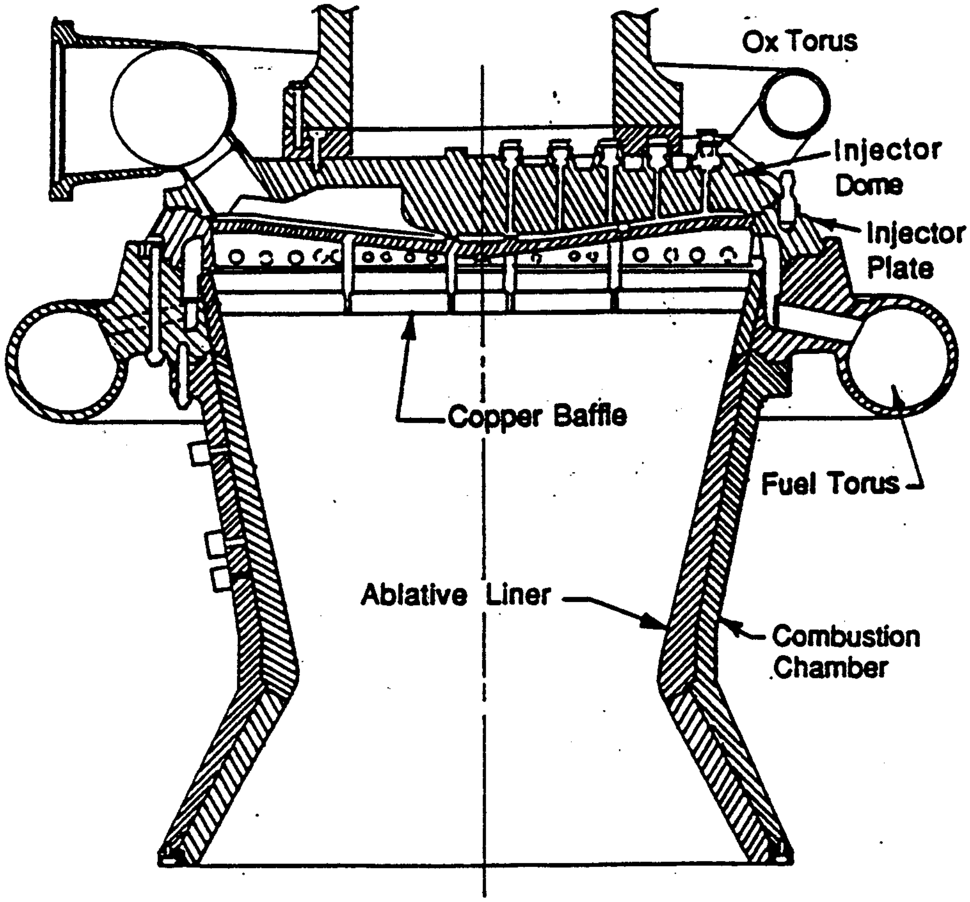
Ablative cooling combined with utilization of carbon-carbon high temperature combustion components makes the pressure fed engine attractive for a booster application where low cost and minimum operational complexity are desired. The ablatively cooled chamber approach permits higher chamber pressures for a given tank pressure and therefore the opportunity to exploit engine performance in the same envelope is greatly enhanced.

A materials study included phenolics and carbon-carbon for the PF thrust chambers. Joining, attachment flanges, flex seal design, and other disciplines were studied. The thrust chamber and nozzle extension are considered as two separate parts for ease of construction, quality control, and the ability to select materials. An ablative composite within a structural shell is the preferred configuration. One of the most important factors in the selection of materials for the PF LRB is the ablative materials erosion and charring response to exhaust gases. The major reactive chemical species are H_2O, CO_2, H_2, and OH (Table 7.3.1.1-1). These exhaust gas species were compared to those of other propulsion systems. Because the other systems produce comparable reactive species, these can be used to guide the material selection. Typically, silica phenolic recedes much less than carbon phenolic for the anticipated LRB exhaust gas cases. For the LRB scenario, the anticipated total degradation with fuel film cooled silica phenolic as a thrust chamber liner is 0.72 in.



	NPL	FPL
Thrust, S.L. klbs	535	750
Thrust, Vac klbs	672	887
ISP, S.L. sec	253.1	270
ISP, Vac, sec	318	319
Mixture Ratio	2.67	2.67
Total Flow Rate, lb/sec	2113	2773
Chamber Pressure, Psia	499	660
Exit Pressure, Psia	8.97	11.7
Expansion Ratio	11.47	
Chamber Type	Ablative	
Nozzle Type	Ablative	
Weight, Dry, lbs	4500	
Propellants	LO2/RP1	
Gimbal Angle	±6°	
Gimbal Type	Head End Flex Seal (Optional)	
Throttle Range	65 - 100%	

Figure 7.3.1-1 LO2/RP1 LRB Pressure-Fed Engine



D_t =76.2cm (30.0in)
D_c=96.5cm (38.0in)

Figure 7.3.1.1-1 M-1 Ablative Thrust Chamber

Table 7.3.1.1-1 Comparison of LRB with Other System's Exhaust Species

System	Pc (psia)	H2O	CO2	OH	H2	Other
LRB (LO2/RP-1)	800	33	16	7	11	33
M1 (LO2/LH2)	1000	66	0	4	25	5
Titan IV, Stage 2 (NTO/A50)	800	39	5	3	8	45
PBPS (NTO/N2H4)	300	44	0	3	12	41
Delta (Transtage) (NTO/A50)	100	39	5	3	8	45

7.3.1.2 Injector

The compelling injector design considerations have been stability and performance. Figure 7.3.1.2-1 and -2 show the PF injector preliminary design concept. The chamber pressure of 660 psia with 0.20" orifices provides the required chug stability but requires that the upper range frequency modes be damped. The chamber diameter of 44.4", throat diameter of 32.2" contraction ration of 15 degrees, combustion chamber length of 40.0", and desired contraction ration of 1.90 are consistent with past successful designs. Three PF engine configurations (Table 7.3.1.2-1) were studied to identify the best compromise in performance vs stability. Based on the analysis results, "Engine 3" was selected. This engine, at Pc = 660 psia and 0.20" orifices, permits cast injector fabrication with low cost drilling manufacturing techniques.

Three stability aid configurations were examined, as identified in Table 7.3.1.2-2. The recommended method C is also the least expensive to implement. Since the F-1 rocket engine development, better analysis models, proven subscale verification techniques, improved injector element configurations, and well developed acoustic resonators are now available. Combustion stability was a major problem during the F-1 development, stability problems were discovered late in the program, and the problems were solved through trial and error methods at full scale. The F-1 injector pattern was a spin-off of the smaller size H-1 rocket engine. The belated "solution" involved greatly derated performance through the expediency of using a short multi-bladed baffle.

Now, simple, low cost, high performance and stable LRB engines can be developed. A very large thrust-per-element O-F-O triplet injector is the key to high efficiency/stable combustion with minimum acoustic damping/low cost implementation.

7.3.2 Pressurization System

As part of our LRB Phase A study we recommended a preferred pressurization system concept. This system was selected over numerous other candidates and was driven by the high LRB pressurization requirements (1000 psia, 18,000 ft3 ullage), vehicle packaging limitations, and system safety and reliability. Figure 7.3.2-1 illustrates the basic system operations. The pressurant is stored at 40°R and 3000 psia to minimize both pressurant weight (10,500 lb) and volume (905 ft3). For example, if the pressurant were stored at 225°R, the required pressurant weight would be 13,500 lb and 2250 ft3 at 4000 psia. The technical issues associated with loading and maintaining the pressurant at 40°R prior to launch are resolved by the ground support system design and significantly enhance the pressurization system's performance without affecting the vehicle complexity and weight.

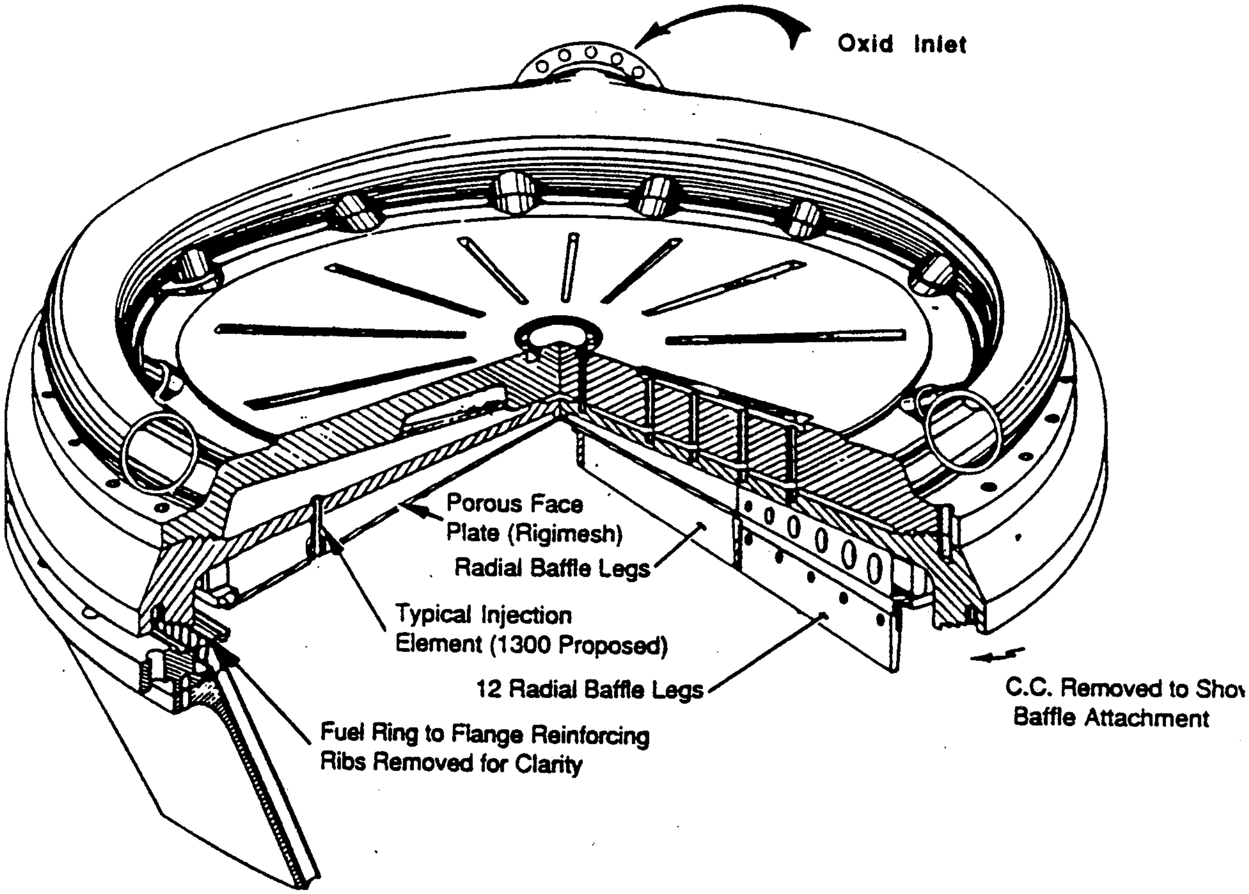


Figure 7.3.1.2-1 M-1 Coaxial Injector, 12-Rib Bolt-on Dome

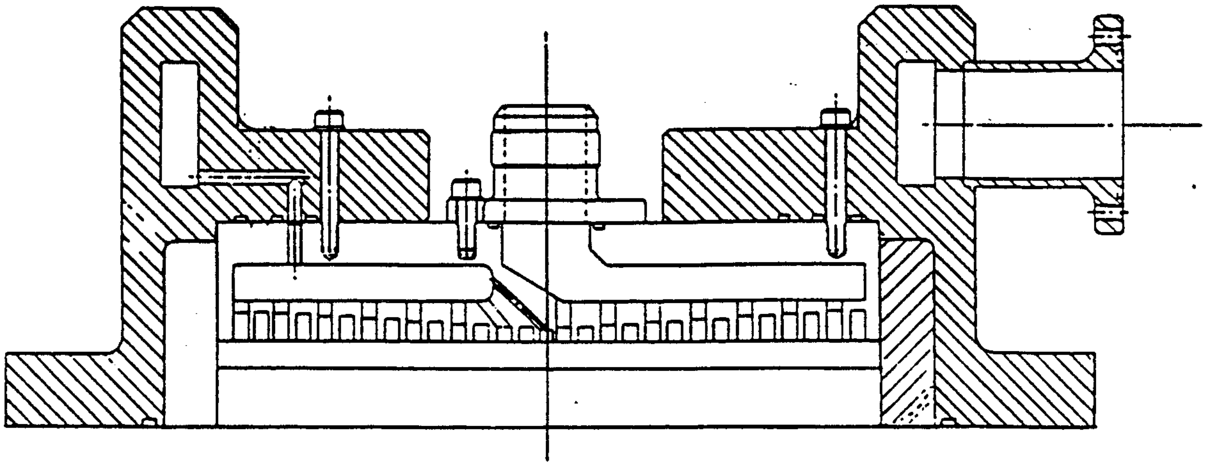


Figure 7.3.1.2-2 Core Concept Injector

Table 7.3.1.2-1 Pressure-Fed Frequency Stability Trades

	Engine 1	Engine 2	Engine 3
Oxygen Supply Pressure (psia)	1000	1000	1000
Chamber Pressure (psia)	800	780	660
Orifice Diameter (in.)	.25	.053	.2
ISP vac (sec)	320	321	318.8
ISP sl (sec)	270	271	270.5
Chug Stability	1191	546	370
High Frequency Modes	1T	1T-5T,1R	1T-3T,1R
	240 Elements	3000 Elements	400 Elements

Table 7.3.1.2-2 Stability Aids Required for Pressure-Fed

Configuration A	Configuration B	Configuration C
3-Bladed Baffle (8" High) & 3T/1R Helmholtz Resonator or 1/4 Wave Cavity (Depth 8.7"/3.8")	5-Bladed Baffle (4" High) & 1T/1R Bituned Helmholtz Resonator or 1/4 Wave Cavity (Depth 8.7"/3.8")	1T/2T/1R/3T截Tritined Helmholtz Resonator or 1/4 Wave Cavity (Depth 8.7"/5.2"/3.8")

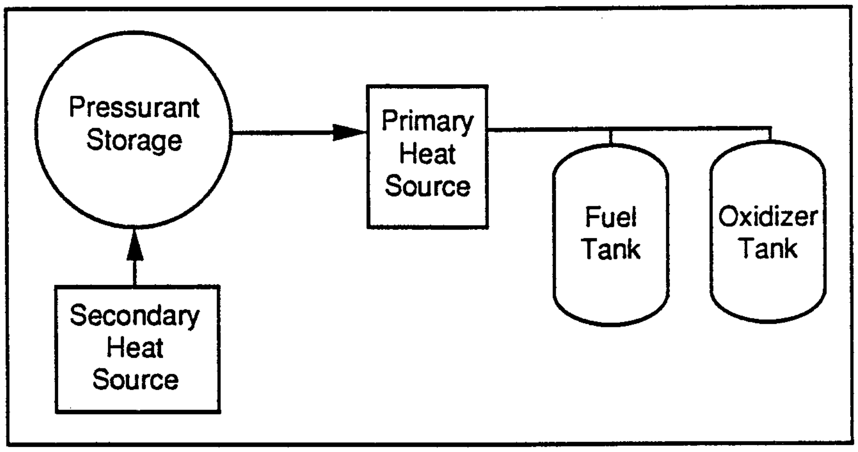


Figure 7.3.2-1 Phase A Pressure-Fed Propulsion System Operation

The baseline LRB system introduces heat into the storage vessel to expel the pressurant during ascent. This secondary heat source, gas generator/heat exchanger, was selected over stored ambient helium because of the ambient helium volume and weight requirements. Although the ambient helium required to expel the pressurant is only 900 lb, an 8.5 ft diameter, 5000 psia vessel is required to store it. The ambient helium storage vessel could weight in excess of 35klb. A catalyst bed was eliminated as a secondary heat source because of the complexity associated with the use of additional propellants to combust in the bed and the technical issues associated with the combustion products mixing with the pressurant gas.

The pressurization system primary heat source is a LO2/RP-1 gas generator/heat exchanger and was chosen because of the propellant availability and overall system simplicity. A primary candidate considered was the H2/O2 catalyst bed, but was eliminated because of the consideration addressed above. Figure 7.3.2-2 presents the system schematic of the LRB baseline system.

7.3.2.1 Gas Generators

The PF LRB gas generator design is similar to the Aerojet gas generator still in production and flown on Titan IV. This injector incorporates the latest technology improvements of the Oxygen/Hydrocarbon Injector Characterization contract for the Air Force Astronautics lab and will utilize existing designs and test data. Both 18" and 8" diameter injectors and chambers have been designed and built for LO2/RP-1 propellants.

The gas generators will be designed to operate at 0.33 mixture ratio to provide 1400 F gas to the helium heating exchangers. This gas generator design is similar to the Titan I gas generator with design features for assuring excellent combustion performance and operational reliability.

7.3.2.2 Heat Exchangers

The preliminary design data of the PF LRB pressurization system heat exchanger is presented in Table 7.3.2.2-1. Two of theses heat exchangers are required per LRB. The baseline heat exchanger design concept is similar to Aerojet's Titan fuel heat exchanger. This flight -type design, consisting of U-shaped bundle of tubes encased in a cylindrical shell is illustrated in Figure 7.3.2.2-1.

7.3.3 Fill, Feed, Drain and Vent Subsystems

The pressure-fed LO2 feedline consists of three major component subassemblies. The LO2 tank outlet,two forward flex sections 17.0 in. dia assembly of solution aged INCO 718 nickel

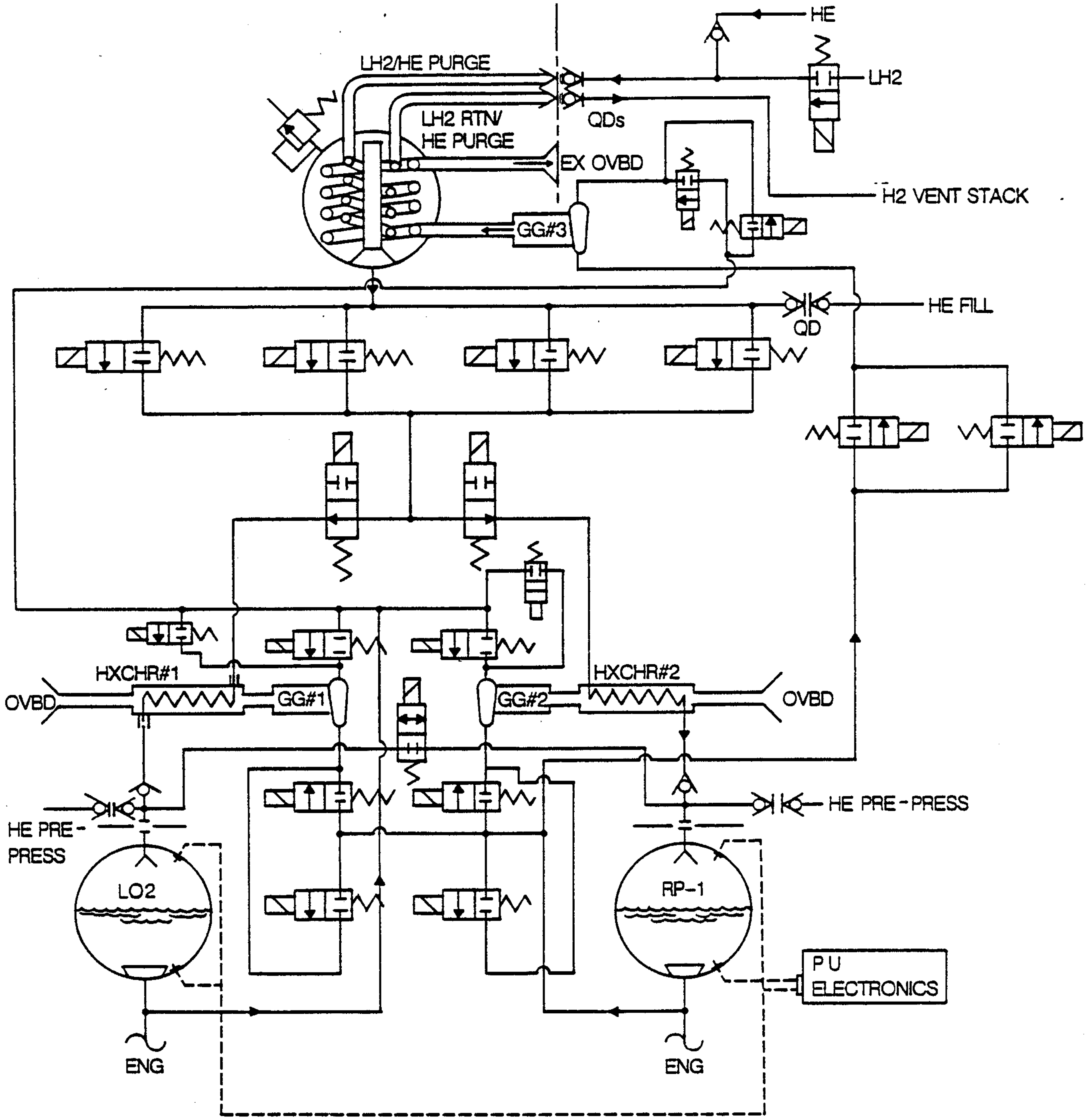


Figure 7.3.2-2 LRB Baseline Pressurization System Schematic

Table 7.3.2.2-1 Pressurization System Heat Exchanger

Total External Dimensions	18"x36"x6"
Total Estimated Weight	1050 lbm
Helium-Side Parameters	52 lbm/sec 40 °R in, 800 °R out 1090 psia in, 1000 psia out
GG/Hot Gas-Side Paramenters	150 lbm/sec 1810 °R in, 1090 °R out 400 psia in, 370 psia out
Heat Transfer Rate	49329 btu/sec

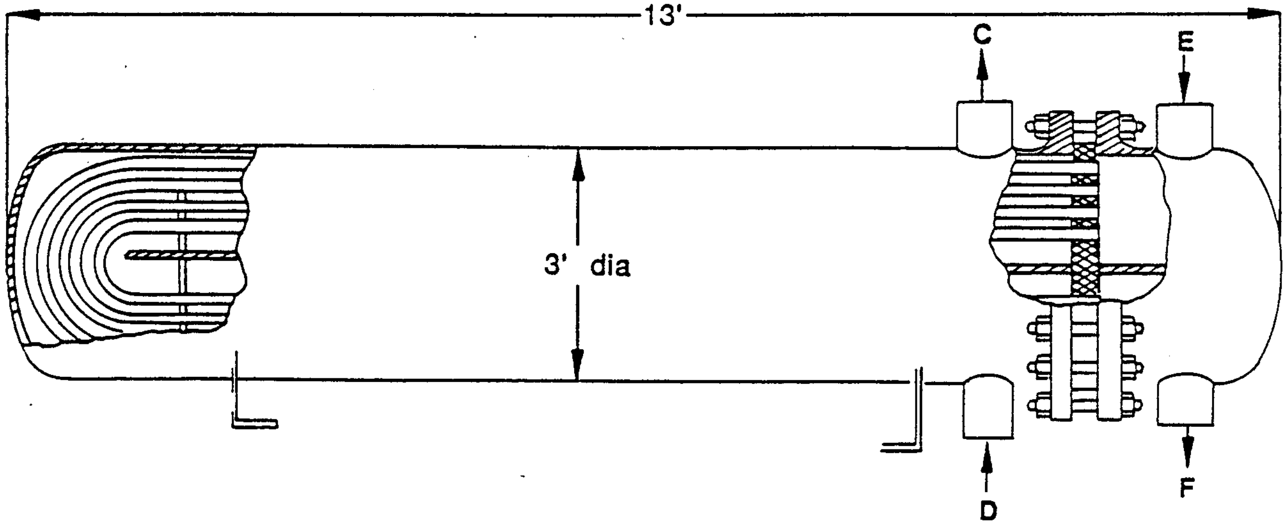


Figure 7.3.2.2-1 Aerojet Fuel Heat Exchanger

base alloy. The feedline then splits into two 17" dia. lines down either side of the RP-1 tank. The forward flex sections contain three internally gimballed flex joints to accommodate both cryogenic and flight induced motions. The straight sections, external to the RP-1 tank are fabricated from Al-Li (Weldalite ™049) or 2219 aluminum alloy. The aft flex section/engine inlet manifold is manufactured from solution aged INCO 718 nickel base alloy, each of the four branches being 12.5 in./dia. and including three internal gimballed flex joints. All segments of the LO2 feedline assembly are coated with TPS. The RP-1 engine outlet manifold assembly is manufactured from solution aged INCO 718 nickel based alloy, each of the four branches being 9.7 in./dia. with three internal gimballed flex joints. Figures 7.3.3-1 - 7.3.3-3 depict the feedline installation for pressure-fed LRB.

7.3.4 Hazardous Gas Detection and Compartment Purge Requirements

Refer to Section 6.3.4

7.3.5 Separation

Refer to Section 6.3.5

7.3.5.1 Booster Separation Subsystem

Refer to Section 6.3.5.1.

7.3.5.2 Release System

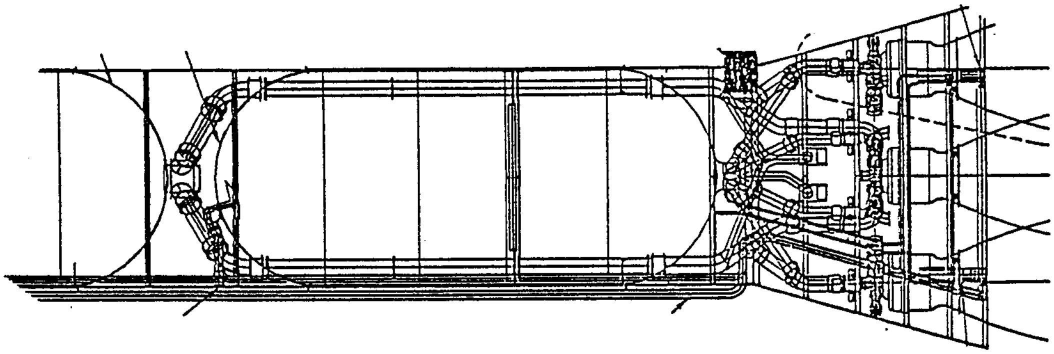
Refer to Section 6.3.5.2.

7.3.5.3 Booster Separation Motor (BSM) Cluster

Refer to Section 6.3.5.3.

7.3.5.4 BSM Critical Features

Refer to Section 6.3.5.4.



Oxidizer Feed System

Oxidizer:	LO2
Diameter:	2 x 17 in. ID
Materials:	Fwd Flex Section - Sol. Aged Inco 718 Mid Straight Section - AL 2219 (Weldalite) Aft Flex Sections - Sol. Aged Inco 718 No. Flex Joints Fwd = 3 Aft = 12 Pre-Valves = 4
Weight:	4134 lbs

Fuel System

Fuel:	RP-1
Diameter:	4 x 9.07 in. ID
Material:	Sol. Aged Inco 718 No. Flex Joints = 12 Pre-Valves = 4
Weight:	2026 lbs

Figure 7.3.3-1 LRB Pressure-Fed Propellant Feed System

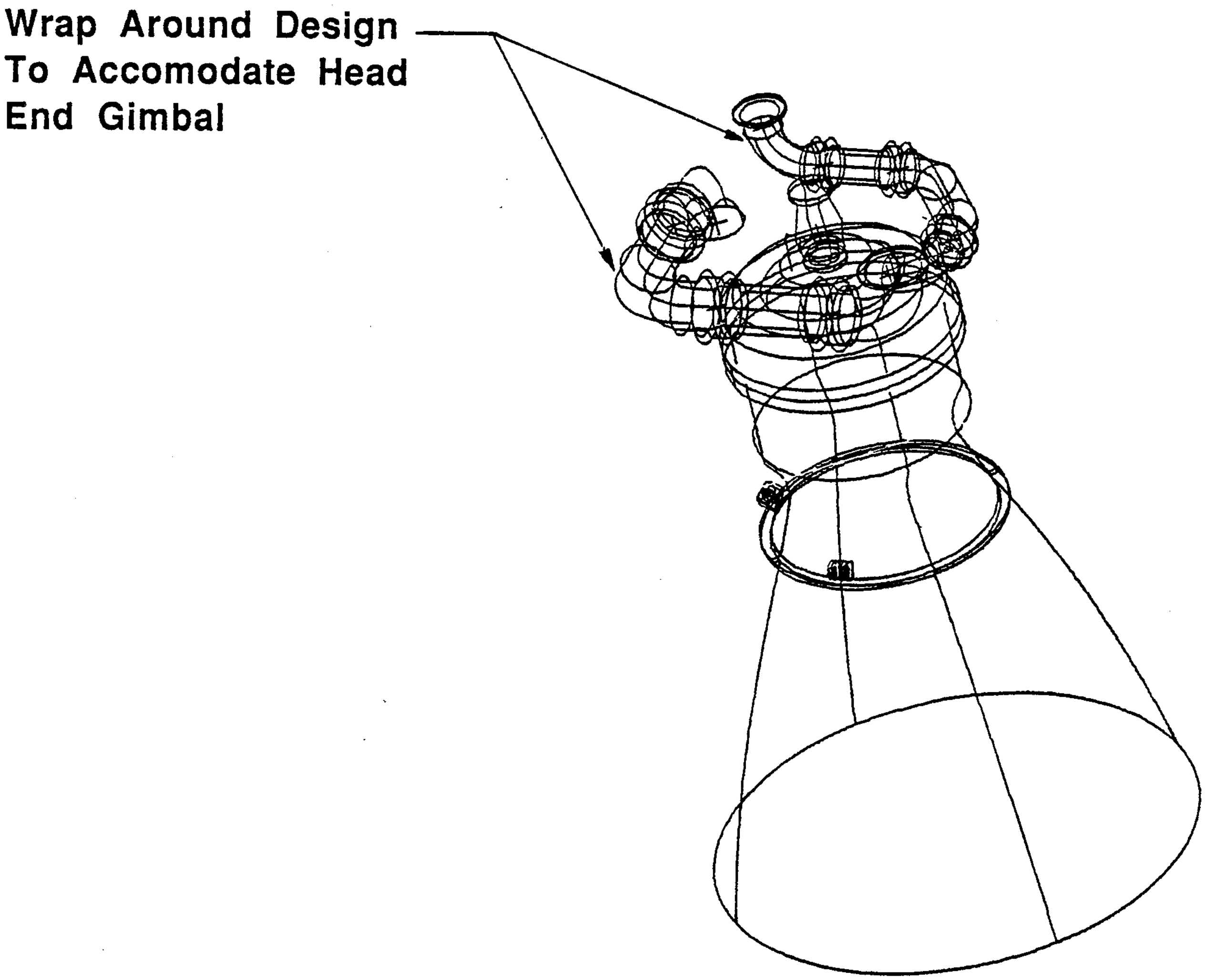
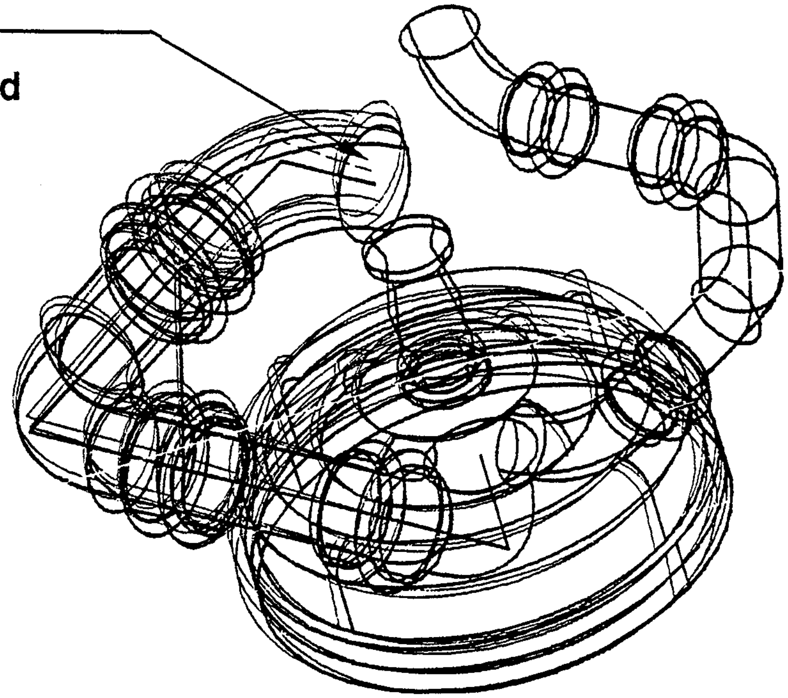


Figure 7.3.3-2 LRB Pressure-Fed Engine Feedline Inlet Design



Maximum Deflection of LO2 Feedline Required to Meet ± 6° Gimbal of Engine in all Directions

Figure 7.3.3-3 LRB Pressure-Fed Engine Wrap Around Feedline Design

7.3.5.5 LRB Separation Sequence

Refer to Section 6.3.5.5.

7.3.5.6 Debris

Refer to Section 6.3.5.6

7.3.6 Thrust Vector Control

Refer to Section 6.3.6.

7.3.7 Interfaces

Refer to Section 6.3.7.

7.3.7.1 LRB Umbilical Assembly (LRBUCA)

Refer to Section 6.3.7.1.

7.3.7.2 Ground Umbilical Carrier Assembly (GUCA)

Refer to Section 6.3.7.2.

7.4 ELECTRICAL/AVIONICS

7.4.1 General Configuration

Pressure Fed LRB electrical and avionics systems are essentially the same as for the Pump Fed LRB described in Section 6.4. Because of this inherent similarity, only the differences between the two configurations will be reported here. For all other details see Section 6.4.

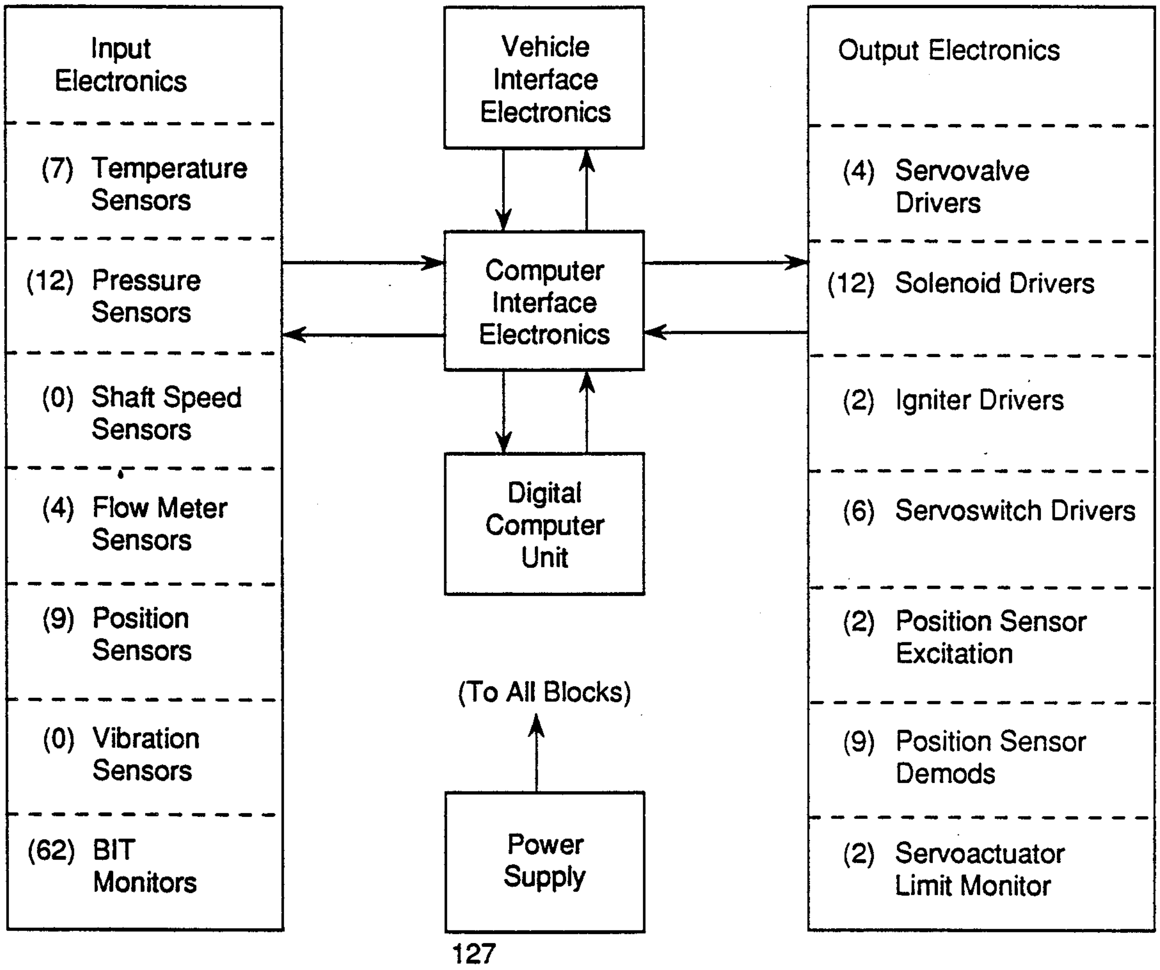


Figure 7.4.2-1 Pressure-Fed Engine Controller

7.4.2 Engine Controller

Pressure Fed LRB engine controller input/output requirements are less than for Pump Fed engines because of the absence of turbo pumps, and associated valving and control functions. A block diagram for a Pressure Fed engine controller is given in Figure 7.4.2-1; comparing to Figure 6.4.2-1 it can be seen that there are fewer input and output electronics for the pressure-fed system .

7.5 SYSTEMS ANALYSES

7.5.1 Structural Analyses

This section presents analysis for the Pressure-Fed LRB structural system. Included in the analyses are; Loads and Dynamics Analysis, Stress Analysis and Materials Evaluation.

7.5.1.1 Loads/Dynamics Analysis

Refer to Section 6.5.1.1

7.5.1.2 Stress Analysis

A separate report entitled Liquid Rocket Booster (LRB) for the Space Transportation System (STS) System Study, Stress Analysis Report for Pump-Fed and Pressure-Fed LRB, Jan. 15, 1989 is attached as Appendix A. This report presents a preliminary design stress analysis of the pump-fed and pressure-fed configurations using the structural design requirements specified in the LRB CEI Specification, Rev. 1 April 1988. These requirements meet those specified in MSFC-HDBK-505A, Structural Strength Program Requirements.

The stress report utilizes vehicle static and dynamic loads presented in section 6.5.1.1 and material properties outlines in section 6.5.1.3. On-pad Max-pitchover, Lift-Off, Max Q and Boost Ascent loading cases along with proof pressure loading conditions and presented.

7.5.1.3 Materials

Trade Studies - Trade studies were conducted during Part 1 of the study program to determine the material best suited for the pressure-fed vehicle and its performance goals. These studies were the same as conducted for the pump-fed vehicle and described in Section 6.5.1.3. A major difference in material requirements between the two vehicle types was caused by the high operating pressure of 1000 psi in the pressure-fed propellant tanks. Pump-fed operating pressures were under 60 psi. The pressure-fed tankage then required material with high specific strength in order to minimize structural weight, minimize propellant volume and weight, and to meet performance goals. The high strength is required at both room temperature and at cryo temperatures. Using the tables and figures of Section 6.5.1.3, Weldalite™049 was the winner based on strength of parent and weld metal.

Results- In the system trade studies described in Section 4.0, Weldalite™049 was the only material that enabled the pressure-fed vehicle to meet its performance goals. When the structural weights for the candidate materials shown in Tables 6.5.1.3-1&2 were used in performance studies, only Weldalite ™049 met the payload requirement within the dimensional constraints put on the vehicle. On this basis, Weldalite™049 was used for the pressure-fed vehicle design.

This material is currently under development but at this time it appears that all development and testing will be completed by the time that the pressure-fed vehicle construction begins. Since use of Weldalite™049 is an enabling technology for the pressure-fed LRB, it has been identified as a technology requirement and is addressed in Section 12.0.

7.5.2 Thermal Analysis and TPS

Pressure-fed LRB thermal analysis and TPS are very similar to the pump-fed LRB discussed in Section 6.5.2. These details will not be repeated here.

TPS requirements of the helium pressurant tank are met by 3 in. SOFI with a weight of 280 lb.

7.5.3 Propulsion Analysis

Propulsion analyses were performed to support propulsion system trade studies (Section 4.3) and pressure-fed propulsion system design (Section 6.3).

Analyses for the pressure-fed engine requirements and design is summarized in Section 7.3.1, Pressure-Fed (PF) Engine. Complete documentation of the engine analyses and design is contained in Appendix L, LRB Engine Status, Aerojet Tech Systems.

The system requirements for the other propulsion subsystems, i.e. pressurization, TVC, fluid and gas interfaces, separation, etc, are presented with their designs in Sections 7.3.2 through 7.3.8.

8.0 LOGISTICS REQUIREMENT

8.1 OVERVIEW

Martin Marietta's approach to logistics support is to influence the design process, identify and develop the support requirements, acquire the necessary resources and provide the support for the minimum cost. The ILS organization is an integral part of the engineering effort evidenced by the fact that logistics has been a factor in the total LRB project. During the Phase A of the LRB study preliminary logistics analyses were performed as part of the system trade studies.

8.2 MAINTAINABILITY REQUIREMENTS

The baseline configurations for the pump-fed and pressure-fed designs, do not appear to have any areas which will have a negative impact on the maintainability of the LRB. Further analysis will be accomplished in Phase B efforts with specific areas being addressed such as built-in-test, accessibility, and STS impacts.

During the detailed design phase of the LRB, an extensive logistics support analysis will identify any latent support problems, determine the total support resources such as spares, training, operation and maintenance manuals, ground support equipment, and other areas as required, and develop a single logistic support database. Maximum usage of current STS assets will form the baseline for the LRB logistics program.

As a part of the STS program, the LRB project will support the Integrated Logistics Panel, the Logistics Verification and Information System and other current STS support programs (KIMs, MSS, STARs, etc.)

8.3 REUSABILITY

During the Phase A study the concept of reusability was evaluated. Both configurations were addressed from three options: totally expendable, partially recoverable, or totally recoverable.

Areas of concern for either a partially or totally recoverable design included reliability, safety, maintenance actions, acceptance test requirements, and life-cycle costs. Due to the amount of refurbishment required, especially in the engine and avionics areas, the decision for a totally expendable booster remains the optimal for the logistics program.

8.4 TRANSPORTATION

An initial evaluation of transportation requirements determined that air or ground transportation were not feasible due to size and weight of the LRB. Water transportation similar to that used on the ET program has been further reviewed and a preliminary concept is available.

A transporter, consisting of three major components, will be utilized in both horizontal assembly as well as shipping from the manufacturing facility to KSC. Three support carriages make up the upper support structure which in turn is attached to a lower bogey or wheel structure. Each carriage also includes four sets of dual pneumatic wheels allowing for free steering rotation. Braking is accomplished through pneumatically activated, compressed air system. The brake system will lock if pressure drops below 40 psia: Figure 8.4-1 illustrates the proposed transporter fixture.

The LRB is transported on a transportation trailer which provides support for the LRB, but has no active power systems connected to it. Transportation environments which may adversely affect the LRB vehicle (solar radiation, salt spray, lightning, etc.) are alleviated by appropriate protective measures or packaging during transportation, including transportation of subassemblies or the incomplete vehicle. During storage and transportation, LRB propellant tanks are normally pressurized with dry air, but pressurization is not necessary. Either or both tanks may be connected to a breather system if necessary. Dessicant breathers are provided during transportation and storage to protect the interior of the propellant tanks from contamination. The LRB vehicle and its subsystems do not require electrical power or continuous monitoring during storage or transportation.

8.5 GROUND OPERATIONS

Ground operations will be limited to on-line replacement of failed LRUs, go/no-go verification, and other organizational level activities. Training of maintenance and operator personnel will be accomplished in accordance with KSC operational requirements and the logistics support analysis.

Propellant handling and storage will be accomplished according to current KSC procedures.

Further ground operations requirements are discussed in Sections 2.2 and 5.4.

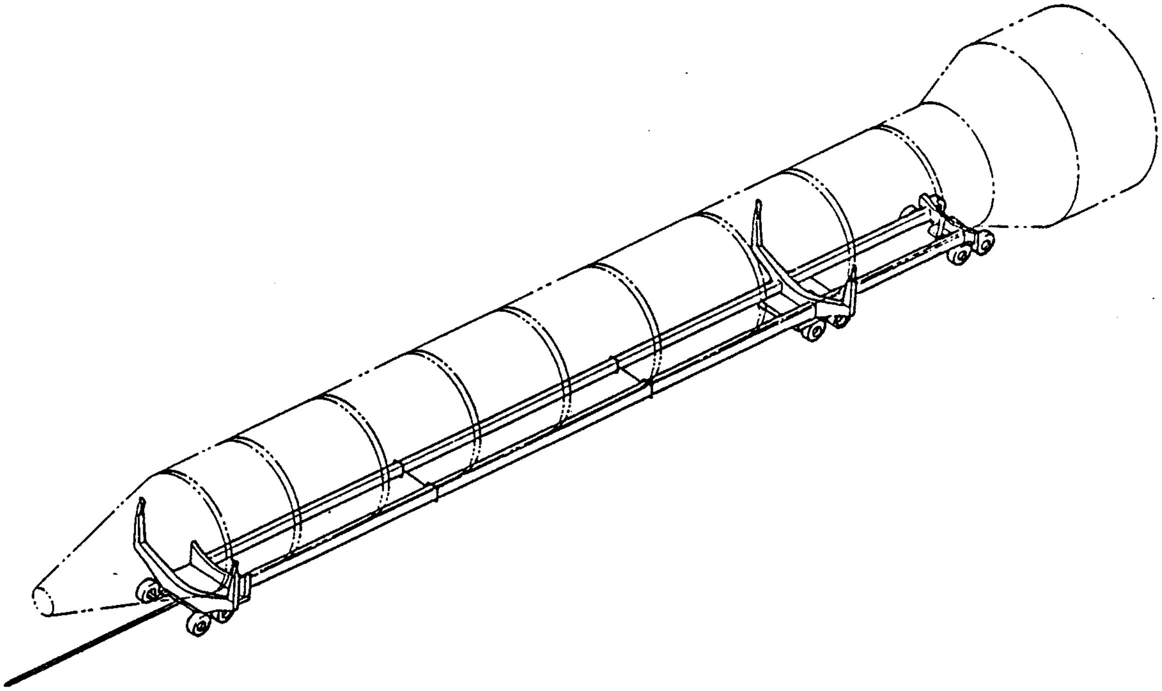


Figure 8.4-1 Transporter Fixture

8.6 FACILITIES

Currently the STS program has a logistics facility available for LRB requirements. Storage of LRUs and consumables will be managed as a part of the Shuttle Processing Contractor effort. For units requiring repair actions, an optimum repair level analysis will determine repair procedures and location of the rework activities. Contractor facilities will be used as necessary to maintain items having requirements outside of KSC's capabilities. Repair of failed LRUs/SRUs will be accomplished to the maximum extent at the facilities available at KSC.

9.0 SAFETY, RELIABILITY AND QUALITY ASSURANCE

9.1 SAFETY AND HAZARD ANALYSIS

Martin Marietta's approach to risk management is a systematic method for hazard identification and control from initial concept definition through final recovery or disposal. Using this method, hazards relative to the LRB have been identified and analyzed to enhance the safety and reliability of the LRB final baseline concept. Risk analyses and hazard control methods have been identified and documented to optimize system safety while minimizing hazard control cost and system constraints.

Lessons learned by Martin Marietta and NASA have been documented in SAMSO-STD-79-1, NSTS 22254, NHB 5300.4 (1D-2), and NSTS 07700, Volume X. Using the information contained in these documents, a safety checklist, 3731-SCL-2, was prepared at the beginning of the trade study period to guide engineering analysis through potential alternatives with respect to incorporation of safety features and considerations. A senior engineer from the Safety Department was assigned to work on the LRB Project full time to participate in trade studies and ensure that safety was given appropriate weighing and was realistically factored into each trade analysis. The major role played by Safety is reflected in the fact that the original baseline vehicle, using hypergolic propellants, was superceded by the current baseline, which uses LO2 and RP-1. This major program revision was based largely on safety and environmental considerations.

9.1.1 Risk Management Approach

Information from the various trade studies was incorporated along with the documents previously mentioned into a Preliminary Hazard Analysis (Appendix M). This analysis used a sophisticated computerized approach, called PHAROS, to identify potential hazards. PHAROS considered combinations of LRB systems, mission phases and composite hazards as elements of a three dimensional matrix. Individual elements of this matrix were considered by the Safety representative one at a time to determine if they represented a realistic potential hazard and, if so, how such a hazard might be resolved.

Hazard descriptions and recommended closure rationale were entered by the analyst and recorded by PHAROS in the form of Hazard Analysis Worksheets (HAWs). These worksheets were generated in a format compatible with the requirements of NSTS 22254 to facilitate later revision and updating. PHAROS also generated records of hazards which were not considered or analyzed, either because they did not apply or because the immaturity of the design did not permit a realistic appraisal of the risk(s) involved. These records were also made a part of the PHA, along with a complete description of the analysis rationale and computer program operation. This provides traceability of the hazard analysis process and reconsideration of hazards initially not analyzed when the design matures such analysis becomes possible.

The current output of this process consists of the safety considerations involved in each trade study, the 3731-SCL-2 safety criteria, the preliminary hazard analysis, and the system safety critical requirements which are reflected in the Level II and III safety requirements and design safety features which are listed in the following section. The Martin Marietta Manned Space Systems Safety Department will continue to be involved in the design of the LRB to ensure that safety is made an integral part of the LRB and its subsystems and components.

9.2 PRELIMINARY RELIABILITY ASSESSMENT

Based on the designs discussed in sections 6.0 and 7.0, reliability assessments have been performed. The overall design reliability factors goals are 0.998 for both the pressure-fed system and pump-fed system. Figures 9.2-1 through 9.2-6 show the reliability allocation tree for the two configurations.

While the overall reliability of both configurations are of equal value subsystem reliabilities are not equivalent throughout the designs. The differences in the structure and engine sub-systems reflect the increased reliability of the pressure-fed engines versus the turbo-pump-fed engines.

All remaining reliability quantities are determined by a series reliability with a single-point failure of the overall system. The cost-effectiveness of redundancy will be further explored in subsequent phases of the LRB program.

9.3 QUALITY ASSURANCE REQUIREMENTS

9.3.1 Approach

Martin Marietta's approach to product assurance will closely parallel those activities on the ET program, which received NASA's highest quality and productivity award and have made us a recognized leader in spaceflight hardware safety, quality and reliability. A Director of Product Assurance will be responsible for all safety, reliability, maintainability and quality assurance functions, which will be carried out by subordinate managers in each of these areas.

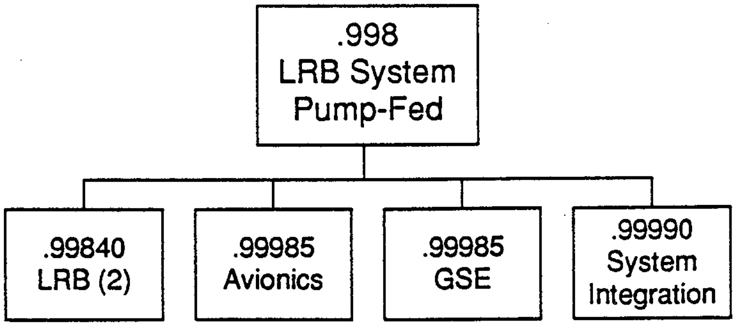
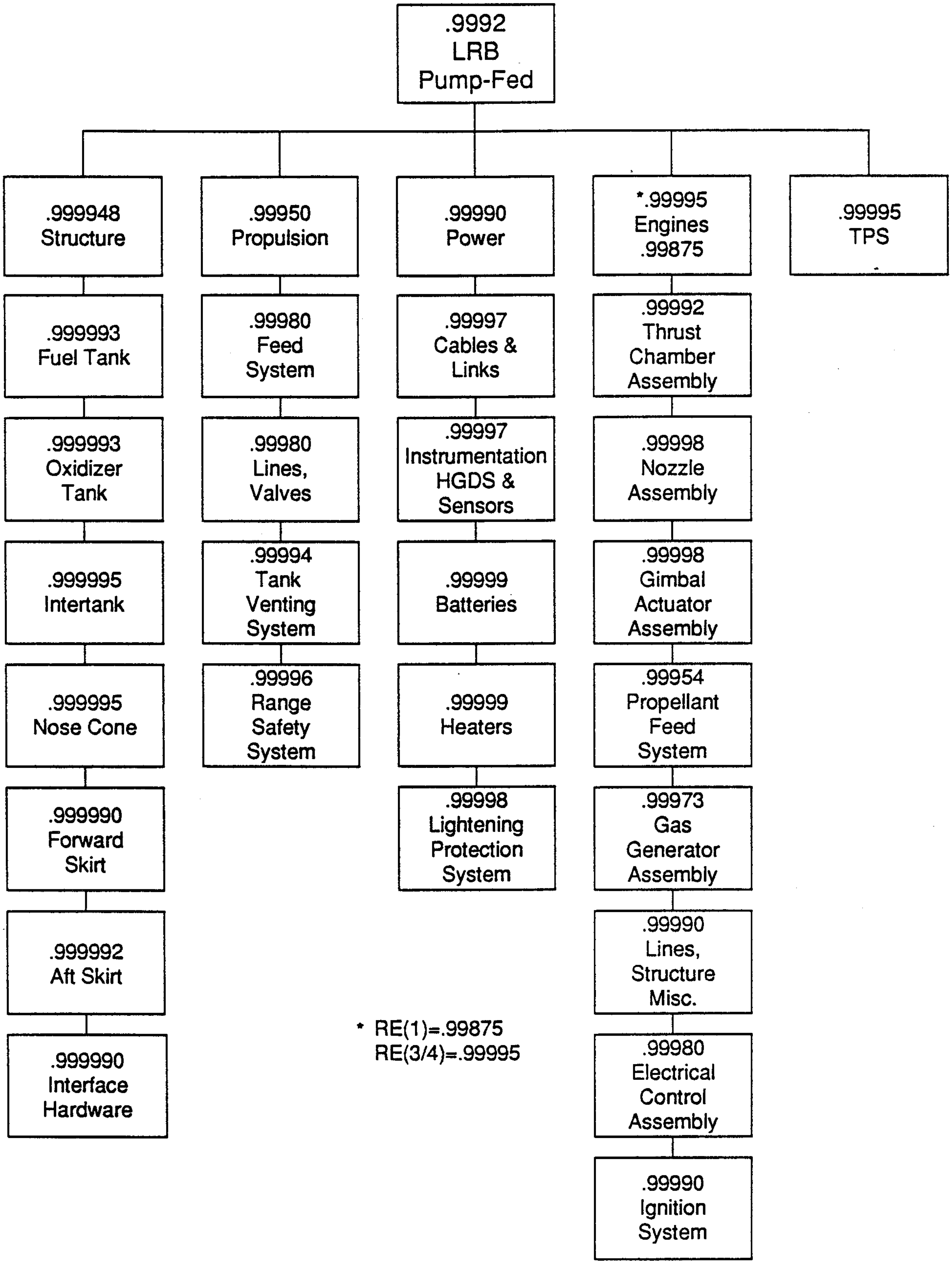


Figure 9.2-1 LRB Reliability Allocation



* RE(1)=.99875
RE(3/4)=.99995

Figure 9.2-2 LRB Reliability Allocation

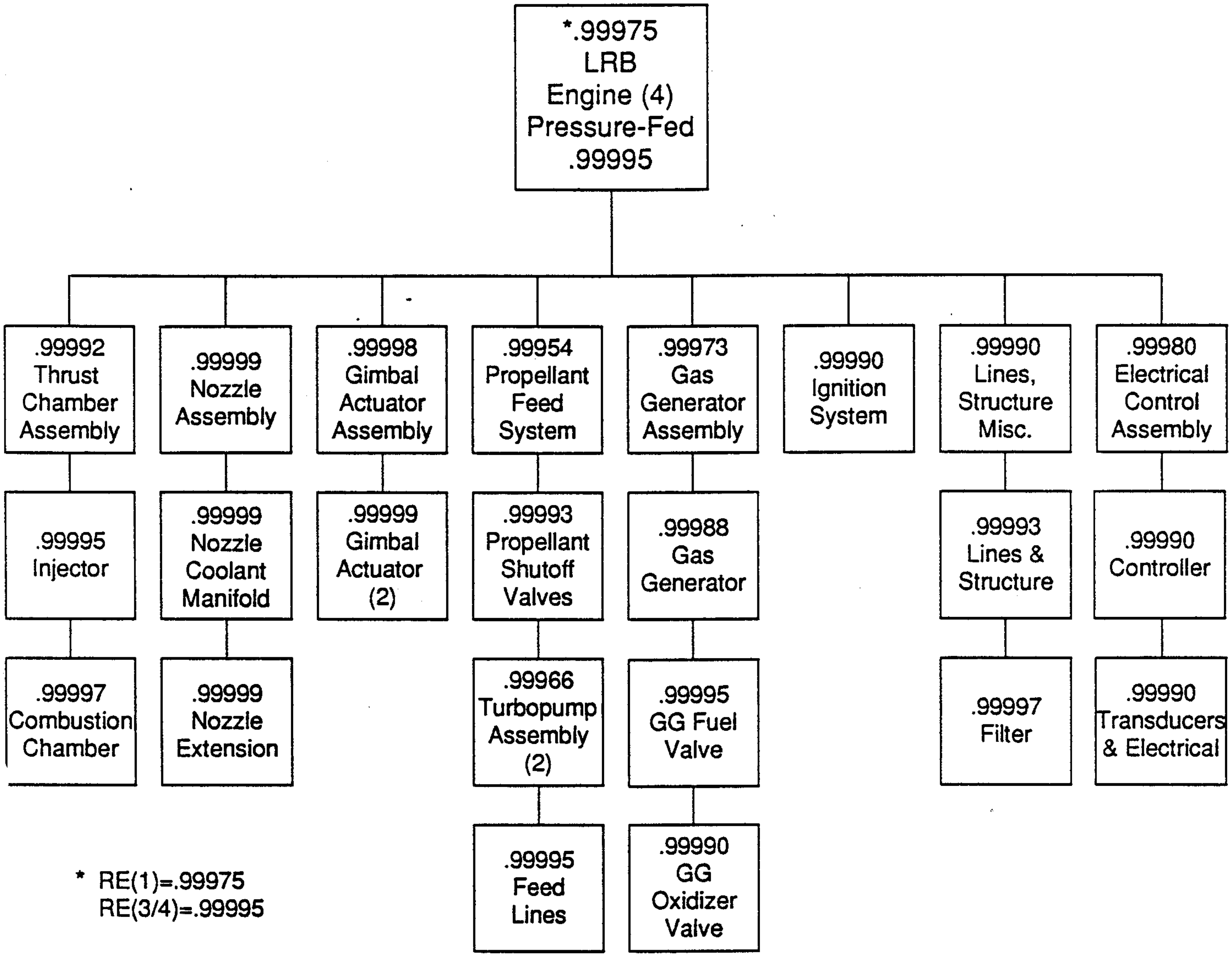


Figure 9.2-3 LRB Reliabilty Allocation

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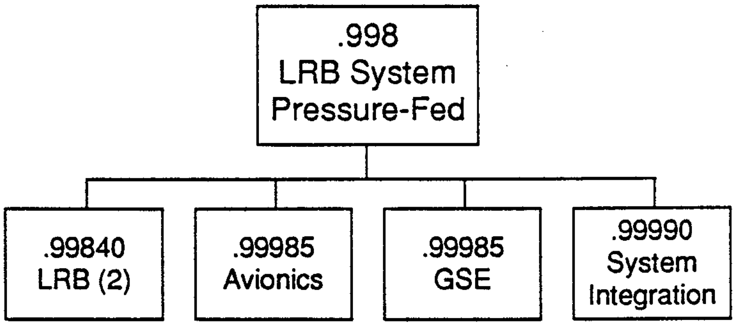
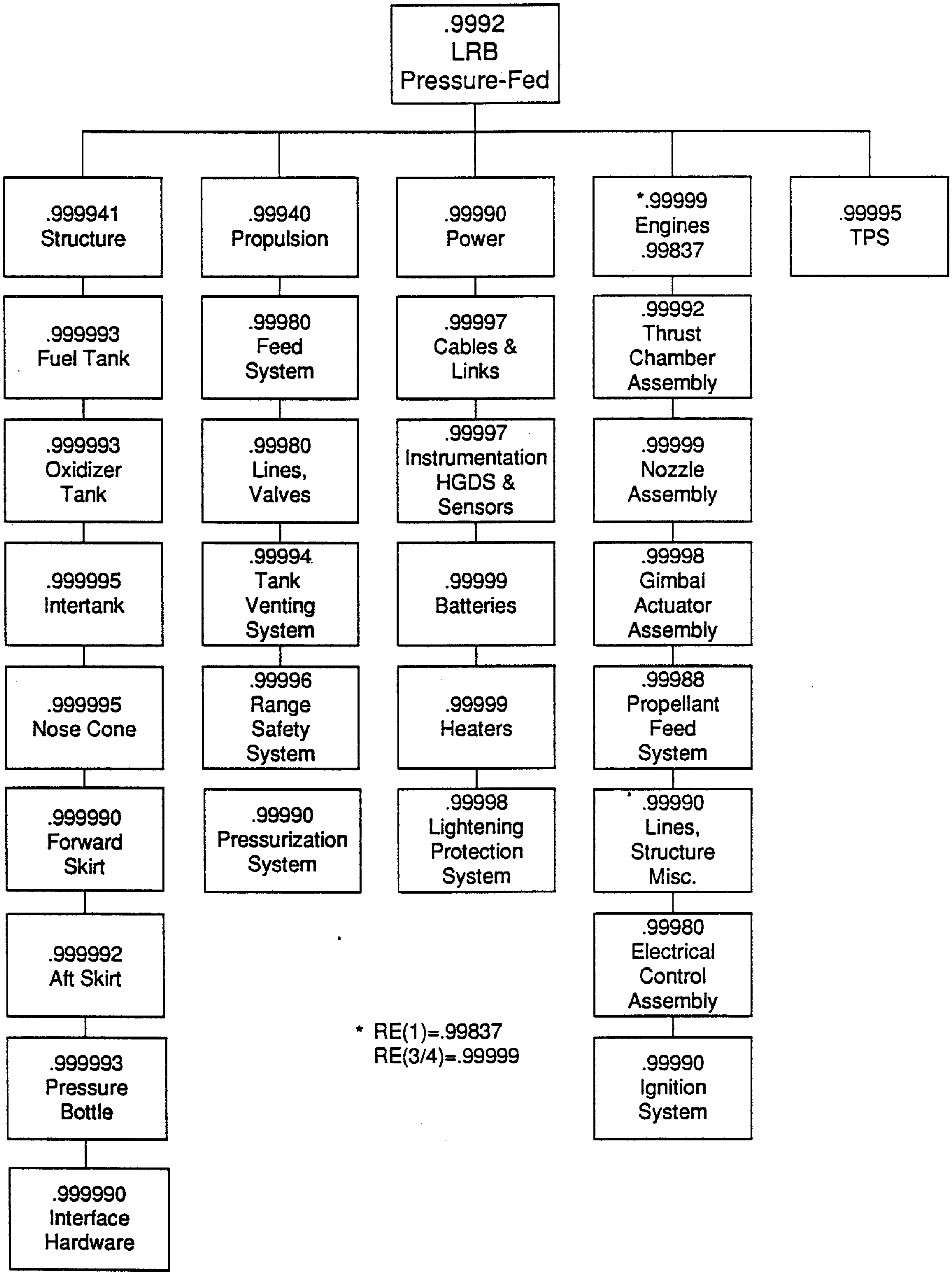
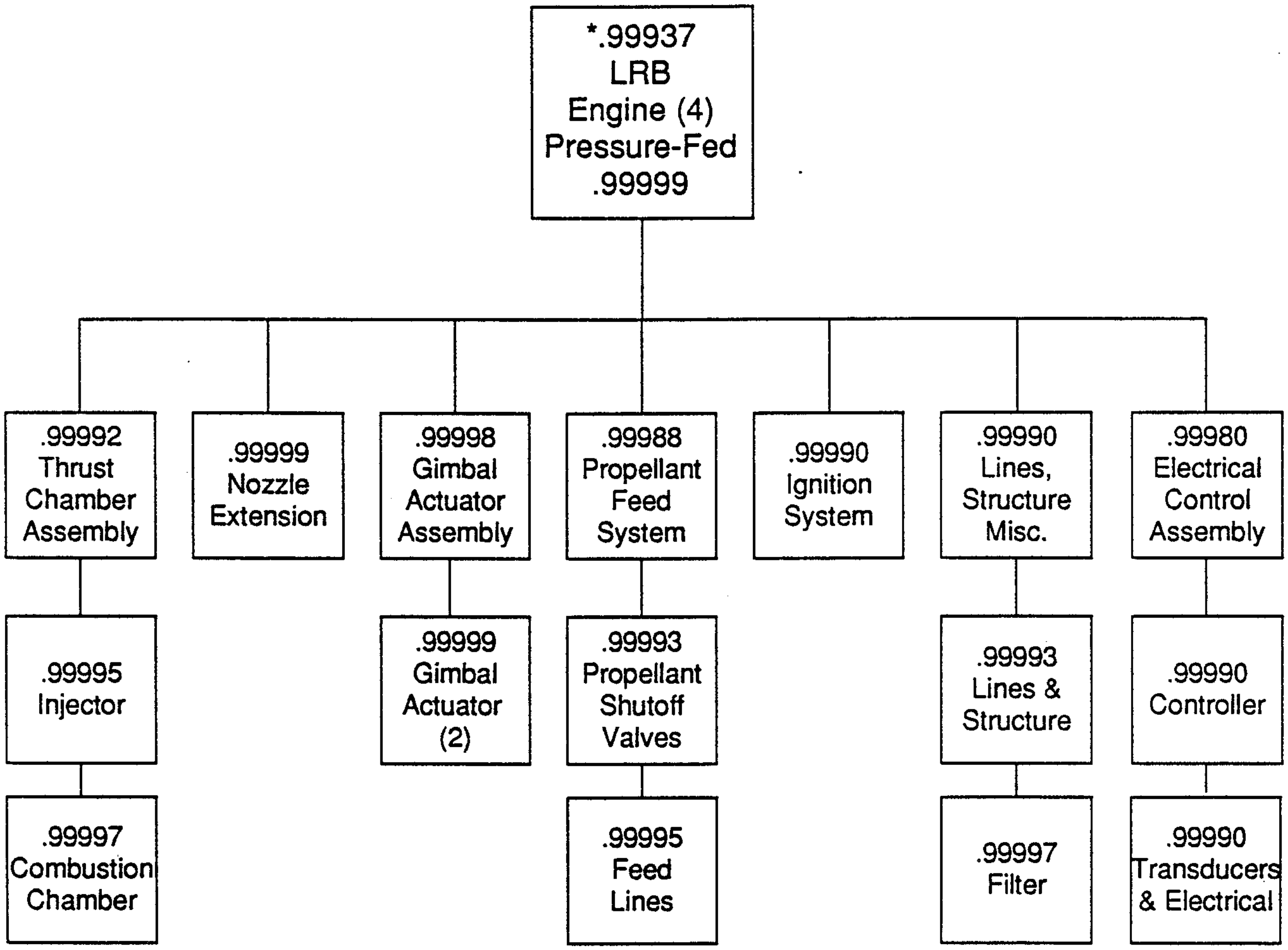


Figure 9.2-4   LRB Reliability Allocation



* RE(1)=.99837
RE(3/4)=.99999

Figure 9.2-5 LRB Reliability Allocation



* RE(1)=.99937
RE(3/4)=.99999

Figure 9.2-6 LRB Reliabilty Allocation

The existing Martin Marietta quality assurance program will be expanded to take into consideration the unique requirements of the LRB. These requirements will be contained in a Quality Assurance Program Plan, which will establish methods by which safety, reliability and quality will be made an integral part of the LRB hardware. A certification board will establish and implement training criteria for quality control engineers and inspectors, who will review technical drawings, specifications and procedures to insure integration of the necessary quality control elements into hardware design and manufacturing processes. Quality Control inspectors will participate in design reviews, change control activities, and in-process manufacturing. Manufacturing records and technical documents will be placed under configuration control to assure traceability and proper hardware configuration.

9.3.2 Controls and Inspections

Controls will be placed on procurement activities to insure that vendors comply with applicable product assurance requirements. Source selection, procurement documentation and in-plant inspection will be conducted by Product Assurance personnel, who will also conduct receiving inspections, verification of procurement source data and assessment of procurement source operations.

Fabrication operation inspections, article and material controls, access controls, article identification and storage, and contamination controls will all conform to product assurance requirements. Process controls will be implemented and verified. Quality inspection, nondestructive testing, procedure verification, functional tests and nonconformance evaluation will all be carried out by trained and certified personnel. Written procedures will include manufacturing process plans, standard technical procedures, process instructions, test procedures, and systems test and verification plans.

Nonconformances will be identified and resolved by use of the Martin Anomaly Reporting System (MARS). Nonconformances will be evaluated and dispositioned by a material review board. Martin Marietta will also participate in the Government Information and Data Exchange Program (GIDEP), and will initiate and process GIDEP Alerts in accordance with established procedures.

9.3.3 Other Areas

An existing metrology laboratory will periodically calibrate all measuring instruments by procedures allowing traceability to the National Bureau of Standards. Calibration records will be maintained and controls will be established to preclude measurement with inaccurate equipment. Stamps and seals will be used to verify quality inspection and calibration.

Handling, storage, preservation, marking, labeling, packaging, packing and shipping procedures will be established and incorporated into drawings and instructions to insure protection of parts, subassemblies and systems after manufacture.

Hardware and software of all computerized systems used in the manufacture or testing of LRB components, is subjected to a formal design review and failure modes and effects analysis (FMEA) to insure that there are no undetectable or uncorrectable failure modes which would compromise safety of the manufacturing operation or quality of the finished component.

9.4 SAFETY ENGINEERING

9.4.1 General

The LRB and its subsystems are designed to control hazards. The following paragraphs list some of the design features which are to be incorporated as controls to hazards discovered during the preliminary hazard analysis.

9.4.1.1 Inspection and Access

Preflight inspection of the LRB is accomplished using special tools and various access aids. Access doors, covers, or hatches which are not removable are self supporting when open. Handles and controls for mechanisms such as hatches, access doors and platforms have sufficient clearance to prevent injury to fingers and hands. Accessways conform to the requirements of MIL-STD-1472. Access equipment is specially designed prevent flight vehicle damage during assembly/erection or disassembly. Launch facility access ramps and the configuration of accessways on the LRB allow prompt escape of the ground crew in an emergency.

9.4.1.2 Failure Control

Two failure tolerant redundancy will be employed where such failures would jeopardize the Space Shuttle mission, vehicle or crew, where component reliability is a major concern, or where it is cost effective. Except where multiple fasteners are not feasible, single fasteners are not used to carry structural loads. Where two, three or four fasteners are used, all design loads can be carried if one of the fasteners fails. Where five or more fasteners are used, all structural loads can be carried by eighty percent of the fasteners employed. Failure of any single fastener which could jeopardize system operation or could cause loss of mission of vehicle is identified and documented in the Critical Items List (CIL). Pressure vessel feed through connectors are installed to minimize leakage and preclude ejection in the event of failure of attaching hardware or disconnection of internal or external connectors. Connectors at which leaks could be hazardous are addressed in the CIL.

9.4.1.3 Line Replaceable Units

LRB systems are designed so that it is physically impossible to install LRUs in a position or configuration other than that in which they are intended to function. Bolt holes for certain flanges and all manhole covers on the LRB are drilled on common fixtures for manufacturing economy. To prevent the possibility of inadvertent installation of the wrong part, two of the holes on each installation are drilled slightly off center. This pattern is different for each location on the LRB. This design makes it physically impossible to install the bolts in the off-center holes unless the correct part is installed in the proper orientation at each such location.

9.4.1.4 Use of Strain Gauges During Proof Test

All welds on the LRB pressure vessels are burst welds; that is, a flaw large enough to jeopardize the structure will not necessarily be large enough to cause a leak. For this reason, testing is accomplished using strain gauges to verify that structural strains are within design limits at proof pressure. During proof testing, a simultaneous leak check is conducted on all welds and tank penetrations. Welds are x-rayed before testing to assure structural integrity.

9.4.1.5 Draining

The LRB vent and drain system is designed to protect the LRB, personnel, and the environment. Drains are provided as necessary to prevent the accumulation of rainwater while the vehicle is in the upright position or while it is in the horizontal position required for transportation. Vacuum relief protection for the propellant tank during draining is provided by vents in the pressurization system which provide ventilation of the RP-1 tank ullage space. Vacuum relief for the LO2 tank is provided by nitrogen purge introduced during draining.The configuration of the system prevents relief system isolation with propellants loaded. LO2 and RP-1 drain valves are interconnected to prevent simultaneous drainage of fuel and oxidizer into the flame bucket prior to launch.

9.4.1.6 Nuclear Event Protection

The LRB electrical systems and components are protected from electromagnetic pulse, neutron emission and gamma radiation from a nuclear event consistent with the capability of the structure to survive the blast and thermal effects of such an event. Electronic assemblies are provided with circuitry which can diagnose system damage by a nuclear event not apparent by visual inspection. Critical systems sensitive to electromagnetic pulse, neutron emission or gamma radiation are designed to fail safe and return to operation immediately after the occurrence of a nuclear event.

9.4.1.7 Preflight Testing

Testing is conducted by the LRB automated redundant instrumentation for anomaly testing (LARIAT) prior to countdown initiation and during static firing. Before applying power to or accepting signals from the LRB, LARIAT performs a self-diagnostic check to insure that its internal circuits are functioning correctly and to insure that testing is properly performed to preclude damage to the LRB. LARIAT is integrated with the LPS to reduce ground crew workload and assure proper integration of LRB checkout functions into countdown operations. LARIAT software contains a "watchdog" program which continuously monitors the status and operation of test equipment to provide an alert of possible LRB or test equipment malfunction prior to launch. LARIAT is powered by an uninterruptable power supply and contains current limiters, overvoltage protection and circuit status checks to prevent inadvertent arming of PICs and other subsystems during test, and to insure that the test is aborted in an orderly sequence and that systems are safed if a malfunction occurs during test firing.

9.4.1.8 Ground Temperature Conditioning

Thermal conditioning is accomplished on the ground by purge gas supplied through the LRB umbilical interface and by electric heaters where purging is not practical. Thermal conditioning prevents air or nitrogen liquefaction, ice formation on the structure or within the HGDS during loading, and overheating during and after test firing, when heating loads on the LRB are most severe. The nose cap of the pressure fed LRB is purged with heated gas to prevent air liquefaction.

9.4.2 Structure

In order to save weight, current structural design favors the use of Weldalite™ 049 aluminum/lithium alloy for much of the primary structure and tankage. During manufacture, special controls, protection measures and disposal methods protect personnel and the environment from exposure to or contamination with lithium or its oxides or comling of different scrap metals. Some non-structural components of the LRB are made of carbon fiber composites. Where these components could be subjected to lightning strike or induced currents as the result of lightning strike, they include a conductive sacrificial ply to mitigate delamination caused by heating of the matrix and mutual inductive repulsion of the fibers.

9.4.2.1 Thermal, Acoustic, Static and Dynamic Loads

The integrated liquid rocket booster (ILRB) and all of its subsystems has the capability of withstanding all heating, vibration and acoustic loads from engine ignition to disposal, including those which result from simultaneous firing of all LRB engines and SSME engines while the ILRB is connected to the MLP during static firing. All loads imposed by the ILRB are within limits established for the STS vehicle and launch facility.

9.4.2.2 Venting

All interior spaces in the LRB are either purged, vented or intentionally sealed. All areas in which ice or liquid air could collect are drained and vented to prevent condensate accumulation or overpressure resulting from subsequent vaporization. Drains are oriented to prevent impingement on incompatible surfaces or on test and inspection personnel prior to launch. Drains or vents do not provide a conduit for aerodynamically induced airflow during flight. Vents are not directed toward areas through which crewmembers or other personnel would be required to pass in an emergency requiring Orbiter evacuation. Fluids are not vented in such a manner that they mix with incompatible fluids or impinge on incompatible surfaces such as flammable TPS. Systems designed to vent in flight or after separation are nonpropulsive unless the purpose of such vents is to provide a propulsive force. Cryogenic tank venting subsystems are protected by design from blockage by ice. Purge gas is vented to the atmosphere through vent ports to prevent pressurization of purged spaces and to avoid hazards to personnel due to localized oxygen deficiency. Gaseous oxygen is vented to a connection on the umbilical interface to prevent hazardous combustion or ignition of flammable or combustible materials, such as TPS, in atmospheres enriched with oxygen.

9.4.2.3 Thermal Protection System (TPS)

The LRB TPS is designed to provide protection from aerodynamic heating loads and to prevent ice/frost formation on the LO2 tank during loading and prior to launch. On the pressure-fed LRB, additional TPS is used on the helium tank to assist tank conditioning prior to filling, prevent liquid air formation, and retard heat soak into the tank during and after static firing. TPS protects against thermal loads resulting from heat soak into components or subsystems during or after engine firing. TPS on the exterior of the LRB is capable of maintaining adhesion on the substrate when subjected to leaks at a pressure equivalent to the threshold of leak detection. All external surfaces of the LRB above the engines are maintained within a temperature range which is not hazardous to test and inspection personnel.

9.4.2.4 LRB Interface Connections

LRB-ET aft interface connections allow vertical movement of the ET during loading to accommodate thermal strains caused by ET LH2 tank cooling. Configuration of fittings, couplings, electrical connectors and other interfacing components makes reversal or mismatching of connections physically impossible. System fittings, flanges and fluid connectors are keyed or restricted so that it is physically impossible to connect an incompatible component, commodity or pressure level. Umbilical separation assemblies are purged with nitrogen gas to prevent ice formation at the interface between ground and flight systems. Purge gas is ducted from the umbilical interface into the oxygen vent system to dilute the oxygen concentration of the effluent. This reduces the potential for fire caused by oxygen concentration in the presence of flammable or combustible materials. Connectors on cryogenic systems intended to disconnect in flight are designed to operate when encased in ice.

9.4.2.5 Antigeysering System

Geysering is reduced in the LO2 tank by a splash plate mounted above the propellant screen, which breaks up a small geyser if one should occur. Additionally, helium gas is injected into the LO2 feedline to prevent vaporization which would produce a geyser.

9.4.3 Electrical System

9.4.3.1 Electrical Circuit Protection

Current limiting or circuit protection devices are selected to preclude fusing or welding of contacts or pins in electric circuits or excessive heating of conductors or components within the current limits permitted by the devices. Current limiting is also employed.to prevent battery degradation in the event of a short circuit. Cable wiring and insulation, including that within propellant tanks, is selected to be compatible with the surrounding environment. All harnesses are secured to remain clear of sharp edges and moving parts. Harness installations are designed with sufficient flexibility, length and accessability to permit disconnection and reconnection without damage to wiring or connectors. All circuits penetrating the propellant tanks are limited to 200 milliamperes current maximum. Both wire and insulation within the tank are capable of surviving a short circuit between any conductors or between any conductors and ground for an indefinite period without excessive heating of the conductors, loss of insulation capability, or ignition of the contents. Electric heaters are sized so that they cannot draw sufficient current to overheat without tripping their ground circuit breakers. Control or switching in the power return leads of a component is not used unless the source lead is switched simultaneously. All electrical systems in the LRB are returned to a single point ground. The LRB structure is not used for return circuit paths. The RP delivery system is grounded throughout to prevent the accumulation of static electricity during loading or draining. Electrical components are hermetically sealed or otherwise ignition proofed to prevent ignition of flammable or explosive mixtures. All electrical circuits are protected as necessary from potentials induced by opening of current-carrying circuits.

9.4.3.2 Connectors

All connectors have self-locking features unless other considerations preclude self-locking design, in which case lockwire or other approved methods are used to accomplish the same purpose. The pin pattern at connectors is laid out to minimize the possibility of system damage due to shorts between adjacent pins. Power and signal circuits are not allowed on adjacent pins of connectors. Pins are gold plated to improve electrical contact and reduce wear during assembly and testing. Diagnostic checks performed after final mating assure circuit continuity and minimize the possibility of undiscovered shorts between connector pins. Only female connectors are used to terminate sources of power.

9.4.3.3 Transducer Simplicity

All transducers are designed with a minimum of moving parts. Each pressure transducer which uses a wiped wire resistance element is filled with a hard metallic reinforcement at the position corresponding to atmospheric pressure. This feature prevents damage to the element or the generation of metallic wear particles caused by constant movement of the wiper due to barometric pressure changes or vibration at atmospheric pressure. Transducer cases on externally mounted transducers used for propellant measurements contain dual seals to prevent loss of fluid or hazardous contact with electrical components in the event of a single sensing element rupture. Differential pressure transducers with an external reference port are designed to withstand the effects of reverse pressurization. Transition to fast fill in the LO2 tank is determined by a combination of timing from the initiation of slow fill and measurement of the cycling of the vent/relief valve. This feature prevents potential difficulties caused by a failed level sensor.

9.4.3.4 Momentary Interruptions

Electrical and electromechanical equipment is capable of surviving momentary power interruptions without loss of function or production of hazardous conditions. Electrically operated valves are designed to tolerate momentary power excursions without erratic movement. Latching valves are not used on the LRB. Electrical and electromechanical equipment reverts to a safe configuration after an input power loss occurs. During testing, personnel are not permitted near electromechanical devices which could otherwise pose a hazard due to movement. There are no systems on the LRB which require the continuous application of electrical power prior to launch to prevent the occurrence of hazardous conditions (i.e. freezing of mechanical joints).

9.4.4 Instrumentation

Avionics and engine instrumentation are computer controlled within the LRB to reduce crew workload and Orbiter general purpose computer memory dedication during the first two minutes of flight. Each LRB contains a rate gyro assembly (RGA) which furnishes trajectory information to the Orbiter. In the event of malfunction, the Orbiter provides arbitration resolution. Due to limited bearing life, rate gyro assemblies are not activated until shortly before launch.

9.4.4.1 Preflight Electrical Power

In order to conserve battery power, preflight electrical checking is accomplished using electrical power supplied through the umbilical interface. Batteries are checked for temperature, voltage level and current capacity before launch.

9.4.4.2 Integral Fire Detection System

The ILRB is equipped with an infrared fire detection system which provides a warning of fire in the nose cap, intertank, and aft skirt during propellant loading and flight. The system provides warning of a fire; fire suppression capability is provided by the inert purge gas prior to launch and by atmospheric pressure reduction during flight.

9.4.4.3 Hazardous Gas Detection System (HGDS)

The LRB hazardous gas detection system monitors the nose cap, intertank space, and aft skirt area to detect propellant leaks during loading or test firing. The system consists of a manifold with gas ingestion ports at appropriate points. The manifold is constructed of aluminum tubing with sealed connectors to allow sampling only at the designated ports. The manifold terminates in three separate connections to the umbilical interface, where ingested gas is ducted to a mass spectrometer on the ground for analysis. The mass spectrometer is a broad range instrument capable of detecting the heavy molecules of RP-1. The HGDS is grounded throughout to prevent the accumulation of static electricity which could ignite RP-1 fumes ingested by the system.

9.4.4.4 Range Safety System

A range safety system (RSS) is provided to destroy both LRBs simultaneously after they are separated from the STS vehicle. The RSS safe and arm (S&A) device on each LRB is armed at LRB separation. The receivers in each LRB operate on the same frequency and utilize the same codes, which are different from the codes used by the ET RSS. The two subsystems in each LRB are cross-strapped to each other so that arm and fire commands processed by either system A or system B detonate both systems, resulting in LRB destruction. RSS subsystem power remains on from LRB separation through ocean impact. The RSS initiation circuitry is designed so that inadvertent detonation due to electromagnetic pulse from lightning, radar, a nuclear event, or other anomalous causes cannot occur.

The S&A device will not cause blast, thermal or other damage to surrounding subsystems in the event that one or both pyro initiator controllers are initiated while the S&A device is in the SAFE position. Pyrotechnic assemblies and components are located so that they are not jeopardized by shock from the initiators when the S&A device is in the SAFE position. Confined detonating fuse (CDF) and other pyrotechnic assemblies are located and routed so that they are not subjected to heating, cooling, mechanical shock, or flexing to the extent that their chemical or physical characteristics are changed or that their performance is degraded. The two firing circuits are physically separated to prevent a single event from damaging both systems.

9.4.4.5 Pyrotechnic Handling

Special handling equipment and procedures are employed when transporting, storing or handling pyrotechnic components or equipment containing them. Pyrotechnic separation circuits of the LRBs are cross-connected so that receipt of a separation command from the Orbiter by either or both LRBs initiates the separation sequence for both LRBs simultaneously. All PICs are protected from inadvertent activation by induced currents, static discharge or test equipment malfunction by circuits which short the electrical leads and connect them to ground potential before initiation. The electrical systems and wiring of the LRB is shielded to preclude ignition of separation pyrotechnics due to electromagnetic pulse from lightning, radar, a nuclear event, or other anomalous causes. Inaccessible PICs and pyrotechnic devices are tested to verify that they have not been activated after they are rendered inaccessible but before launch.

9.4.5 Engine System

9.4.5.1 Engine Pressurization Capability

Each pump fed LRB engine produces ullage pressurization gas at a rate approximately 33% of that required by the propellant tanks. Gas flow is reduced by a restriction valve which limits pressurization from each engine to 25% of that required. If one engine is shut down during flight, the restriction valve is opened to provide sufficient ullage pressurization from the remaining three engines. During engine operation, ullage pressurization gas flow is sufficient to maintain minimum ullage pressure if the pressure relief valve is not fully closed.

9.4.5.2 Engine Gimballing

Thrust vector control is provided by gimballing the engines about the thrust centerline. Correct system operation is verified during engine start. The engines can be gimballed manually on the ground to provide for inspection access or transportation clearances.

9.4.5.3 Engine Drainage

Thermal conditioning of the engines is provided by circulation of liquid oxygen. The engines are purged prior to conditioning to eliminate moisture from the engines. A fail safe indication of proper engine thermal conditioning is provided prior to engine start.

9.4.5.4 Prevention of Heat Exchanger Single Point Leaks

Heat exchangers are so constructed that no SFP leak will allow entrainment of oxidizer in the turbine exhaust or leakage of exhaust gas into the LO2 tank pressurization line.

9.4.5.5 Valve Timing

All valves are sized and timed to open and close so that damaging shock waves due to abrupt opening or closing of any valves singly or in combination are prevented.

9.4.6 Separation System

9.4.6.1 LRB Separation Sequence

Initiation and control of the ILRB separation sequence is accomplished by Orbiter command. Each LRB provides position and system operation data to the Orbiter which supplements data supplied by the Orbiter to determine the optimum time of separation. When the Orbiter computer system determines that LRB shutdown and separation is required, the appropriate signals are issued to both LRBs and appropriate responses are generated by the LRBs. Initiation of the separation sequence by the Orbiter insures that no other condition or signal, or combination of conditions or signals, other than a positive separation command from the Orbiter is interpreted by the LRBs as a separation cue or is capable of causing separation of the LRBs from the ET. The first event in the separation sequence, after receipt of a separation command from the Orbiter, is an acknowledgement signal from each LRB. After generation of this signal, the LRBs remove all electrical power from the electrical connectors prior to initiating the sequence which fires the pyrotechnic separation devices. Booster shutdown and separation can also be initiated by crew command. The command separation switch and other LRB controls and displays are located on the Orbiter C3 panel.

9.4.6.2 Separation Motor Thrust

The separation motor thrust vector is oriented to provide the necessary rotation and translation forces on each LRB to provide safe separation under all conditions, while at the same time protecting the ET and Orbiter from excessive heat or blast loading from the separation motor exhaust. The separation motors are shielded and sealed on the launch pad before launch to preclude ignition by a lightning strike or the accumulation of static electricity.

9.4.6.3 Thrust Termination After Engine Start

The LRB engines are started at T-4.8 seconds to permit engine operation verification prior to pyro bolt release. The launch processing sequencer will terminate the launch and safe the STS vehicle if an engine anomaly is detected prior to T-0. If the pyrotechnic system on one of the holddown bolts on the LRB fails to fracture the bolt, it will be fractured in tension by vehicle thrust at T-0. The vehicle therefore can safely sustain a failure of any one bolt on either side. The ILRB has the capability of being safed, drained of propellant, and purged of hazardous fluids at any time prior to holddown bolt release at launch.

10.0 PRODUCTION

Martin Marietta will integrate LRB production in and around the External Tank (ET) operations at the Michoud Assembly Facility (MAF). In-depth integration of LRB and ET production operations will permit maximum effective use of the existing work force and infrastructure of buildings, utilities, and support services.

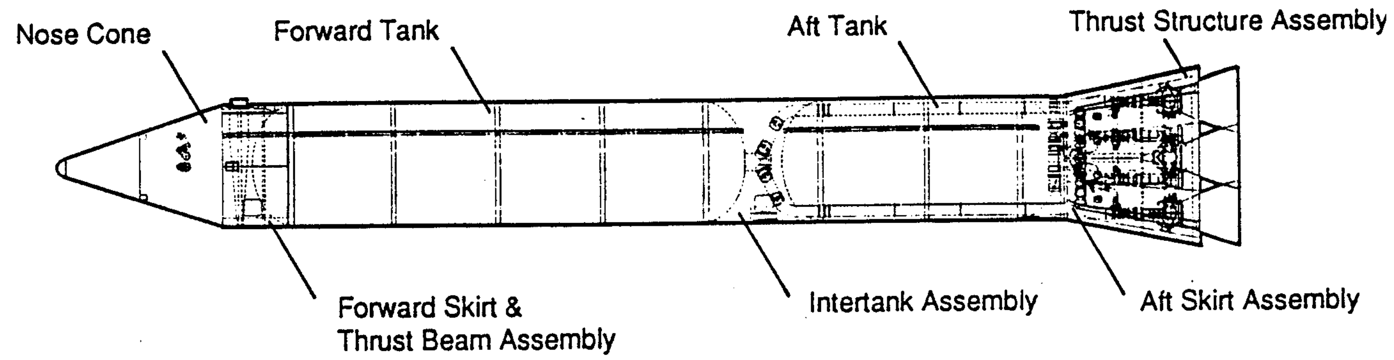
10.1 MANUFACTURING OVERVIEW

The manufacturing plan, in accordance with the LRB Mission Model, provides a five day, three-shift tool and facility capacity for fourteen (14) flight sets per year. The LRB will be assembled complete with test and checkout at MAF. The LRB will be shipped in flight sets on transporters to KSC via NASA owned barge. A basic premise of the LRB manufacturing plan is that shared use of facilities with the ET will be accomplished with no impact to the ET program.

The LRB Make/Buy Plan reflects that MAF is primarily an assembly facility. All welded and structural assembly, Thermal Protection System (TPS) application, final assembly, and test and checkout will be performed at this location. All fabricated parts, structural details, systems, and subsystem components will be purchased. Engines will be received at MAF, tested, and certified flight ready.

The manufacturing approach for the LRB program makes extensive use of automated processing and hard tooling to attain the highest quality process control and program productivity. All major fabrication processes i.e. machining, riveting welding, cleaning and finishing, and TPS application will be computer controlled operations. Hard tooling will be used for major welding and structural assemblies to permit the precision manufacture of the large structural components at the rates required for the Space Shuttle Program.

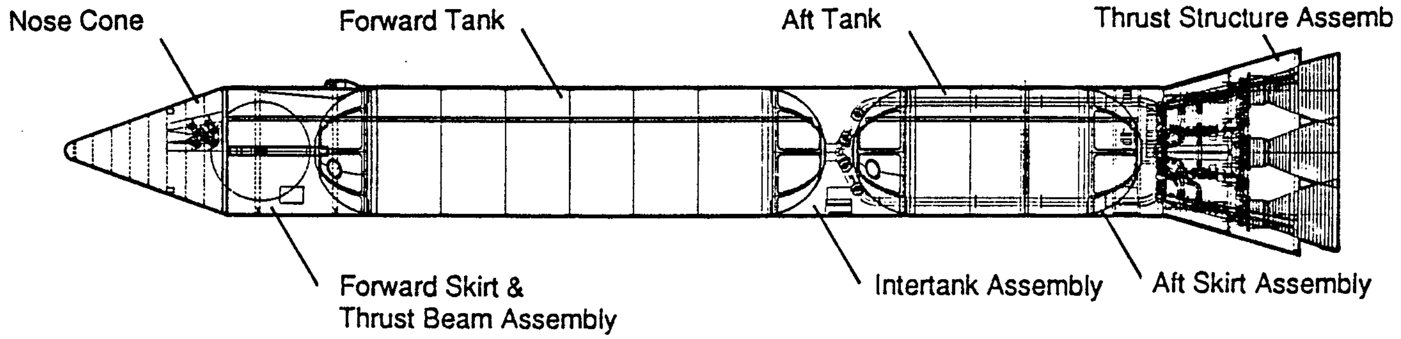
The pump and pressure-fed configurations are shown in Figures 10.1-1 and 10.1-2. The major structural components to be fabricated are the nose cone, forward skirt and thrust beam, forward LO2 tank, intertank (I/T), aft fuel tank, aft skirt, and thrust structure. A detailed description of the manufacturing plan and major tool and facility sequence flow is provided in DR-6, Project Implementation Plan, Section 5. As an overview, key features of the manufacturing plan are discussed here.



Construction:

- Propellant Tanks are Welded Monocoque Structure
- Nose Cone Assembly is Riveted Skin and Stringer Structure
- Unpressurized Structures are Welded Monocoque Structure

Figure 10.1-1 LRB Pump-Fed Structural Components



Construction:

- Propellant Tanks are Welded Monocoque Structure
- Nose Cone Assembly is Riveted Skin and Stringer Structure
- Unpressurized Structures are Welded Monocoque Structure

Figure 10.1-2 LRB Pressure-Fed Structural Components

10.2 PUMP-FED MANUFACTURING

The stiffness designed, pump-fed LRB configuration permits use of the cost effective, straight wall, monocoque construction. All structures including the propellant tank panels are rolled and welded mill stock plate. Plate thicknesses vary from .500 inch in the forward structures to .700 inch in the thrust structure. All panels, except the purchased conical thrust structure panels, are rolled at MAF on a Computer Numerically Controlled (CNC) vertical incremental roll press. These panels are longitudinally welded into barrels with the two pass, variable polarity plasma arc (VPPA) weld process. After trimming on a horizontal boring mill the barrels are completed for the unpressurized structures by horizontal VPPA welding the interface flanges (integrally machined roll ring forgings).

The pump-fed propellant tanks are constructed with rolled plate monocoque barrels, elliptical gore type domes, and with interface flanges and intermediate frames machined from integrally machined roll ring forgings. The forward LO2 tank configuration is shown in Figure 10.2-1. The elliptical domes use (6) stretch formed and chemical milled panels that are VPPA welded on tooling similar to that used for dome fabrication on the ET. The tank circumferential welds are also VPPA welds accomplished in horizontal weld fixtures similar to the type used on the ET program.

10.3 PRESSURE-FED MANUFACTURING

The unpressurized structures for the pressure-fed LRB are similar in design to the pump-fed structures and are fabricated in the same manner with rolled and welded mill stock plate. The pressure-fed LRB differs significantly in design of the propellant tanks and has the additional requirement for a high pressure helium tank for the pressurization system. In brief, the pressure-fed propellant tank manufacturing plan utilizes integral flow turned barrels manufactured in a process similar to the current SRB segments. The tank domes are open die forged spherical panels that are contour milled after forging. Basic configuration of the forward LO2 tank is shown in Figure 10.3-1. Due to the thick wall barrel stiffness, there is no requirement for intermediate ring frames except in the fuel tank at the ET interface.

One of the main issues of concern for the pressure-fed propellant tank manufacture is the development of the thick wall welding process. Weld land thickness for the dome panel longitudinal weld is 1.50 inches. Weld land thickness for the tank circumferential weld is 2.80 inches. These thicknesses with conventional fusion arc weld processes require machined weld joint preparations and multi-pass welding with intermediate X-ray inspection to prevent deep weld repairs.

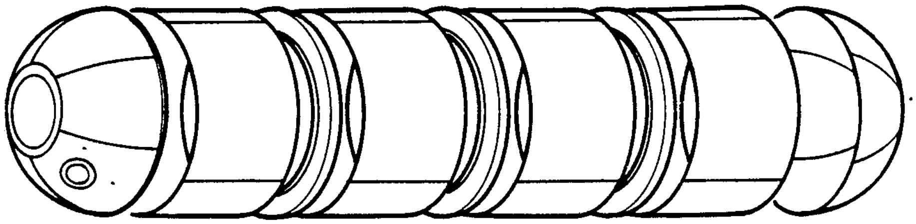


Figure 10.2-1 Pump-Fed LO2 Tank Configuration

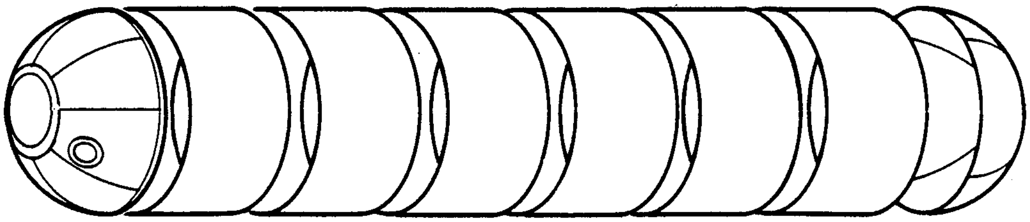


Figure 10.3-1 Pressure-Fed LO2 Tank Configuration

The type of weld process to be used for the fill pass welding will require a weld development program with selection based on best overall performance for weld strength, fill rate, dimensional performance in shrinkage and distortion, and ability to meet allowable defect criteria. For this study, for cost estimating purposes, we have baselined the Gas Metal Arc (GMA) weld process for it's high fill rate capability. In section 12.4.1, we discuss potential application and savings that could be obtained with development of a higher risk, local chamber, electron beam weld process.

With the GMA process the manufacturing plan for the dome panel gore to gore weld uses a VPPA penetration and cover pass weld on the outside skin line and five oscillated GMA fill passes on the inside skin line. The tank circumferential welds are run in horizontal weld fixtures and use a Gas Tungsten Arc (GTA) penetration weld (for narrow torch clearance) and five simultaneous inside and outside oscillated GMA fill pass welds.

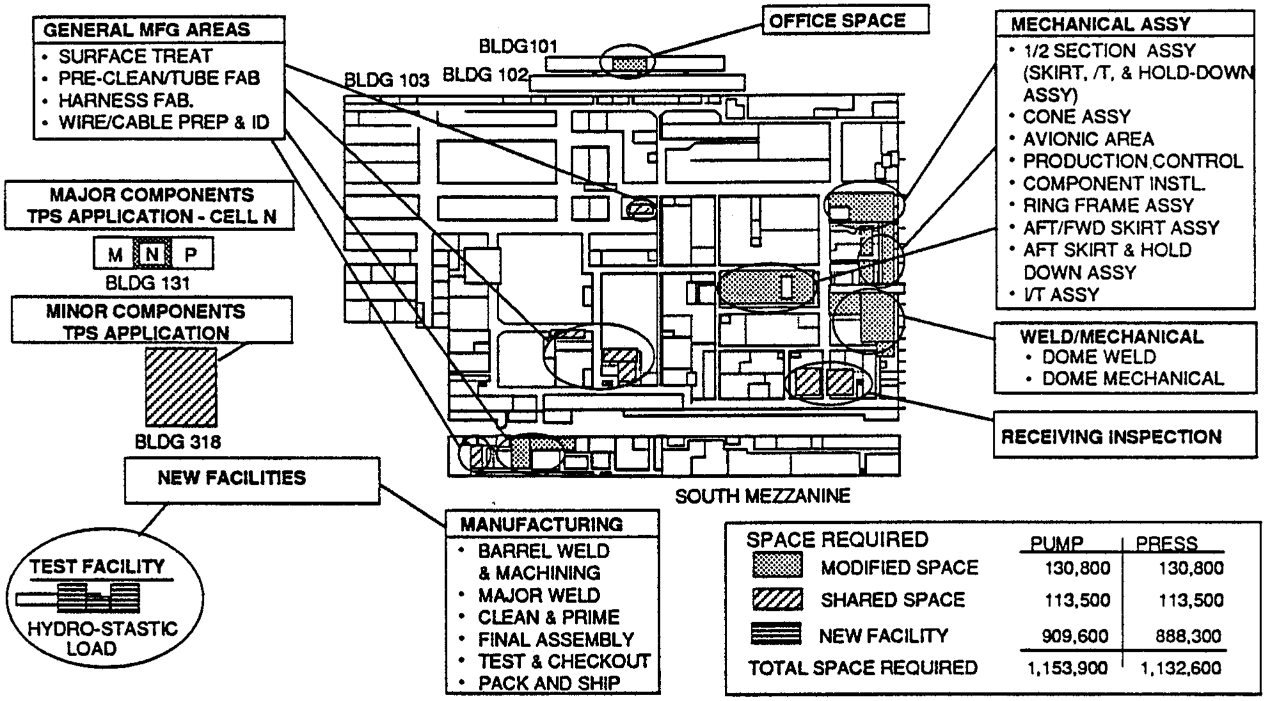
The helium pressurant tank is circumferentially welded in an electron beam vacuum weld chamber. The one piece hemispherical domes are purchased hot spun heads with integrally machined polar cap fittings. The domes will be received match machined for the close fit required for electron beam welding.

Structural assembly for the LRB is accomplished in two horizontal stack positions. At these positions the major structural elements are joined at the joint interfaces on the LRB transporter. After horizontal stack and verification of ICD requirements, the LRB moves on the transporter through final assembly, test and checkout, and pack and ship positions.

10.4. FACILITIES OVERVIEW

The facilities plan will provide for the shared use of ET facilities, modifications of existing facilities, construction of new facilities, and the acquisition and installation of general plant equipment at MAF to enable the successful implementation and execution of the LRB manufacturing plan. These facilities and equipment will support the planed LRB Mission Model of fourteen (14) flight sets per year on a five-day, three-shift operation. The modifications, construction, installations, and on-going shard facilities usage to provide for LRB production at MAF will be accomplished with no impact to the ET Project. Figure 10.4-1 provides an overview of the proposed LRB areas.

The functions of the new and modified facilities and equipment will be in accord with the LRB Make/Buy Plan and the continuing operation of MAF as an assembly facility. LRB facilities and equipment will accommodate trim and weld, structural assembly, proof/load test. TPS applications, final assembly, an test and checkout operations. Material processing facilities will accommodate the receiving, inspection, and disposition of purchased raw materials including



SPACE REQUIRED	PUMP	PRESS
▩ MODIFIED SPACE	130,800	130,800
▨ SHARED SPACE	113,500	113,500
☰ NEW FACILITY	909,600	888,300
TOTAL SPACE REQUIRED	1,153,900	1,132,600

Manufacture of the LRB will be Accomplished at MAF Utilizing Existing External Tank and New Facilities Without Interference to ET Production

Figure 10.4-1 Facilities Overview - Michoud Assembly Facility (MAF) Site Plan fabricated parts, structural details, engines, and system and subsystem components. New office facilities and manufacturing facility office areas will accommodate LRB Project office personnel and associated equipment.

LRB production will utilize some existing facilities at MAF without modifications on a shared, non-interference basis with ET including the chemical clean line, electrical wire cut, cable clean, and tube fabrication areas in Building 103 (26,300 sq ft). Building 318, the Component Ablator Facility (87,200 sq ft), will also be utilized on a shared, non-interference basis with ET for the application of TPS to small LRB components. Use of extensive site infrastructure of MAF such as the Industrial Wastewater Treatment Facility (IWTF), high-voltage electrical system, steam system, chilled and process water systems, compressed air and high-pressure-nitrogen systems, plant security system, telecommunications, and roadways and parking lots will serve to limit front-end project investment and reduce costs. Site service such as tooling fabrication, training, laboratories, proof load, and plant maintenance shops are in-place and available. The completed LRB's will be shipped from the existing MAF harbor and dock facilities which provides access to all MSFC and SSC test sites as well as both the Eastern and Western Test Ranges.

Areas within Building 103 (121,500 sq ft) will be modified to accommodate dome weld and machining, structural and mechanical subassembly, electrical cable harness fabrication, and avionics processing. Modifications will include installation of tool and equipment foundations; general plant equipment; underslab utilities; substations; overhead crane network; construction of class 100K clean rooms; and establishment of production control, in-process staging, and crib areas.

Building 131, Cell N (9,300 sq ft), will be modified to provide Super-Light Ablator (SLA) application to LRB major components such as nose cones and thrust structures. Modifications will include installation of tool and equipment foundations, general plant equipment, SLA spray and cure enclosures, overhead crane system, extension of existing utility services, HVAC modifications and additions for SLA cure, duct work modifications to the existing thermal oxidizers for emissions control, and installation of controllers.

A new LRB Manufacturing facility will be constructed to accommodate barrel weld and machining; major weld; Helium pressurant tank Assembly (pressure-fed version only); major component cleaning, priming, painting, and TPS application; structural assembly; final assembly; engine processing; test and checkout; and pack-to-ship. This will be a state of the art aerospace vehicle assembly facility, similar in construction to Building 103, with a low-bay clear height of approximately 30 ft and high-bay clear heights of approximately 80 ft for cleaning and TPS operations. The facility will have a heavy-duty floor; tool and equipment foundations; large assembly bays and through aisles; tench and column-supported utilities; temperature and humidity controls; extensive overhead crane network; class 100K clean rooms; cleaning and TPS applications cells; local area network; security controls; manufacturing office areas; tank farm operations; effluent piperack to the IWTF; parking aprons and approach roads; and production control, in-process staging, and crib areas. The pressure-fed version will require 461,700 sq ft and the pimp-fed version will require 346,000 sq ft. The pressure-fed version requires an increased number of weld positions over the pump-fed version and, hence, more area.

A new LRB Hydrostatic Test Facility (13,600 sq ft) consisting of two separate vertical (80 ft clear height) test cells, a test control building, and test fluid tank farm will be constructed along with parking aprons and approach roads. These facilities will accommodate proof test of fuel and oxidizer tank welds through a combination of internal hydrostatic pressure and externally applied loads. Facility construction will embody the same principles as the existing Building 451/452 ET Pneumatic Test Facility with the exception of clear height, crane capacity, and test fluid medium. The facility will provide horizontal to vertical tank rotation, tool foundations, temperature and humidity controls, test-fluid generation (inhibited DM water), test-fluid storage and recycling, and test-fluid disposal (when no longer recyclable) via piperrack to the IWTF.

A new Materiel Processing Facility will be required to accommodate LRB raw materiel including receiving, inspection, staging, and release to production control. The facility will be of warehouse-type construction with loading docks, heating and ventilation, parking apron, and approach roads. The pump-fed version will require 110,00 sq ft and the pressure-fed version will require 93,000 sq ft. The pressure-fed version requires less space due to the greater availability of production control areas in the Manufacturing Facility.

A new LRB Office and Engineering Facility will be required to accommodate office personnel as well as associated office and the ADPE. The facility will consist of a multi-story building encompassing a reception area, management offices, general offices areas, conference rooms, a management information center, telecommunications facilities, computer rooms, local area network, data files, food services, and other support functions. The pump-fed version will require 440,00 sq ft due to a higher anticipated office headcount than the pressure-fed version which will require 320,000 sq ft.

The types of facilities required for the two versions of the LRB, pump-fed and pressure-fed, are very similar. Differences are attributable to increased quantity of tool positions and higher crane system tonnages for the pressure-fed version and increased project headcount for the pimp-fed version. The types of general plant equipment required are also very similar with differences attributable to increased quantities of weld and x-ray packages for the pressure-fed version and increased office and ADPE equipment requirements, due to higher headcount, for the pump-fed version..

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10.5 Contamination Prevention

During manufacture and subsequent handling and testing, special controls are imposed to prevent tank contamination which would jeopardize flight safety. LRB propellant tanks are protected by screens at the outlet of each tank. The screen traps contamination which would otherwise jeopardize engine performance. Screen segments are attached by bolts installed in blind tapped holes on the screen support structure. This method of installation precludes the possibility of failed fasteners downstream of the screen.

11.0 ENVIRONMENT ASSESSMENT

The environmental impacts associated with the LRB are discussed in DR-7, Environmental Impact Assessment.

12.0 TECHNOLOGY REQUIREMENTS

12.1 OVERVIEW

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

1) High specific strength aluminum lithium, Weldalite™ 049;
2) Electromechnical TVC actuator systems;
3) Low cost automonous avionics; and
4) Flex seal nozzle gimbling.

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

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

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

12.2 MATERIAL

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

12.3 PROPULSION SYSTEM DEVELOPMENT

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

12.4 MANUFACTURING DEVELOPMENT

There are no mandatory new technology requirements for manufacture of the structural elements of a pump-fed LRB if currently qualified materials (i.e. 2219 Aluminum) are used. Only those usual items of development for new products (e.g. weld schedules and SOFI spray routines) would be required. Use of Weldalite™ 049 as the primary structural material would require the development and qualification of all the fabrication processes. This development discussed in Section 12.4.4 should be considered enhancing technology for the pump-fed LRB as 2219 Aluminum is a viable backup material.

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

12.4.1 Thick Wall Welding

As discussed in Section 10.1, the GMA weld technology was selected as baseline for fabricating the pressure-fed tanks because it is a mature process that provides the high fill rate required for thick wall welding. The process that will actually be used will necessarily be determined by a weld development program. All the potential fusion arc processes (gas tungsten arc, variable polarity plasma arc, gas metal arc) have severe shortcomings for thick wall welding, namely: low joint efficiency, limited penetration capability, slow travel speed, high heat input, wide weld bead and heat affected zones, and high residual stresses and distortion. For these reasons we have studied the potential benefits of using the electron beam (EB) weld approach for the pressure-fed tanks. In the EB process very deep narrow welds are achieved with one pass penetration speeds of up to 70 inches per minute in 6.0 inch aluminum plate as shown in (Figure 12.4.1-1). The low heat input, with resulting minimal distortion and high joint efficiency, makes EB welding attractive for joining thick sections. Problems of applying EB welding to the pressure-fed propellant tanks arise mainly from concerns over joint fit up, need to weld in a vacuum, and qualification of the narrow weld joint.

Evaluation of the EB weld process in IR&D Project M-04R has concluded that excellent weld strength properties can be achieved with aluminum alloy 2219-T87 welded with EB in a vacuum chamber at soft vacuum (10^{-1} - 10^{-2} mm Hg). These results for EB welds are compared with VPPA welding data in Figure 12.4.1-2 for plate thicknesses up to 1.0 inch.

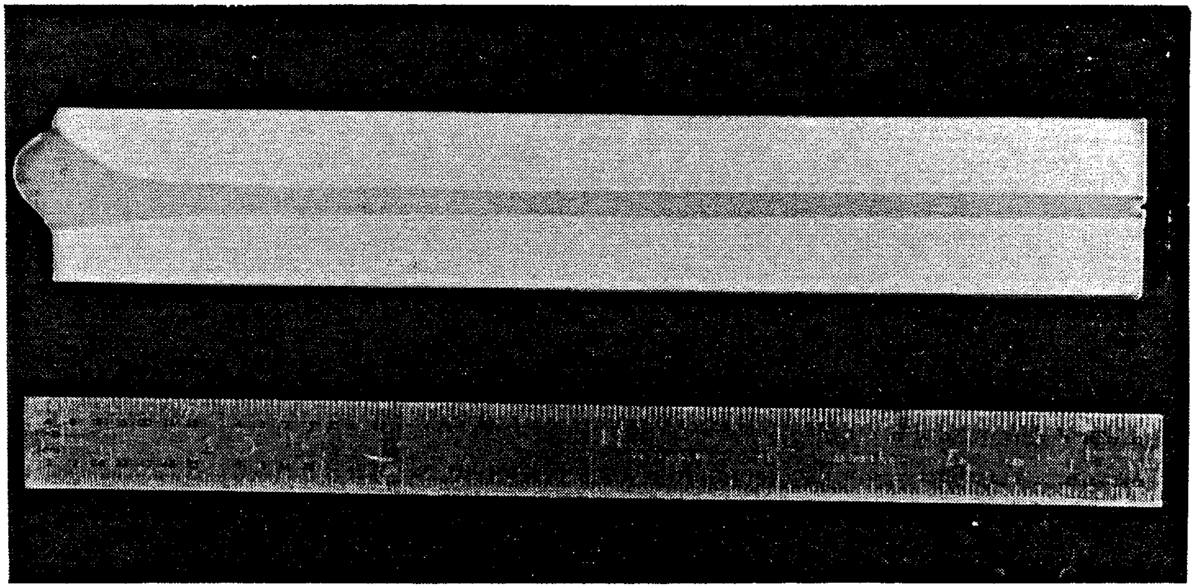


Figure 12.4.1-1 Electron Beam Weld in 6.0 inch Aluminum

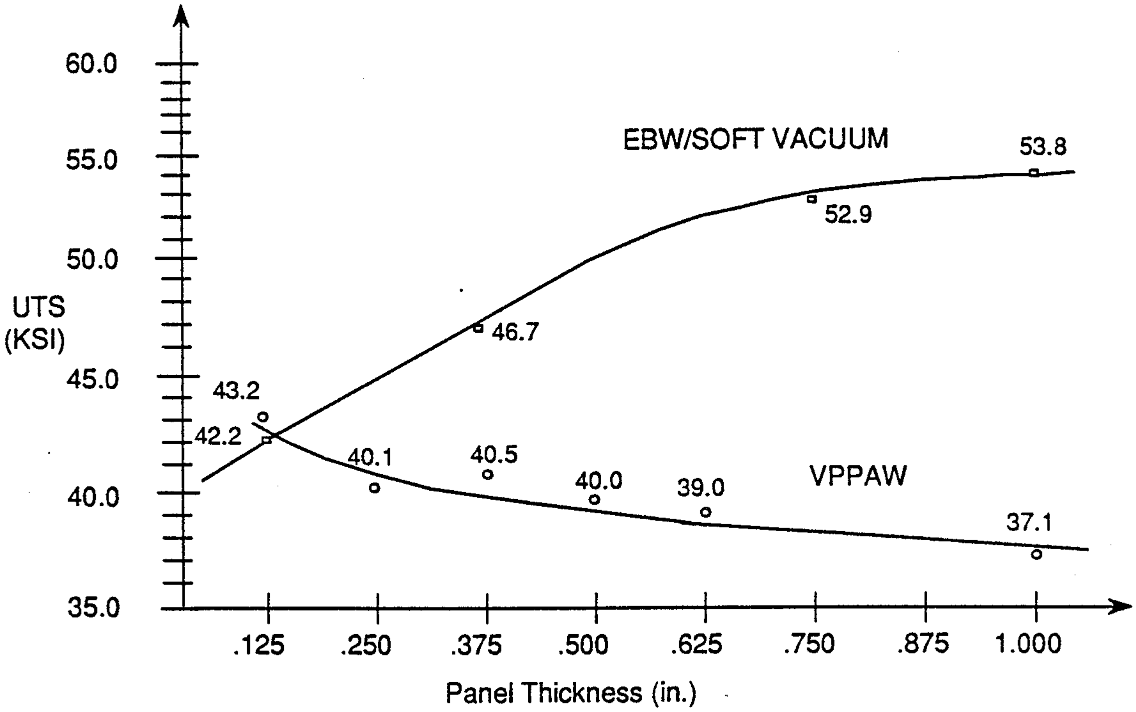


Figure 12.4.1-2 EB Weld Versus VPPA for 2219-T87 Plate

Figure 12.4.1-3 proposes a concept for local chamber, soft vacuum, EB welding the pressure-fed tank circumferential welds. In this concept the tank barrels and dome are held stationary while the EB welder orbits on a circular guide track as illustrated in Figure 12.4.1-4. This concept was developed jointly with FERRANTI/SCIAKY, Inc. Briefly, the weld cell has an expanding internal mandrel used for alignment of the weld joint. The internal and external vacuum chambers are sealed for vacuum pump down by inflatable seals. The EB gun and carriage include features for weld seam scanning and tracking. After welding, the tank is hydraulically raised on its support to position the weld at the ultrasonic inspection station. The water coupled ultrasonic head scans the weld for NDE. Weld preparations are completed off line by dry machining on a dedicated boring mill. Barrels and domes are delivered from the mill and placed in position by an automatically guided vehicle. A major side benefit of EB welding is the ability to weld with the tank elements stacked vertically compared to horizontal fixturing. This procedure reduces barrel and dome handling for rotation to horizontal position and vastly improves alignment and fit-up capability versus horizontal fixturing.

Our ROM estimates for non-recurring and recurring costs for EB welding versus the GMA process for the pressure-fed tanks are presented in Table 12.4.1-1. These estimates are based on replacing the tank horizontal weld fixtures with (3) vertical cells, and on replacing the tank dome weld fixtures with (2) EB vacuum weld chambers with double fixtures for each chamber (i.e. set-up is made on one fixture while welding is in progress on second fixture). It was assumed for these estimates that pressure-fed components, due to their thickness, are stiff, hold their shape, and can be machined accurately for close fit-up. It was further assumed, due to minimal EB weld shrinkage, that components can be acquired net (after development) and trimming for weld fit up would not be required for barrel-to-barrel and dome gore-to-gore welding. Labor estimates are detailed at the assembly level for this study (i.e. they are not parametric costs).

Our analysis suggests potential for approximately $220,000,000 in program savings. Providing further sub scale development is positive for weld qualification, we recommend that full scale EB weld development be scheduled appropriately with other LRB pressure-fed technology development programs.

12.4.2 Flow Turning

The pressure-fed propellant tank construction uses integral flow turned barrels. These barrels are to be manufactured by Ladish Corporation with their proprietary equipment process used on SRB segments but developed for Weldalite™ 049. Ladish Corporation has expressed confidence in the feasibility of this development providing Weldalite™ 049 can be forged similarly

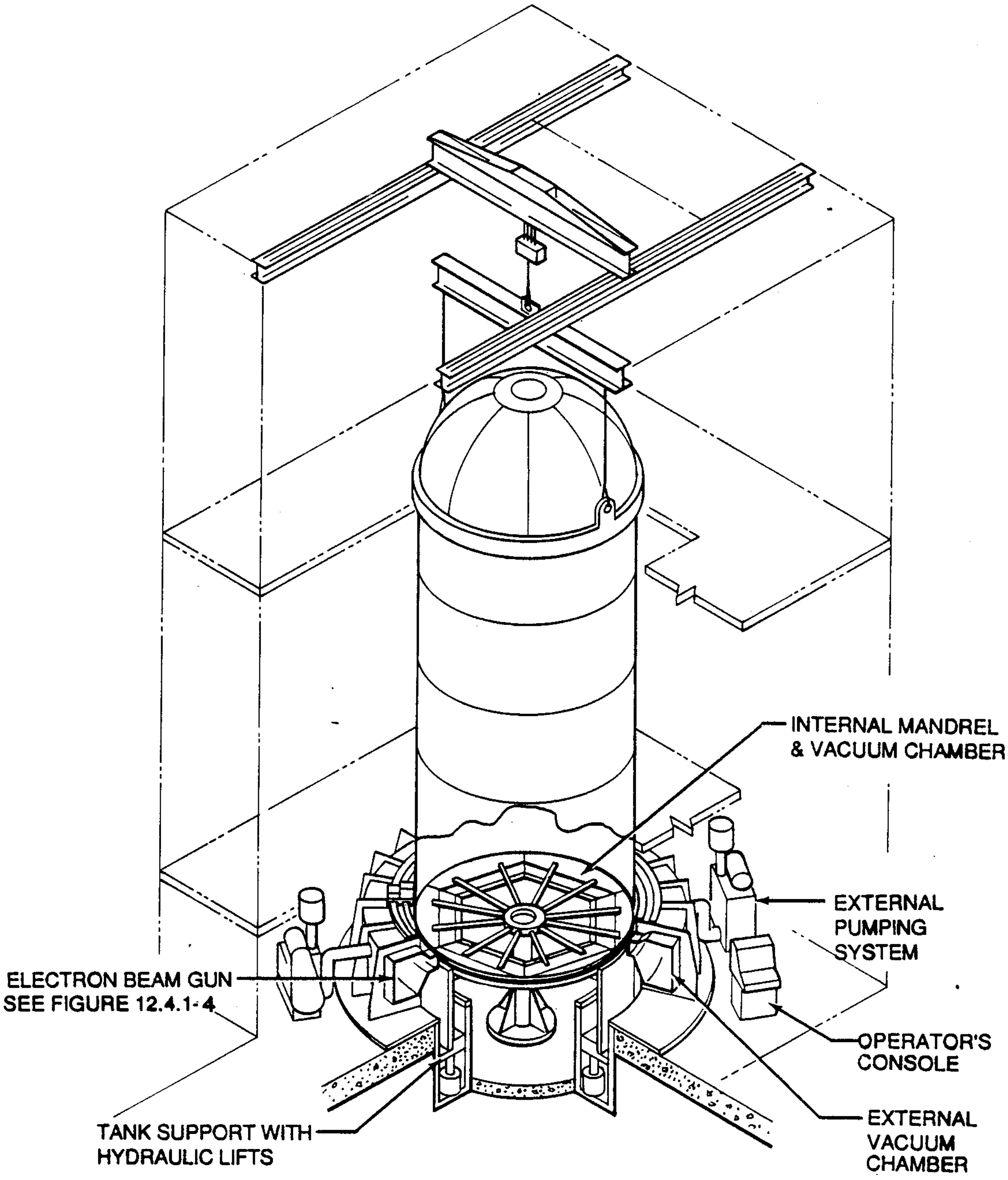


Figure 12.4.1-3 Pressure-Fed Tank Electron Beam Welding Cell

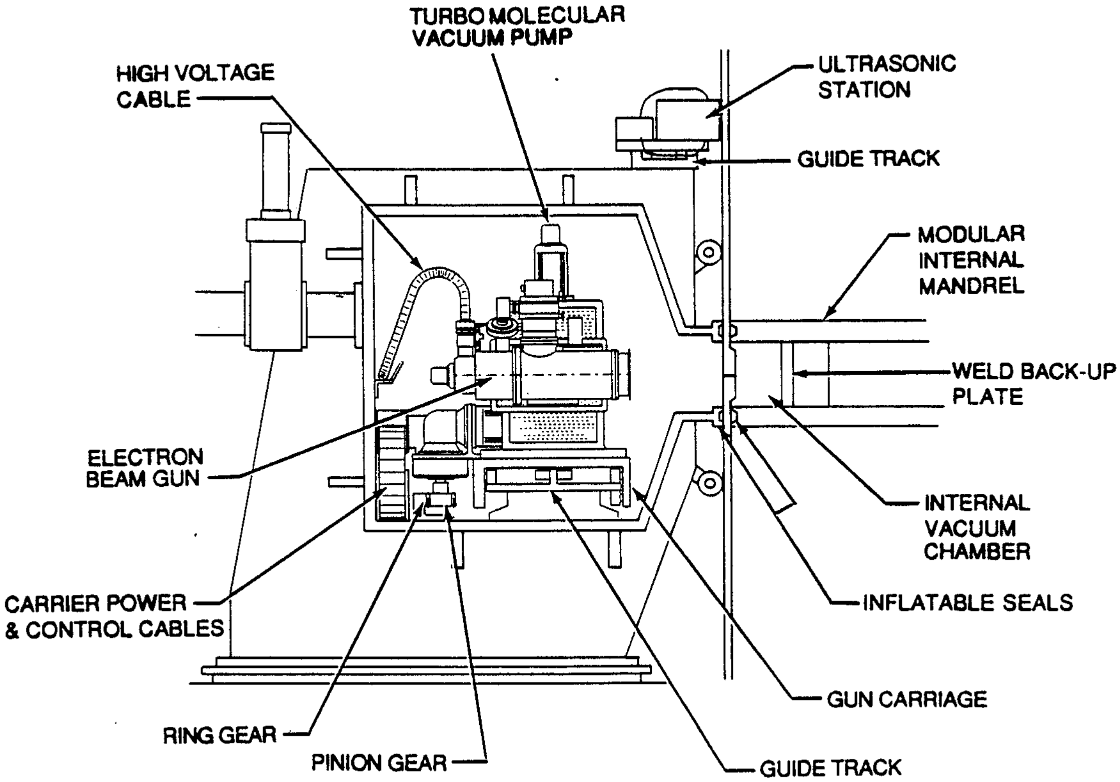


Figure 12.4.1-4 Electron Beam Welding Cell Detail

Table 12.4.1-1 ROM Cost Estimates Electron Beam Welding Vs VPPA-GTA/GMA

ITEM	VPPA GTA / GMA	EBW	"Delta" Cost EBW
Non- Recurring Costs ($M)			
Tooling	$20.0	$ 6.0	-$14.0
Weld Equipment	$15.0	$ 9.0	-$ 6.0
Construction (125000 S.F. Vs 43000 S.F.)[1]	$31.0	$22.0	-$ 9.0
Totals	$66.0	$37.0	-$29.0

Recurring Costs[2]			
Material	--	--	--
Subcontract	--	--	--
Labor	$264.7	$71.0	-$193.7
Totals	$264.7	$71.0	-$193.7

Note1 25000S.F.Vertical Cells
Note2 TotalProgram 244 Units

Grand Total -$222.7

to 2219 Aluminum.[1] Ladish has planned a demonstration of aluminum flow turning using 2219 Aluminum. At this time, material has been procured but processing has not been commenced.

A new flow turning machine and new tooling will be required to process the 194 inch diameter pressure-fed barrels. Maximum capability of existing equipment is 160 inches. A new machine with tooling will cost $10-12,000,000.[2] Amortization of these costs plus $1-2,000,000[2] development costs for flow turning Weldalite™ 049 is more cost effective than applying alternative manufacturing to produce the (2196) barrels required for the LRB program. Machined ring-rolled forgings are the primary alternative to flow-turned barrels, and their production would require considerable additional material and machining time versus flow-turned barrels. It will be necessary to develop the flow-turned barrel process and procure equipment by late 1992. With Ladish process development beginning now on 2219 Aluminum and with ring-rolled forgings as an alternative, this is not a high risk area.

12.4.3 One Piece Helium Pressurant Tank Domes

The helium pressurant tank configuration proposes two (2) one piece hemispherical domes welded at the girth. Material is Weldalite™ 049. Weld land thickness at the girth is 3.3 inches and the dome inside diameter is 146 inches. Industry capability exists to hot press and spin heads of this thickness and diameter. However, development will be required on the process to control spin form thinning and to resolve machining and heat-treatment techniques. The 190 inch diameter requirement for a preform blank exceeds available mill stock widths; presaging development work to produce an adequate size blank forged from an ingot. Technical risk associated with production of one piece domes appears low. Development should be considered enhancing technology as other approaches would be to develop a welded preform blank or eschew spinning altogether and use the more expensive gore type construction.

12.4.4 Al-Li Manufacturing Requirements

As with any new material, extensive development programs will be required for Weldalite™ 049 to establish and verify fabrication processes and qualify the products for flight use. We anticipate that application of Weldalite™ 049 on the ET and development for other new programs such as ALS will drive fabrication process development in advance of the LRB program. Rapid progress is expected in 1989 as Weldalite™ 049 rolled sheet and plate become available in tonnage quantity from Reynolds Aluminum Company. Expenditure of approximately $1,000,000 has been identified at MAF for Weldalite™ 049 development in fiscal year 1989. This funding is anticipated from IR&D M40D, Aluminum-Lithium Alloys, NASA Technical Directives 690 and 691; and Engineering Service Order 89805, Engineering Aerospace Alloys.

Reference Page

Reference 1-Telephone conversations R.E. Jones, MMMSS, and R.D. Troyer, Sales Engineer, Ladish Corp. period April to October, 1988.

Reference 2-Martin Marietta Manned Space Systems estimates based on discussions with R.D. Troyer per Reference 1.

13.0 OPTIMIZATION STUDIES

In the Part 3 extension program, additional work was performed optimizing vehicle configurations and performance. Section 13.1 describes configuration optimization, 13.2 describes propulsion system optimization, and 13.3. describes vehicle performance optimization. Additional work was performed optimizing manufacturing methods and cost and is described in Section 12.4, Manufacturing Development.

13.1 CONFIGURATION DESIGN

13.1.1 Pump-Fed Vehicle Material

The initial design of the pump-fed vehicle was based on strength considerations. Material trade studies performed at that time were based on propellant tank barrels with integral machined stiffeners and thin skin shells resulting in a high strength, low weight design. When it was determined that on-pad displacements after SSME ignition were excessive and flight control system authority after launch was unstable, the pump-fed design was changed to provide the necessary overall stiffness. The stiffening was accomplished by changing both tank and skirt shells from stringer stiffened shells to 0.5 in thick monocoque plate shells. Using a rolled plate concept instead of machined integral stiffened panels resulted in considerably lower fabrication costs even though the structural weight was significantly increased.

The original material trade studies were then reviewed to determine if the outcome of the trade would change. Weldalite™ 049, the winner of the original trade based on strength was compared with 2219 aluminum. Again 2219 aluminum came out a close second to Weldalite™ 049 mainly because of the higher density and increased weight of the 2219 material, .103 lbs/in.^{3} to .097 lbs/in.^{3} for Weldalite™ 049. Performance trades showed that the 2219 based vehicle did not quite achieve the 70,500 lb payload requirement whereas the Weldalite™ 049 resulted in excess payload. Results of the second trade study, S-8B, are shown in Figure 13.1.1-1.

At that same time, additional detail design definition in the pump-fed vehicle caused significant changes to vehicle size and weight. It became apparent that vehicle sizing had to be optimized and finalized so that final performance parameters could be determined.

13.1.2 Vehicle Sizing

As more definition was put into both pump and pressure-fed vehicles, the dry weight of the vehicles generally increased. This increase led to an increase in propellant weight and volume

Discipline: Structures
Trade No: S-8B
Title: Materials Trades (Pump-Fed)
Baseline: Weldalite™049
Candidates: 2219, 2090, HP 9-4-30
Selection Criteria:

Criteria	Wgting Factor	Weldalite™049		2219		2090-T8E41		HP 9-4-30	
		Score	Wgt Score	Score	Wgt Score	Score	Wgt Score	Score	Wgt Score
Costs	10	9.5	95	10	100	9.5	95	6	60
Performance	20	10	200	6	120	9	180	2	40
Manufacturing Complexity	20	6.5	130	10	200	6	120	7	140
Weight	20	10	200	6	120	8	160	1	20
Technical Risks	10	9	90	10	100	9	90	7	70
Schedule Risks	10	9	90	10	100	9	90	9	90
Safety	10	8	80	10	100	7	70	10	100
	100		885		840		805		520

Figure 13.1.1-1 LRB Trade Studies Plan

requirements which led to larger diameters in the vehicles. An increase in the pump-fed diameter led to a thinner tank wall thickness required for stiffness which reduced dry weight.

To resolve these sizing iterations, a design optimization process was initiated which consisted of cross plotting four variables important to structural weight and stiffness. These variables were total propellant weight, tank diameter, tank wall thickness, and resulting STS payload weight. The WASP Program was utilized to run a matrix of values for the variables to determine payloads and the data was then plotted in a three-dimensional carpet plot. Pump-fed vehicle results with Weldalite™ 049 are shown in Figure 13.1.2-1 and with 2219 aluminum in Figure 13.1.2-2. With this sizing method, designs which met the 70,500 lb payload were readily configured. As shown on the two charts, the Weldalite™ 049 vehicle was optimized with 70,500 lb payload at approximately 940,000 lbs of propellant, 182 in. diameter, and 0.5 in. tank wall thickness while the 2219 aluminum vehicle optimized at approximately 956,000 lbs of propellant, 183.6 in. diameter and 0.5 in. tank wall thickness. The 2219 aluminum vehicle required 16,000 lb more propellant and 1.6 in. larger diameter to make the 70,500 lb payload. With this type of cross-plotting, the minimum vehicle size required for the 70,500 lb payload predicted by the WASP Program was quickly defined.

13.2 PROPULSION SYSTEM

At the completion of Part 2 Definition Phase of the study, four areas of the propulsion system were identified for further study and optimization. These areas were, engine ignition and shutdown transients, pressure-fed engine inlet feedline design, thrust vector control actuation system, and pressure-fed engine chamber pressure optimization. These studies and results are described in the following sections.

13.2.1 Engine Ignition And Shutdown Transients

Our initial definition of the engine start sequence and the amount of time involved in the start, along with an engine shutdown transient at the completion of the LRB boost phase, led to a very conservative allocation of propellants in the pressure-fed vehicle design. Over 50,000 lbs of propellants were carried in reserve to cover those requirements. With improved definition of the thrust buildup (see figure 13.2.1-1) which takes less than 2.0 seconds and which allows LRB ignition to be initiated after the SSME ignition, the propellant weight was reduced by over 31,000 lb. Review of the engine shutdown transients verified that residual propellants of 5,900 lb were required for the pressure fed and 5,300 lb for the pump-fed vehicles.

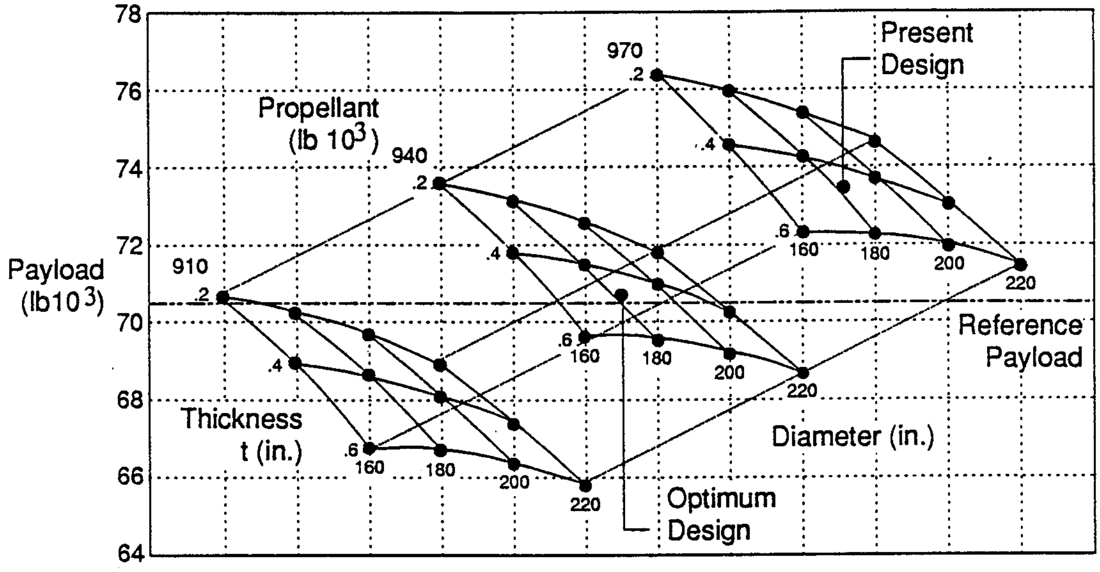


Figure 13.1.2-1 Weldalite™049 Vehicle Size/Payload Relationships

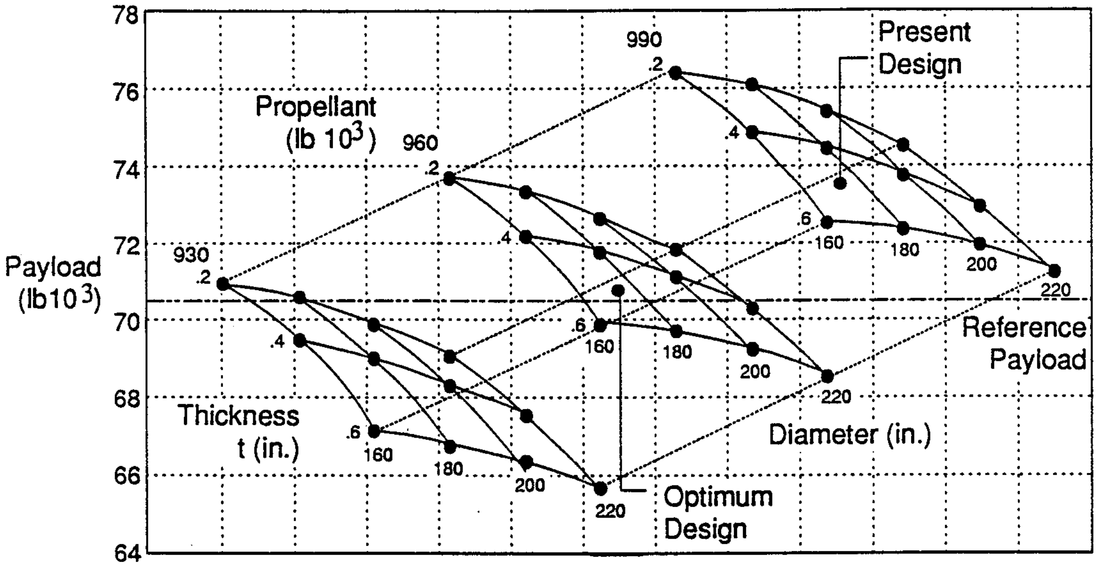


Figure 13.1.2-2 2219 AL Vehicle Size/Payload Relationship

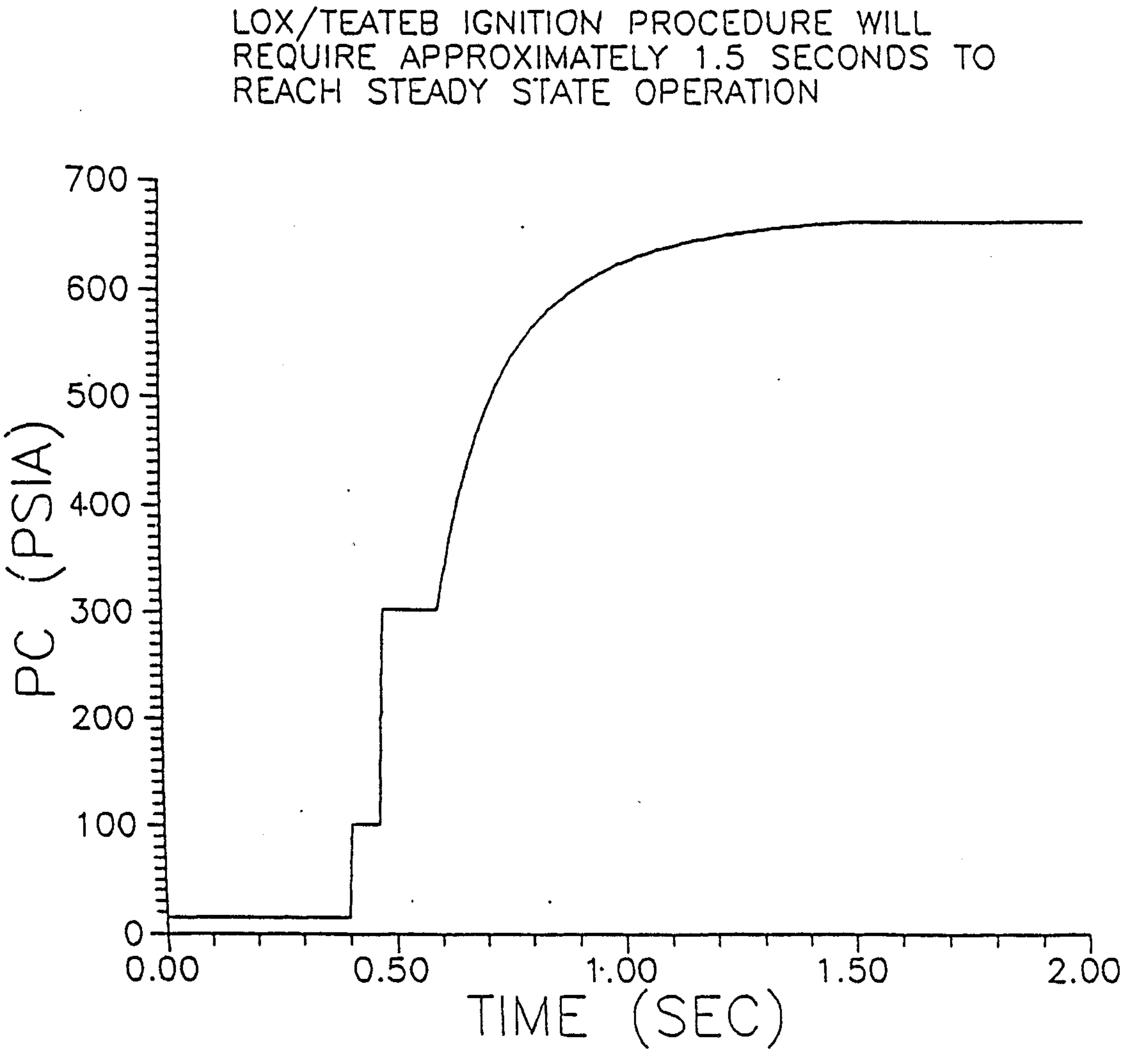


Figure 13.2.1-1 Pressure-Fed Engine Start Transient

As shown in Figure 5.3.1-2, LRB engine ignition T_0 will not begin until 4.18 sec after the start of the sequence. The four engines will be in a stagger start mode a fraction of a second apart. As the initial pitch over displacement of the STS caused by the SSMEs comes back toward neutral, holddown bolts are released and liftoff (T_0) begins at 6.68 sec, just before the minimum point on the deflection curve. It is at this time that the energy remaining in the LRB's from the initial displacement to twang the STS is minimized.

13.2.2 Pressure-Fed Engine Inlet Feedline Geometry

In order to utilize engine gimballing for thrust vector control, TVC, the inlet feedlines were redesigned to include gimbals in each line. The 12.5 in. LO2 line and the 9.7 in. RP-1 line each have three gimbals located as shown in Figure 13.2.2-1 which provide capability for ± 6° about the Y and Z axes.

13.2.3 Ignition System

Aerojet has developed a proven reliability start transient using a mixture of 85 percent triethylaluminum and 15 percent triethylboron (TEA/TEB), which is hypergolic with LO2. The start transient consists of five phases: First, the LO2 flow is established by partially opening the LO2 control valve. The flow is sensed by a rise in chamber pressure reflecting the LO2 vapor cold flow back-pressure. Second, TEA/TEB is injected and hypergolically ignites with the LO2, further increasing the chamber pressure. Third, when the TEA/TEB ignition pressure is sensed, the RP1 fuel valve is partially opened and fuel is injected into the thrust chamber where it ignites with the LO2/TEA/TEB. Fourth, an intermediate level ("Level 1") chamber pressure is sensed which provides the signal to open both the LO2 and RP1 valves to their full open position. Fifth, in a few miliseconds essentially steady state chamber pressure is established without any significant Pc overshoot. It takes approximately one second to fully execute these five steps to steady state condition.

13.2.4 Pressure-Fed Engine Pc Optimization

An analysis was performed to determine the impact of engine combustion chamber pressure (Pc) on the average unit cost of a pressure-fed LRB. The baseline pressure-fed LRB operates at a maximum Pc of 660 psia, a tank pressure of 1000 psia, and is constructed with Weldalite™ 049. Two lower Pc (405 psia) vehicles were sized with the same requirements and constraints as the baseline, one constructed of 2219 Aluminum and one with Weldalite™ 049. Costs were estimated

- Accomodates ± 6° Gimbal

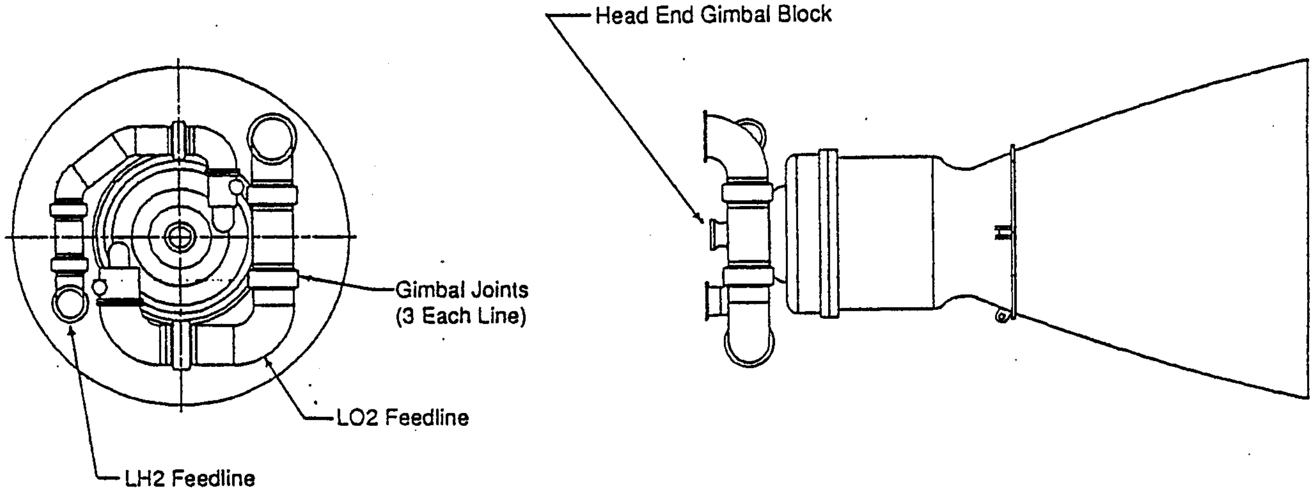


Figure 13.2.2-1 Pressure-Fed Engine Inlet Feedline Geometry

for each. The results shown in Figure 13.2.4-1 illustrates that as the structural cost of the vehicle is reduced as Pc goes down, engine cost goes up so that total cost remains relatively flat. On a cost basis, there was not a clear winner.

13.3 VEHICLE PERFORMANCE

Final performance and trajectory parameters were derived from the Post computer program. It was determined earlier in the study program that between the two sizing programs WASP and POST, the POST Program used by flight mechanics gave more accurate performance results while WASP gave better sizing and weight results. The analysis approach then taken was to use WASP to roughly size the vehicle and propellants and then use POST to make small adjustments to the propellants to optimize the performance.

Optimum performance parameters for both pump and pressure-fed vehicles are shown in Table 5.3.2-1 using fixed vehicle weights and engine data. Propellant volumes were adjusted slightly to obtain optimum performance. Final dimensions for LO2 and RP-1 tanks are shown in Figure 6.1.1-1 for the pump-fed and Figure 7.1.1-1 for the pressure-fed vehicles.

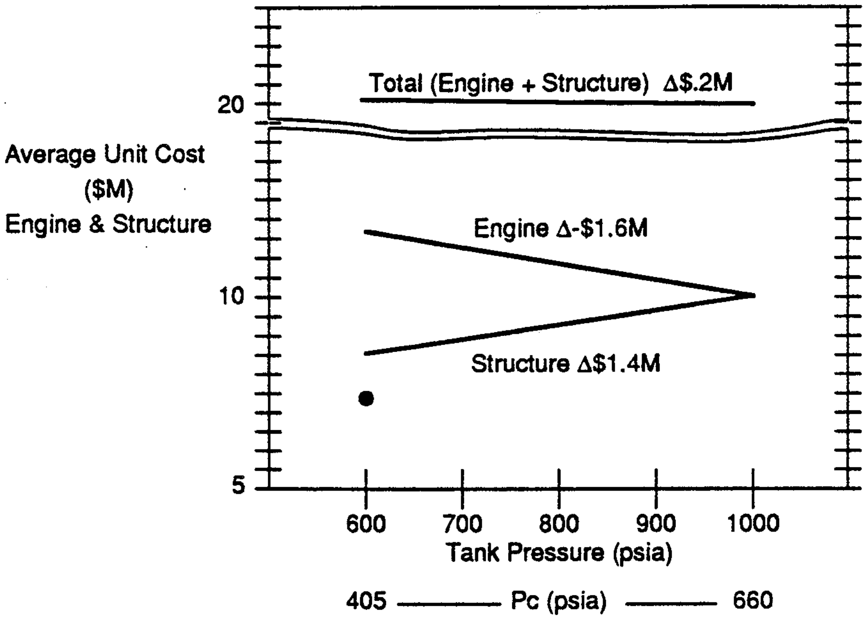
As shown in Table 5.3.2-1, performance for both vehicles was optimized with a reserve on payload of approximately 2,000 lb. The reserve, as shown in the table is 1,999 lb for the pump fed and 2,353 lb for the pressure-fed vehicles. A manager's reserve of this magnitude was felt to be prudent at this stage of design as it would be able to offset unforeseen weight growths in future phases.

Trade Conducted to Determine Costs for Alternate Configurations
- Three Specific Configurations Analyzed

Boosters Sized for Fixed Relative Payloads (70,800 lb, 160 nmi ,28.5° inc)

Unit Costs Remain Relatively Flat for All Three Configurations
- As Pressure is Increased, Structures Costs Grow at Same Rate as Engine Costs Fall

Engine & Structures Cost vs Tank Pressure



	Low Pressure	High Pressure	Low Pressure
Material	2219	Weldalite™049	Weldalite™049
Tank Wall Thickness	1.30"	1.38"	.83"
Weld Land Thickness	1.95"	2.80"	1.70"
Diameter	221"	194"	209"
Injector Holes	1000	500	1000
POGO Supression	Active	Passive	Active
Engine Size	6600 lb	4200 lb	6600 lb
Technical Risk	Higher	Lower	Higher
Performance ISP=	252 S.L./298 Vac	269 S.L./319 Vac	252 S.L./298 Vac
Chamber Cooling	Ablative	Ablative	Ablative
Construction	Monocoque	Monocoque	Monocoque
Weld	Plasma Arc/GMA	Plasma Arc/GMA	Plasma Arc/GMA

Cost Difference is Insignificant: No Clear Winner

Figure 13.2.4-1 Engine & Structure Analysis As Function of Pressure

VOLUME II PART 2

PRESSURE-FED BOOSTER TEST BED SUPPORT

VOL II PART 2 - PRESSURE-FED BOOSTER TEST BED SUPPORT

1.0 PFBTB SUPPORT - OVERVIEW

The scope of work accomplished by Martin Marietta Manned Space systems in support of the Pressure-Fed Booster Test Bed (PFBTB) Program was done in two related but separate efforts. Preliminary tasks were performed under the Liquid Rocket Booster (LRB) Contract No. NAS8-37136, Change Order No. 1, NAS8-37136, Sup. Agreement 1. Follow-on tasks were performed under the LRB Contract Extension NAS8-37136, Sup. Agreement 3, Task 3.

1.1 CO NAS8-37136 SUP. AGREEMENT 1 - 2/88-5/88

The work performed by Martin Marietta Manned Space Systems under LRB Contract No. NAS8-37136 Sup. Agreement 1 from 2/88 - 5/88 was directed towards support of the Pressure-Fed Booster Test Bed, Phase O project with some effort directed towards Phase 1 and Phase 2 support. Martin Marietta tasks were primarily directed toward support of Phase 0 requirements and run tank specification development, Phase 0 program planning and cost analyses and performance of run tank design trade studies. Specific MSFC questions in the areas of stand propulsion systems design and test duration analyses were also answered. The tasks in this effort were performed on an as requested by MSFC basis and were structured to provide program support as the planning for the PFBTB program evolved.

NASA divided the project into three phases. Phase 0 covers the planning, design, procurement, refurbishment, modification, installation and activation activities associated with the test facility and the test bed simulator. Phase 1 covers the design, development, component test and delivery of test articles for the technology hot gas pressurization system and the technology thrust chambers. Phase 2 covers testing of the hot gas pressurization system and technology thrust chambers on the PFBTB as an integrated system.

The initial tasks requested by MSFC were performed and results presented at a review on 4-12-88. These tasks included:

1) Phase 0 requirements and run tank specification review and comments
2) Phase 0 WBS
3) Phase 0 Statement of Work outline
4) Phase 0 Cost and Schedule
5) Preliminary funding plan, issues and impacts
6) Answers to MSFC Action Item Requests on test engine cluster rationale, pressurant flow rates and run tank volumes.

At this point MSFC requested additional effort in the areas of requirements review and scoping, questions on test time, further review of run tank specifications, performance of run tank trades and further program planning to scope the program tasks. Martin Marietta then accomplished the following specific tasks:

1) Review and comment on GDC requirements document. Develop a requirements document outline.

2) Develop recommended test duration times for various test objectives

3) Review and comment on latest MSFC run tank specifications

4) Perform run tank trades studies

5) Perform program planning to scope major work packages to accomplish the Phase 0 Project.

Also, as a follow-up to task 3 efforts above the final versions of run tank specification No. SP031488LM, RP-1 Vessel, and No. SP031288LM, LH2/LO2 Vessel were reviewed and comments presented verbally to MSFC. The results of these initial PFBTB support efforts were documented in an interim report and were sent to MSFC under contract Letter 88 MO-0943, dated June 24, 1988.

1.2 CONTRACT EXTENSION - 8/88-12/88

LRB Contract Extension NAS8-37136 Sup. Agreement 3, Task 3, 8/88-12/88: Task 3 of the LRB Contract extension outlined in Change Order No. 3 specified certain PFBTB support as requested by NASA. NASA elected to confine the support effort to three areas.

One area of support was PFBTB programmatics. The tasks accomplished by Martin Marietta Manned space systems were development of a program work breakdown structure (WBS), task planning including a task tree and preparation of task packages, generation of a program schedule consistent with NASA guidelines and estimation of program costs and manpower requirements.

Another area of PFBTB support was associated with the redesign of certain test stand structure. Martin Marietta analyzed the run tank support structure consistent with the PFBTB requirements. Analysis tasks included development of a NASTRAN model of the F-1 stand structure, loads definition and stress analysis of critical support members. Other tasks in this effort included design of run tank support structure modifications, and preparation of support structure CAD drawings.

Finally, Martin Marietta supported the PFBTB project with some on-site support at MSFC. This consisted of a two person effort over the five month performance period for Task 3. One person provided direct support to NASA in the preparation of PFBTB documentation and the other performed various technician services on the F-1 stand as directed by NASA.

2.0 PFBTB PROGRAMMATICS SUPPORT

The objective of the test bed programmatics support task was to provide a management plan for the program. The planning activity provides the documentation and information necessary to effectively plan and manage the test bed activities. Six documents and computer files have been provided to the NASA program manager. Each of the documents are interrelated and together provide a consistent approach for the management of this program. The documents are: the WBS matrix, the WBS tree diagram, the program task plans, the program tasks trees, the schedules, and the cost estimates.

The purpose of the documents are to detail the activities that must occur to prepare the system for operation and to provide estimates of the cost to implement the plans. Close coordination with personnel at MSFC helped to insure the program remained up-to-date as planning revisions were made.

2.1 WORK BREAKDOWN STRUCTURE (WBS)

The WBS for the LRB Test Bed program is represented in both matrix and hierarchical formats. The matrix is two dimensional. The columns identify the program phases and functions and the rows represent the various hardware elements that comprise the program. For this WBS, the term "hardware" is a broad interpretation that represents studies as well as physical items.

The intersection of any column and row uniquely identifies a function that must be performed against a particular piece of hardware. The WBS matrix, then, identifies every function that has to be performed in order to accomplish the entire program. Thus it is a valuable management tool: offering an overview of the work that must be accomplished.

The WBS matrix (Table 2.1-1) is coordinated with the task plans . The task plan identify four primary organizations responsible for the accomplishment of the test bed program. At each intersection of the matrix where a function must be performed, there is a symbol for the responsible organization. The matrix, then, not only identifies the work to be accomplished, it also identifies who is responsible.

The WBS tree diagrams (Figure 2.1-1) present a hierarchical view of the WBS matrix. This format is suitable for presentations. The tree structure separates the major hardware elements and details the lower level hardware associated with each.

2.2 TASKS

Table 2.1-1 WBS Matrix

LIQUID PRESSURE-FED BOOSTER TEST BED		PROG. SUPT. 10		ENGINEERING SUPPORT 20			EQUIPMENT 30		FACILITIES 40			OPERATIONS SUPPORT 50	
		11	12	21	22	23	31	32	41	42	43	51	52
		MANAGEMENT	PLANNING	STUDY	DESIGN	SE&I	PROCUREMENT	FAB. / REFURB.	DESIGN	CONSTRUCTION	ACTIVATION	OPERATIONS	ANALYSIS
PRESSURE-FED BOOSTER SYSTEM	00-00-00												
INTEGRATED SYSTEM	01-00-00	N/A	N/A	N/W	W	N	N/A	A	N/W/O	N	A		N/A
TEST STAND	02-00-00			N/W	N/W	N	N/A	N/A	W/O	N	A	A	
-PROPELLANT SYSTEM	02-01-00							A	W	N	A	A	
--LO2 TRANSFER SYS.	02-01-01									N			
--RP-1 TRANSFER SYS./STORAGE	02-01-02							A		N			
-DELIVERY SYSTEMS	02-02-00							A	W	N	A	A	
--HYDRAULIC DELIVERY SYSTEM	02-02-01							A		N			
--GHe DELIVERY	02-02-02							A		N			
--AIR DELIVERY - MISSLE GRADE	02-02-03							A		N			
--FACILITY GN2 DELIVERY	02-02-04							A		N			
--VACUUM DELIVERY	02-02-05							A		N			
-SAFETY SYSTEMS	02-03-00							A	W	N	A	A	
--HAZARDOUS GAS DETECTION SYS.	02-03-01												
--AREA WARNING SYSTEM	02-03-02												
--GASEOUS FIRE PROTECTION SYS.	02-03-03												
-STRUCTURES	02-04-00							A	W/O	N	A	A	
--FLAME DEFLECTOR	02-04-01								W	N			
--ASPIRATOR/ROLLING DECK	02-04-02								W				
--STAND TRUSSES & PLATFORMS	02-04-03								N/O				
--OTHER STAND STRUCTURES	02-04-04								W				
-FACILITY POWER & CONTROLS	02-05-00							A	W/O	N	A	A	
--SUBSTATIONS/MCC	02-05-01												
--DC POWER SYSTEMS	02-05-02												
--CONTROL SYSTEM	02-05-03												
--NETWORKS INTERFACE SYSTEM	02-05-04												
--SOUND POWER	02-05-05												
--FILM CAMERA SYSTEM	02-05-06												
--EMERGENCY SHUT DOWN	02-05-07												
-DATA ACQUISITION	02-06-00						N/A	A	W/O		A	A	
--BLOCK HOUSE SYSTEMS	02-06-01						N	A					
--STAND SYSTEMS	02-06-02						A	A					
-HIGH PRESSURE H2O SYSTEM	02-07-00							A	W	N	A	A	
--FIREX	02-07-01							A		N			
--FLAME DEFLECTOR WATER SYS.	02-07-02							A		N			
-GROUND SERVICE EQUIPMENT	02-08-00						N				A	A	

N = NASA
A = ACTIVATION/OPS CONTRACTOR
W = WYLE
O = OTHER

Table 2.1-1 WBS Matrix (cont)

LIQUID PRESSURE-FED BOOSTER TEST BED		RESEARCH & TECHNOLOGY											
		PROG. SUPT. 10		ENGINEERING SUPPORT 20			EQUIPMENT 30		FACILITIES 40			OPERATIONS SUPPORT 50	
		11	12	21	22	23	31	32	41	42	43	51	52
		MANAGEMENT	PLANNING	STUDY	DESIGN	SE&I	PROCUREMENT	STE FAB.	DESIGN	CONSTRUCTION	ACTIVATION	OPERATIONS	ANALYSIS
STRUCTURE SIMULATOR	03-00-00			N/O	N/O	N	N	N/A			A	A	
-COLD GAS PRESSURIZATION SYSTEM	03-01-00				N/W	N	N	N/A			A	A	
--GN2 CNTRL/DIST. SYSTEM	03-01-01				W			A					
--GN2 TANKAGE & MANIFOLD	03-01-02				W			N					
-PROPELLANT 'RUN' SYSTEM	03-02-00			O	N	N	N	A			A	A	
--PRESSURE VENT/RELIEF	03-01-03				N			A					
--LO2/RP-1 FEED LINES & VALVES	03-02-01												
--ANTI-GEYSERING SYSTEM	03-02-02												
-BOOSTER INSTRUMENTATION SYSTEM	03-03-00				N	N	N	A			A	A	
-ENGINE CONTROL SYSTEM	03-04-00			O	N	N	N	A			A	A	
--ENGINE POWER	03-04-01												
--ENGINE MIXTURE CONTROLLER	03-04-02												
-BOOSTER CONFIGURED STRUCTURE	03-05-00				N	N	N	N/A			A	A	
--TANK/TANK ATTACHMENT STR.	03-05-01							N/A					
--TANK/STAND ATTACHMENT STR.	03-05-02							A					
--ENGINE SUPPORT STRUCTURE	03-05-03							A					
-PROPELLANT TANKS	03-06-00			O	N	N	N	A			A	A	
--OXIDIZER RUN TANK	03-06-01												
--FUEL RUN TANK	03-06-02												
-TECH. THRUST CHAMBER ASSY.	03-07-00			O	N/O	N	N	A			A	A	
-HOT GAS PRESSURIZATION SYSTEM	03-08-00			O	N/O	N	N	A			A	A	
PROPULSION SYSTEM	04-00-00			N									
-COMBUSTION STABILITY STUDIES	04-01-00			N									
--HIGH f	04-01-01												
--LOW f	04-01-02												
--FAC STRUCT INTERACTION	04-01-03												
-ENGINE CONTROL STUDIES	04-02-00			N									
--PROPELLANT CONTROL SYSTEM	04-02-01												
--START/STOP TRANS. STUDY	04-02-02												
-PROPULSION CONTROL	04-03-00			N									
-THERMAL	04-04-00			N									
-VIBRO/ACOUSTIC	04-05-00			N									
-MODEL DEVELOPMENT	04-06-00			N									
--I/S PERFORM MODEL	04-06-01												
--SYSTEMS DYNAMIC	04-06-02												
--CONTROL SYST MODEL	04-06-03												
--START/STOP TRANS MODEL	04-06-04												
--CG PRESS MODEL	04-06-05												
--HG PRESS MODEL	04-06-06												

N = NASA
A = ACTIVATION/OPS CONTRACTOR
W = WYLE
O = OTHER

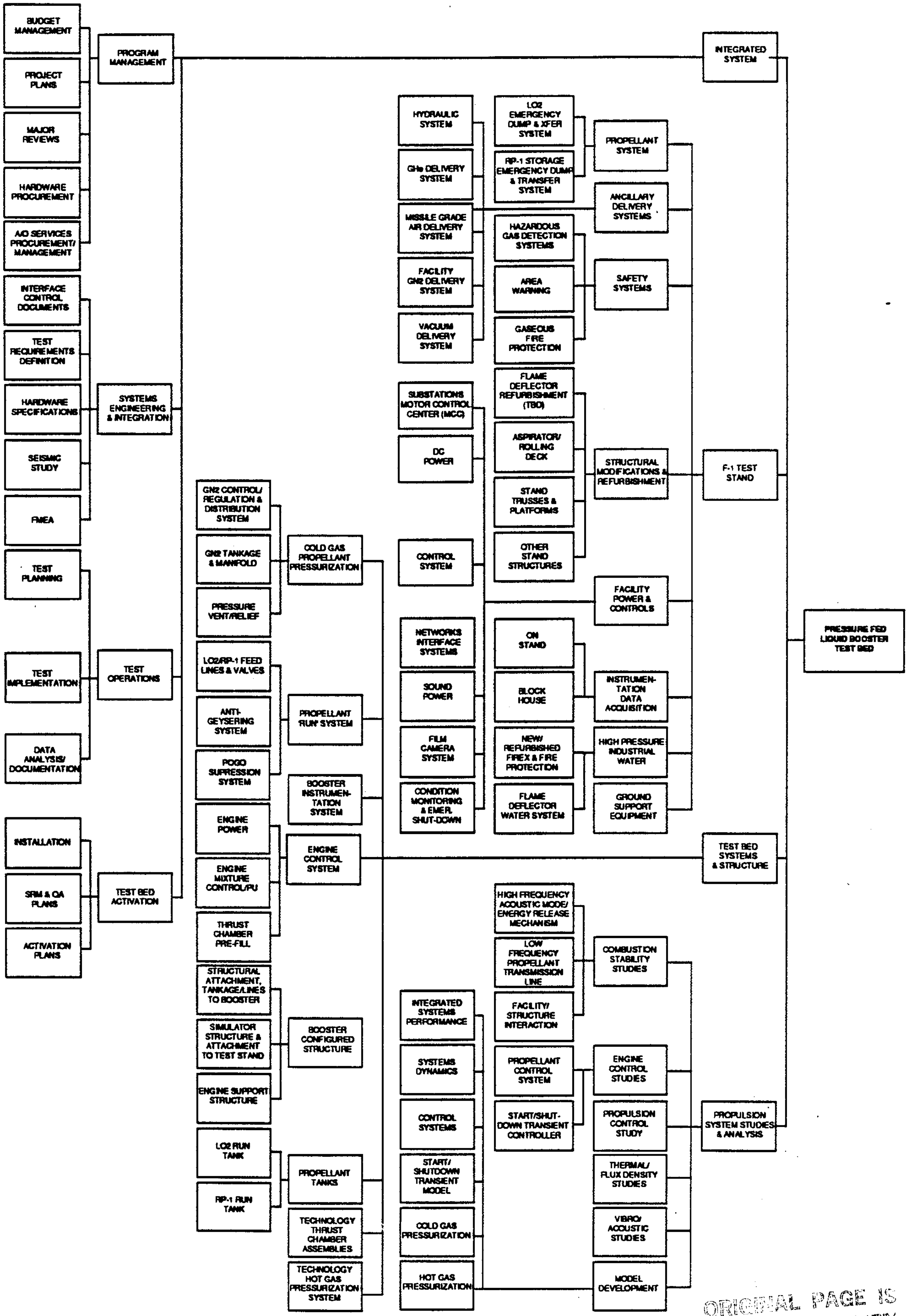


Figure 2.1-1 WBS Tree Diagrams

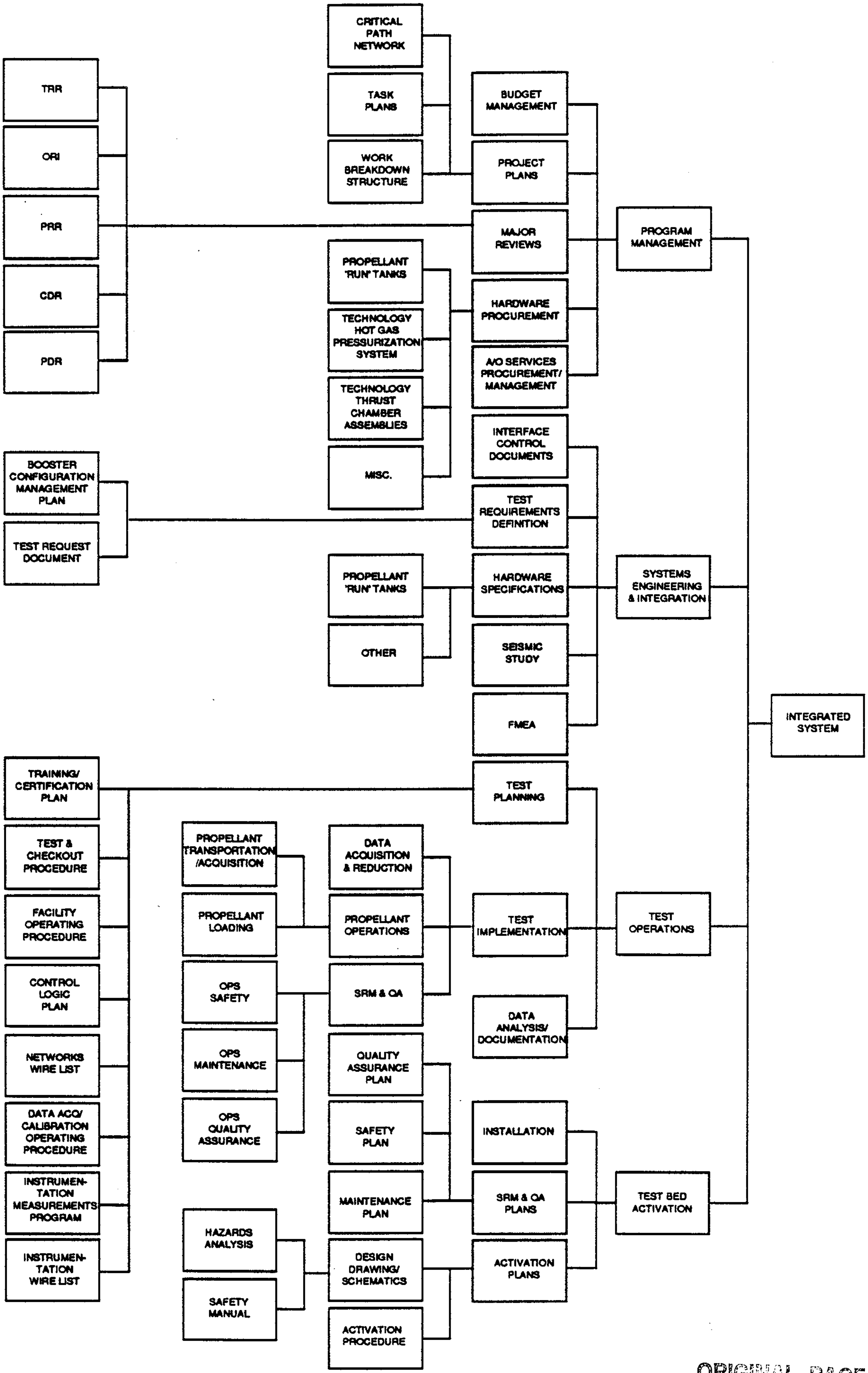


Figure 2.1-1 WBS Tree Diagrams (cont)

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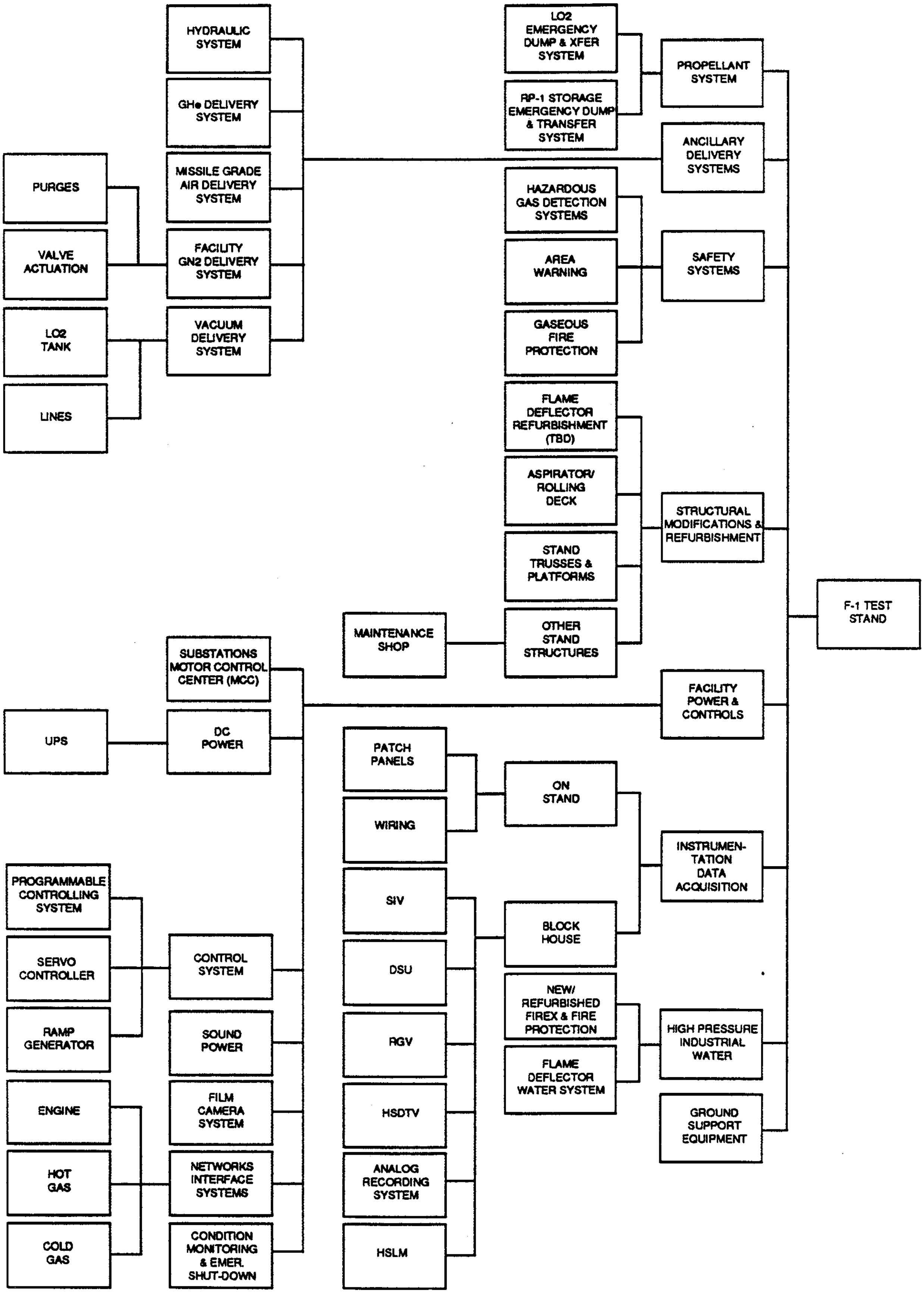

Figure 2.1-1 WBS Tree Diagrams (cont)

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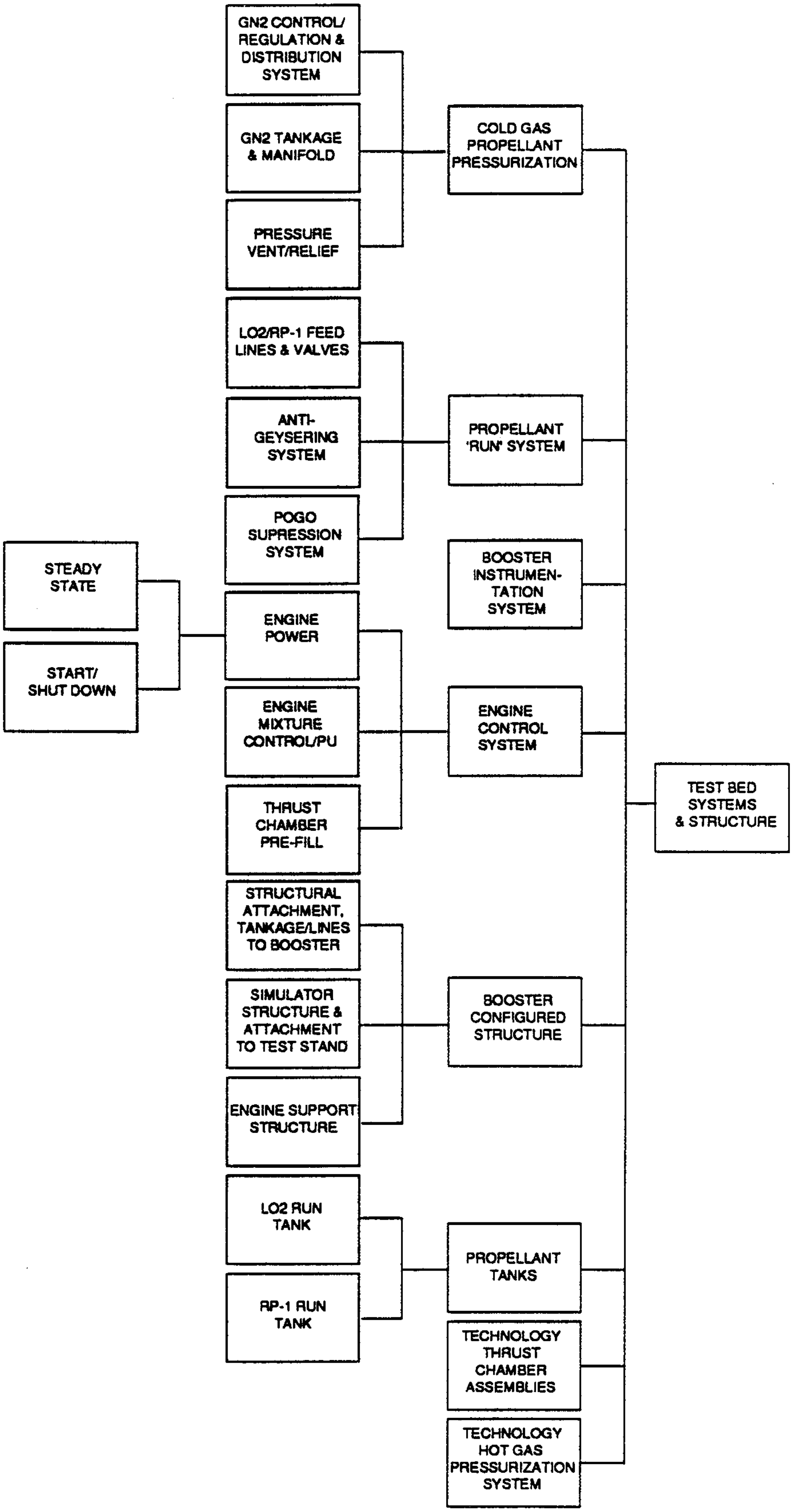


Figure 2.1-1 WBS Tree Diagrams (cont)

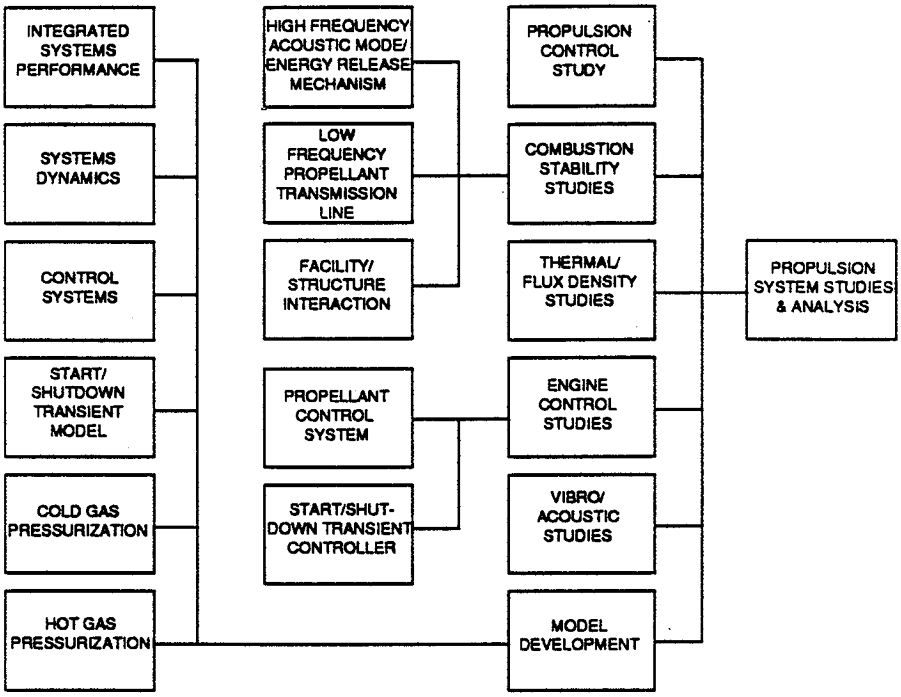


Figure 2.1-1 WBS Tree Diagrams (cont)

2.2.1 Task Tree

The WBS matrix is consistent with all of the program plans for this project. The program task trees (Figures 2.2.1-1 &2) group the work, identify a responsible party for each function and define all of the functions required of each organization. This document will make it easy to assign tasks such that the program will be accomplished by various work groups, and account for all tasks.

2.2.2 Task Plans

The following task plans descriptions will expand on the task trees. They take each element of the task tree and fully describe the activity that will be required to complete it. The descriptions of the task tree are intended to provide a more detailed assessment of the work to be accomplished under each subfunction

Task I, Program Management

This task will provide for all of the overall program management activities necessary to properly plan, manage, and control the PFBTB Project. Program management will address all aspects of the project such as systems and hardware requirements, design, procurement, modifications, fabrication, installation, activation, and test activities. Program performance and budget status will be tracked on a regular basis to ensure that program milestones are met per the established schedule and budget plan. Program progress and expenditures will be continually analyzed and corrective action plans developed were necessary. This task will also include coordination with all PFBTB contractors as a part of this task. Special emphasis will be directed towards interaction with and direction of the PFBTB Activation/Operations contractor.

In addition to the management functions described above, this task will also include the program planning functions needed to scope and control the project. Budget plans will be developed and project planning documents such as the work breakdown structure (WBS), the task plans, and a critical path network will be generated. These plans will be updated on a regular basis as the project progresses. A system of reporting will be developed and administered to present project performance against project plans on a regular and timely basis.

Task II, F-1 Test Stand/Facilities

This task is comprised of all of the efforts necessary to prepare the F-1 Test Stand and supporting facilities for operation. The effort includes all facilities study and design work, as well as the refurbishment, construction, and modifications required to test technology thrust chambers, technology pressurization systems, and propellant feed systems.

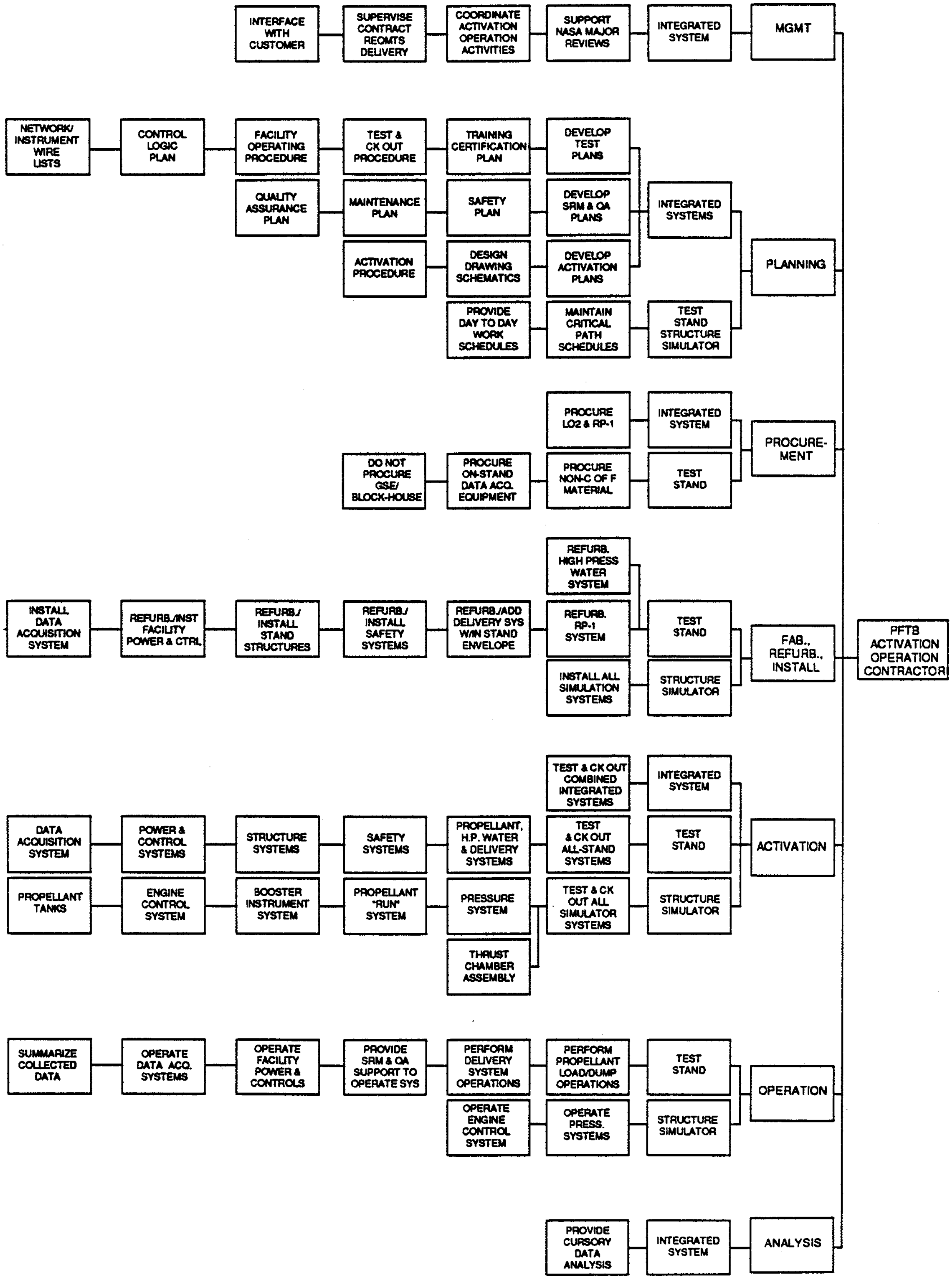


Figure 2.2.1-1 Program Task Trees

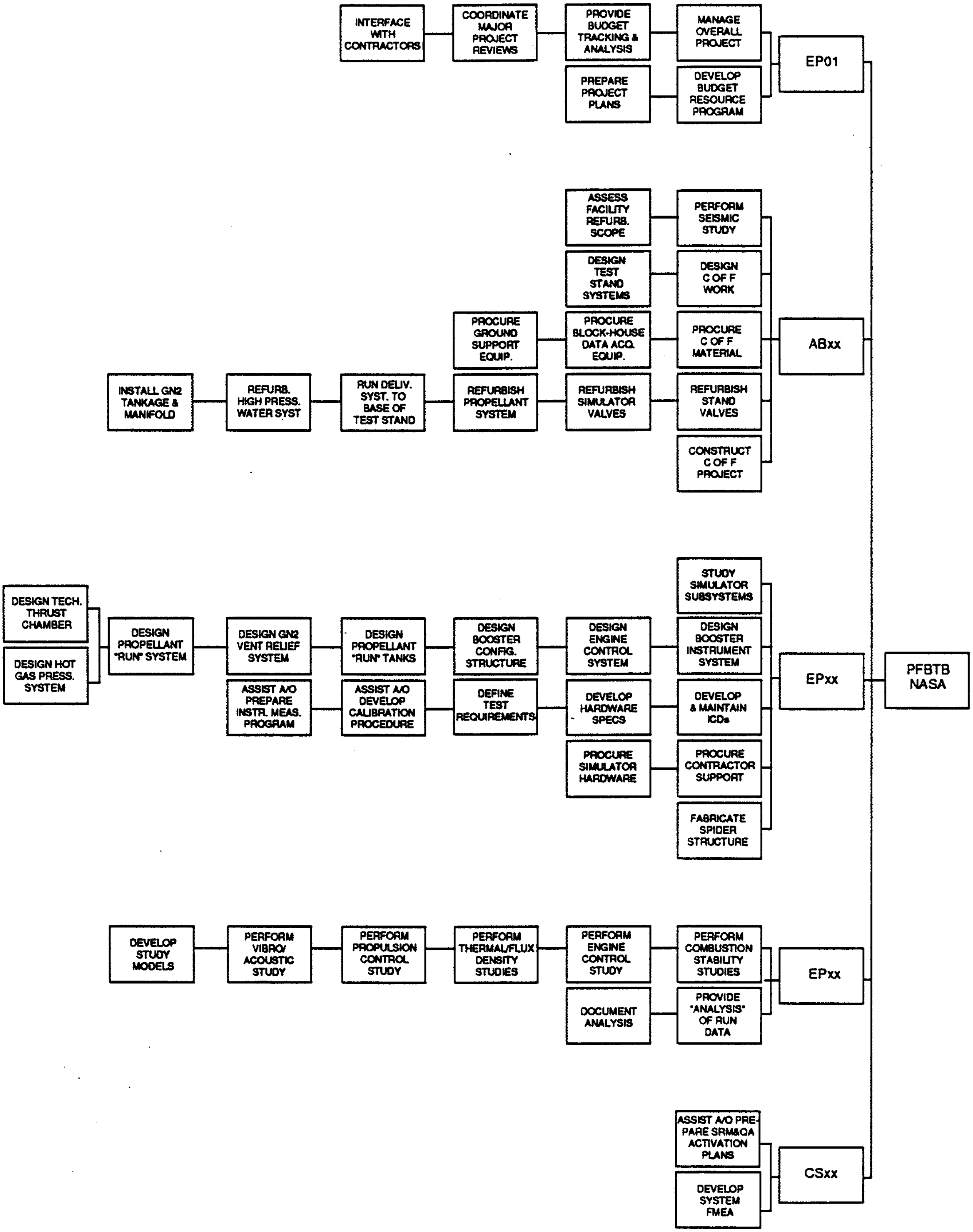


Figure 2.2.1-2 Program Task Trees

N-002/jer

The task shall include the supervision of the Activation/Operations contractor services as described in Task I. Additionally, the task includes supervision, inspection, and engineering services required for all "C of F" activities.

Specific study task responsibilities include: supervision and acceptance of a seismic study performed by a support contractor and supervision and approval of an overall facility requirements definition for the PFBTB effort.

Task II responsibilities includes the complete design of test stand systems from all funding sources. Procurement of contractor services for design efforts will be the responsibility of the task lead. In addition, the task lead will have the responsibility to conduct appropriate design reviews(30%,60%,90%) and approve the final drawings. The task lead shall have the responsibility for procuring the long lead material for all projects.

Additional responsibilities include normal procurement activities for all block-house data acquisition equipment and ground support equipment. Such activities include specification preparation, bid package preparation, and bid evaluation selection.

Arrangements will be made with the construction refurbishment contractors to deliver valves that require refurbishment to the NASA valve shop. The task lead will be charged with the responsibility of coordinating timely refurbishment of such valves.

The task lead will have the responsibility of providing service ties from the system source to the base of the test stand for all delivery systems. Such systems include hydraulics, GHe, Missile grade air, GH2, and vacuum service.

Task III, Simulators/Systems

This task will provide the analytical studies design, SE&I, procurement and fabrication activities to support the PFBTB simulator and its associated systems. Studies will be performed to support the design effort where needed. The two major study efforts will be for the technology thrust chambers and the hot gas pressurization system. These studies will be done by the appropriate contractors under NASA direction.

The simulator and its associated systems will be designed under this task. Designs for each of the following systems will be required. A design shall be provided for the booster instrumentation system. The engine control system design will include details for engine power control, engine mixture ratio control and propellant utilization, and the thrust chamber pre-fill system. The booster configured structures design will include the structural attachment of lines and miscellaneous hardware to the booster, the structural attachment of the complete simulator to the thrust stand, the tank-to-tank spider assembly and the engine support structure. The propellant run tanks, LO2 and RP-1, will be designed by the tank vendors under NASA direction. The cold Gas (GN2) propellant pressurization system design will include the GN2 control/regulation and distribution system, the GN2 tankage and manifolding and the pressure vent/relief system. The designs of the technology thrust chambers and the hot gas pressurization system will be performed by the selected contractors under NASA direction.

This task will also include systems engineering and integration (SE&I) subtasks associated with the PFBTB simulator. Interface control documents (ICD's) will be developed and maintained. Hardware specifications will be developed. These will include the run tanks and other simulator hardware. Another SE&I subtask will include definition of test requirements which will be supported by a booster configuration management plan and unique test request documents. Other SE&I subtasks will include helping the Activation/Operations (A/O) contractor develop the instrumentation calibration procedures and an instrumentation measurement program.

Simulator procurement activities covered by this task include procurement of the A/O Contractor services and all simulator hardware. Simulator hardware includes the run tanks, the technology thrust chambers, the technology hot gas pressurization system and other miscellaneous hardware.

The only fabrication element of this task consists of the fabrication of the tank-to-tank attachment structure. All other elements will be procured.

Task IV, Propulsion Analyses

This task will provide the analyses necessary to support the design and operation of the PFBTB. Combustion stability analyses will be performed to predict thrust chamber/feed system operation. The analysis will include consideration of the high frequency acoustic mode/energy release mechanism, the low frequency propellant transmission line and the interaction of the structure with the facility. Engine control studies will guide engine controls design and operation. These studies will consider the engine propellant control system and the start/shutdown transient controller. A model will also be developed for the start/shutdown transient control system. Overall propulsion control system studies will be performed and a control systems model developed. An integrated system performance model will be developed, as will as a system dynamics model, a cold gas pressurization system model, and a hot gas pressurization system model. The hot gas pressurization system model will be developed from models provided by the hot gas pressurization system vendor. In addition, this task will include studies on thrust chamber thermal flux density and near filed vibro-acoustic levels and response.

This task will also include the analyses of run data generated from tanking tests, cold flow tests, and hot firings. Test reports will be generated to thoroughly document the results of all tests and the analyses of the data.

Task V, SRM&QA Activities

This task will consist of providing direction and assistance to the PFBTB Activation/Operations Contractor in the development of the SRM&QA plans. The plans include a quality assurance plan, a maintenance plan, a reliability plan, and a safety plan. The safety plan shall include a hazard analysis document and a facility safety manual. Monitoring of the A/O Contractor's compliance with the SRM&QA plans is also part of this task.

In addition, this task will include performance of a PFBTB system failure modes and effects analysis (FMEA) to assist in the test stand and simulator systems design.

Task VI, A/O Services Task

Overall

The A/O Contractor task shall include functions in each of following categories: Management, Planning, Procurement, Fabrication, Refurbishment and Installation, Activation, Operations, and Analysis.

Subtask A-Management:

The A/O Contractor shall be responsible for coordination of all activities with NASA programmatics-including schedule and interface requirements. The Contractor shall provide information to support all NASA reviews including: TRR, ORI, PRR, PDR and CDR. Additionally, the Contractor shall fulfill all contractural requirements.

Subtask B-Planning:

The Contractor shall be responsible for developing test plans inclusive of the following: Training and Certification Plan, Test and Check-out Procedure, Facility Operating Plan, Control Logic Plan, Networks Wire List, and Instrumentation Wire List. Additionally, the Contractor shall assume responsibility for the data acquisition/operating procedure and the instrumentation measurements program. NASA will provide inputs to both of these plans.

Plans shall also be provided for Safety, Reliability, Maintainability, and Quality Assurance of the Integrated Structures/Facilities system. Activation plans are also required. Such plans will include Design Drawings and Schematics and an activation procedure.

Subtask C-Procurement:

The Contractor will be responsible for procurement of LO2 and RP-1 for the operations phase of the program. While all of the structure simulator systems will be provided by NASA, the A/O Contractor will be responsible for procurement of all material required for the test stand systems. Exceptions to this requirement include: C of F construction project, block house data acquisition equipment, and all ground support equipment.

Subtask D-Fabrication, Refurbishment and Installation:

The A/O Contractor shall be responsible for the refurbishment of the F-1 Test Stand and the installation of all simulator subsystems. While NASA will conduct construction efforts for the "C of F" project, the A/O Contractor shall be responsible for all other F-1 Test Stand refurbishments and modifications. Specific systems and subsystems to be refurbished are listed below:

Propellant System—NASA will provide for LO2 emergency dump and transfer system - the A/O Contractor will be responsible for refurbishing the RP-1 storage and emergency dump and transfer system. Valves requiring refurbishment will be refurbished by NASA.

Ancillary Delivery Systems—The A/O Contractor will run lines, valves and purges for all listed delivery systems from the base of the test stand to the delivery point. (NASA will provide service from the source to the base of the test stand). Existing hardware will be refurbished where practical-all valves requiring refurbishment will be refurbished by NASA. Delivery systems included are: Hydraulics, GHe, Missile Grade Air, Facility GN2 and vacuum service.

Safety Systems—The A/O Contractor shall install a hazardous gas detection system on the test stand with appropriate controls at a remote location (i.e. block house). Area warning system and a gaseous fire protection system shall be installed.

Structures—The A/O Contractor is responsible for modification and refurbishment of the flame deflector bucket, the aspirator and rolling deck, all stand trusses and platforms, and other stand structures.

Facility Power and Control—The A/O Contractor will install all equipment required for this system. The subsystems included are: Substations Motor Control Centers; Uninterrupted Power Supply; Programmable Controlling System; Servo Controller, and Ramp Generator; Networks Interface System for Engine, Hot gas and Cold Gas Systems; Sound Power; TV/Film Camera; and Condition Monitoring and Emergency Shut-Down Systems.

Instrumentation/Data Acquisition—The A/O Contractor shall be responsible for installing all stand IDA systems including patch panels and wiring. Installation of NASA furnished block house equipment shall also be the responsibility of the A/O Contractor.

High Pressure Industrial Water—With the exception of reusable valves refurbishment of this system is responsibility of the A/O Contractor. The two subsystems included in this system are: the Firex and fire protection subsystem and the flame deflector water subsystem.

The A/O contractor will install every structure simulator element with the exception of the GN2 tankage and manifold which will be accomplished by the NASA Facilities office. The following elements require installation: Cold Gas pressurization system including GN2 control/regulation and distribution system, and the tank pressure/vent relief system; propellant run system including fuel and oxidizer feed lines and valves anti-geysering system, and pogo suppression system; booster instrumentation system; engine control system including engine power, mixture control, and thrust chamber prefill systems; booster configure structure including structural attachment from tank to tank, structural attachment to test stand,and the engine support structure; propellant tanks including LO2 and RP-1 tanks; technology thrust chamber system; and technology hot gas pressurization system.

Subtask E-Activation

This subtask covers the work to be accomplished by the Activation/Operations contractor to activate the PFBTB facility. These activities consist of the test and checkout of all the PFBTB hardware and systems elements. These elements cover all areas of the test stand and the PFBTB simulator. Test stand test and checkout addresses the LO2 and RP-1 transfer and emergency dump systems, ancillary delivery systems such as the hydraulic, GHe, missile grade air, facility GN2, and vacuum delivery systems. Test and checkout tasks consist of valve actuation, purge checks, system leak checks, and operations test. Similar activities will be performed on a safety systems such as hazardous gas/detection/O2 depletion, area warning and gaseous fire protection. Modified and refurbished structures such as the flame deflector, aspirator, rolling decks, stand trusses, platforms, etc., will be checked. As part of the effort, the A/O contractor shall establish and outfit a maintenance shop including: parts storage, hand and power tools, protective equipment, workbenches, special equipment; and a personnel change house. Areas addressed in activation of facility power and controls include the motor control center substations; DC power including the UPS; the engine, hot gas pressurization, and cold gas pressurization networks interface systems; the sound power system; TV and film camera systems; and the condition monitoring and emergency shutdown system. The facility control system activation tasks include test and checkout of the programmable controllers, servo controllers, and ramp generators. The instrumentation and data acquisition system checkout include stand instrumentation (such as patch panels and wiring) and block house equipment (such as SIV, DSU, RGV, HSDTV, HSLM, Analog recorders, and real time frequency analyzers). Also, high pressure industrial water used for the Firex, fire protection and flame deflector plume suppression will be tested and checked as a part of this subtask. Ground support equipment will also be checked, tested and certified.

This subtask will also include similar test and checkout activities for the PFBTB simulator and its associated systems. These include the cold gas pressurization system including GN2 control and regulation, distribution, tankage, manifolds, and the pressure relief and vent subsystems; the propellant run system which includes LO2 and RP-1 feed lines and valves; the anti-geyser system and pogo/instability suppression system; the booster instrumentation system; and the LO2 and RP-1 run tanks. The engine control system will be checked and tested including engine power (both steady state and start/shutdown state), mixture ratio control/propellant utilization and thrust chamber pre-fill. Additional simulator activation tasks are: test and checkout of the booster configured structure including attachment structures and the engine support structure. Final activation activities will include test and checkout of the technology thrust chambers and hot gas pressurization system as they become available. The respective TCA and hot gas pressurization contractors will assist the A/O contractor in these activation tasks.

The A/O Contractor shall install all equipment per subtask D and assemble and integrate all hardware into a single system.

Subtask F Operations

This subtask will provide for all of the work required by the A/O contractor to implement testing and provide data acquisition and documentation services. Test implementation tasks include propellant operations, test data acquisition and reduction and facility operational SRM&QA. Propellant operation includes propellant acquisition, transportation, delivery, and propellant loading. Operational SRM&QA will be accomplished per the approved safety, maintenance, and quality assurance plans and manuals. The A/O contractor will operate all stand systems including facility power and controls, industrial water and data acquisition systems during actual testing. All systems will be operated per approved test procedures and instructions. The A/O contractor shall also maintain and operate all ground support equipment including re-certification as needed.

Additional subtasks also include all operations activities with the PFBTB simulator. This includes operation of the cold gas pressurization system, the propellant run systems (feed and dump), the engine control system, and the booster instrumentation system. The A/O contractor will operate the stand, simulator and engine systems during all test operations. Test operations may include tanking, system cold flow, and hot firing test. The test operations support tasks such as system checkout, instrumentation calibrations, personnel training and certification, and actual shakedown testing are part of this subtask. The A/O contractor will provide operations support as needed for structure, run tanks, and associated systems for the PFBTB simulator. Such support includes maintenance, re-certification, leak testing, etc.

As mentioned previously, the A/O contractor shall operate and maintain all parts of the data acquisition system. This includes both on-stand systems such as instrumentation, wiring and patch panels and the block house systems such as data selection, distribution and recording devices, etc. Part if this task also includes operation f the data acquisition/reduction computer system and data loggers. The A/O contractor shall review all reduced data and certify its validity. Finally, the A/O contractor shall perform preliminary data analyses as instructed by NASA and document the results. All final data analyses and interpretation of the data shall be performed by NASA and other supporting contractors.

2.3 PROGRAM SCHEDULE

The preliminary schedule for Phase 0, 1, and 2 of the Pressure-Fed Booster Test Bed Project was developed as part of the LRB contract extension Task 3, PFBTB support. Phase 0 consists of the planning, design, procurement, refurbishment, modification, installation and activation activities associated with the test facility and test bed simulator. Phase 1 consists of the design, development, component test and delivery of test articles for the technology hot gas pressurization system and the technology thrust chambers. Phase 2 consists of testing of the hot gas pressurization system and technology thrust chambers on the PFBTB as an integrated system.

NASA inputs were used to establish ground rules to develop the project schedule. Although pre-program work started in FY88-3, November 1, 1988 was used as the proposed start date for the PFBTB project. The pre-program work consisted of program planning, cost estimating, and run tank trade studies by Martin Marietta, development of Test Bed requirements by General Dynamics and a PFBTB feasibility study by Wyle Labs. Also, some analyses and design work on the stand structure and stand instrumentation and controls were done by Martin Marietta and General Dynamics prior to program start. NASA also supplied the start and test article delivery dates for the hot gas pressurization system and the technology thrust chambers. These start and delivery dates were:

	Start	Delivery
Hot Gas Pressurization	11/1/88	10/31/91
Thrust Chamber Assembly	11/1/88	10/31/91

The facility feasibility study performed by Wyle Labs is shown on the schedule. This study was complete at the end of FY88. The facility design project, also done by Wyle Labs, is a nine month effort to be started October 1, 1988.

Other inputs used in development of the PFBTB project schedule were the delivery estimates for the LO2 and RP-1 run tanks. These were preliminary estimates provided by potential run tank vendors. Delivery estimates assumed were 24 months for the LO2 tank and 19 months for the RP-1 tank. The longer delivery for the LO2 tank is due to its being a vacuum jacketed unit.

The schedule for the PFBTB project is shown in Figure 2.3-1. This schedule shows an elapsed time of 38 months from program start to the first hot firing. The schedule for Phase 0 hot firings and Phase 2 testing has not been established due to the non-predictability of those activities at this time.

2.4 PROGRAM COST ESTIMATES

The program schedules were manloaded to determine the headcount required to accomplish each task. The manpower estimates were added to the material and subcontract requirements to develop total program estimates. Program estimates are summarized in Table 2.4-1.

This method of estimating provides a test of reasonableness for the estimates. One can quickly determine whether or not enough people are available for a specific task. The method also provides a quick way to change manpower requirements based on schedule slides or other programmatic changes. The spreadsheet (Table 2.4-2) that was developed to estimate the labor cost is oriented to manpower requirements (i.e., the number of manmonths required to accomplish each task). If a schedule slides three months, for example, the spreadsheet can be revised to reflect an additional three months effort. The program costs will be updated automatically. The spreadsheet provided will be a useful tool for both preplanning and monitoring this program.

The hardware and Facility estimates were developed from a variety of sources. The facilities estimates were developed form experience that has been gained from constructing and modifying similar facilities (GN2 storage farms, electrical distribution systems, emergency warning systems, etc.) at the Michoud assembly Facility in New Orleans. In addition, one of the Facilities Engineers has roughly 20 years experience estimating test stand costs at the Stennis Space Center.

The hardware estimates were developed primarily from vendor telephone conversations. The large run tanks were extensively researched. Vendors such as Westinghouse,Taylor Forge, Babcock and Wilcox, etc. were contracted. The information that was collected assisted in the development of parametric cost curves based on the length and diameter of each of the tanks. In addition, costs were analyzed based on several types if material to determine the interaction of construction costs and the material type selected. This work, submitted with the first phase documentation 1, was used to estimate the run tanks. In addition, the lines and valve costs are based on vendor conversations. Ths instrumentation estimates are based on the ET actuals. And the pressurization system estimates are based on MAF experience.

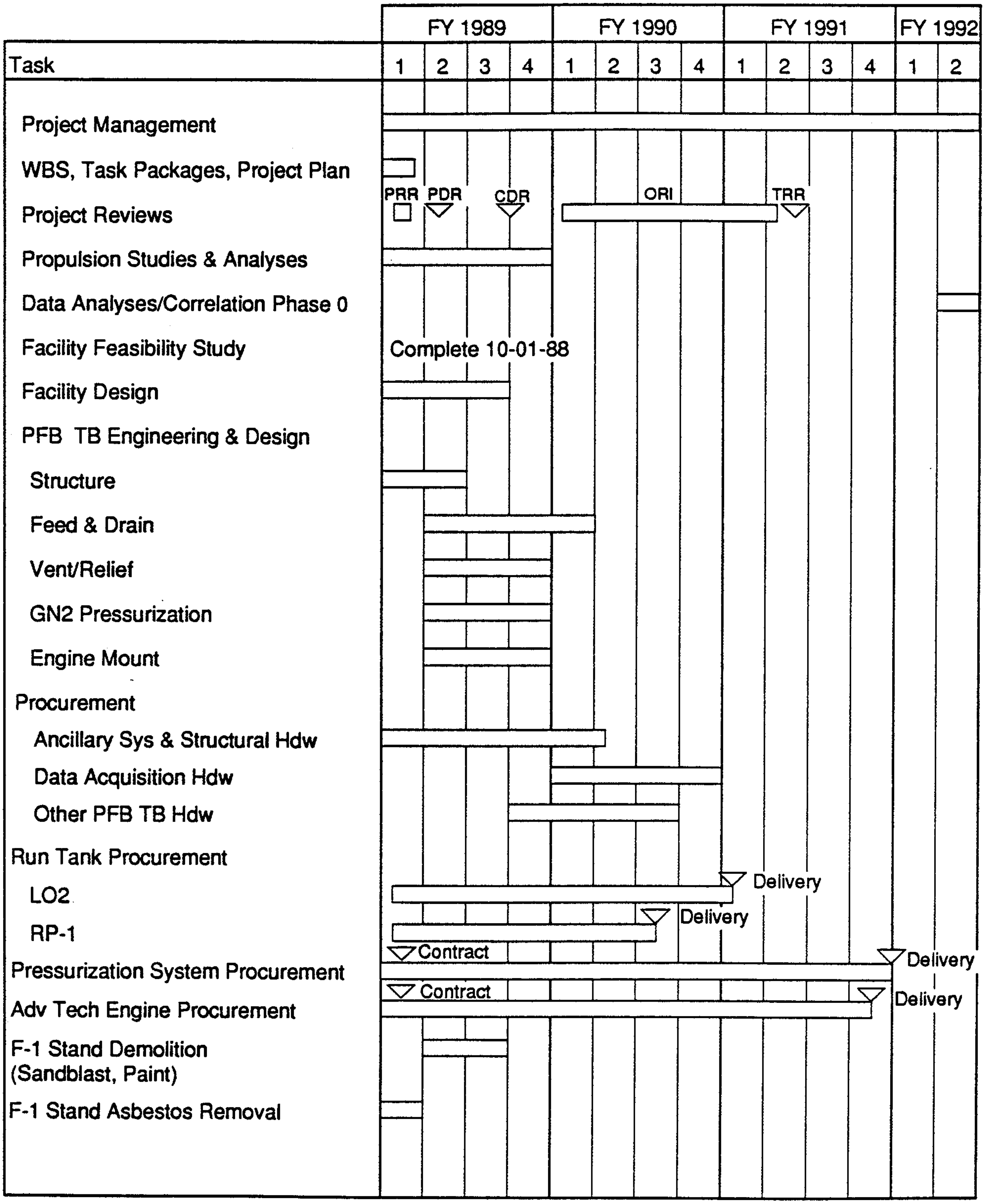
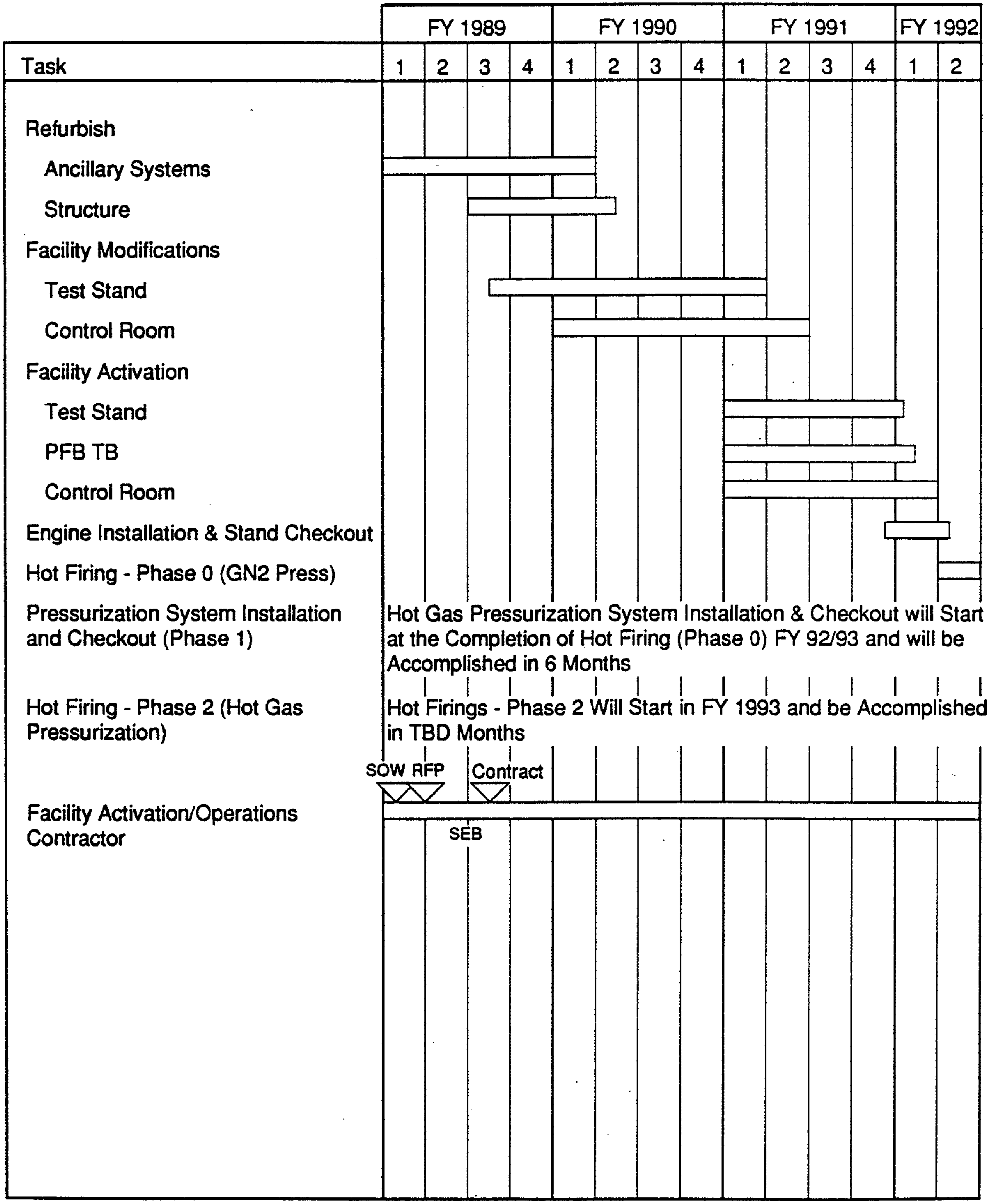


Figure 2.3-1 Pressure-Fed Booster Test Bed Project Schedule



Hot Gas Pressurization System Installation & Checkout will Start at the Completion of Hot Firing (Phase 0) FY 92/93 and will be Accomplished in 6 Months

Hot Firings - Phase 2 Will Start in FY 1993 and be Accomplished in TBD Months

Figure 2.3-1 Pressure-Fed Booster Test Bed Project Schedule (cont)

Table 2.4-1 PFBTB Project Cost Estimate (Phase 0)

Project Tasks - NASA		**Estimated Cost**
I	Program Management	$1,034,000
II	Test Facility (Excluding Test Bed Simulator)	1,953,000
III	Test Bed Simulator	6,508,000
IV	Studies and Analyses	280,000
V	SRM & QA	72,000
Project Task - Major Contractors		
VI	Activation/Operations Contractor	9,376,000
	Phase 0 Total Cost	$19,223,000

Estimates Include All Hardware and Activities Through First Hot Firing

Table 2.4-2 WBS Spreadsheet

Pressure-Fed Booster System	Management	Planning	Study	Design	SE&I	Procurement	Fab/Refurb
Integrated System	$997,920	$813,780	$41,580		$374,220	$274,740	
Test Stand			$100,000	$400,744			$75,000
Propellant System							0
LO2 Transfer System							0
RP-1 Transfer System							$134,000
Delivery Systems							0
Hydraulics							$174,200
GHe Delivery							0
Missle Grade Air							0
Facility GN2 Delivery							0
Vacuum Delivery							$301,500
Safety Systems							0
Hazardous Gas Detection System							$167,500
Area Warning System							$100,500
Gaseous Fire Protection							$308,200
Structures							0
Flame Deflector							$53,600
Aspirator Rolling Deck							$167,500
Stand Trusses & Platforms							$237,600
Other Stand Structures							$80,400
Facility Power & Controls							0
Substations/MCC							$670,000
DC Power Systems							$737,000
Control System							$562,800
Networks Interface System							$33,500
Sound Power							$134,000
Film Camera System							$134,000
Emergency Shut Down							0
Data Acquisition							0
Block House Systems							$134,000
Stand Systems							0
High Pressure Water System							0
Firex							$402,000
Flame Deflector Water System							$402,000
Ground Service Equipment						$300,000	0
Structure Simulator							$1,415,059
Cold Gas Pressurization System				$103,736		$1,296,696	$50,000
GN2 Control/Distribution System				0			0
GN2 Tankage & Manifold				0			$50,000
Pressure Vent/Relief System				0			0
Propellant Run System				$48,000		$600,000	
LO2/RP-1 Feedlines & Valves				0		0	
Anti-Geysering System				0		0	
Booster Instrumentation System				$65,024		$812,800	
Engine Control System				$105,000		$700,000	
Engine Power				0		0	
Engine Mixture Controller				0		0	
Booster Configured Structure				0		0	
Tank/Tank Attachment Structure				$11,880		$148,500	
Tank/Stand Attachment Structure				$9,504		$118,800	
Engine Support Structure				$11,880		$148,500	
Propellant Tanks						0	
Oxidizer Run Tank						$1,800,000	
RP-1 Run Tank						$1,450,000	
Technology Thrust Chamber							
Hot Gas Pressurization System							
Propulsion			$249,480				
TOTAL	$997,920	$813,780	$391,060	$755,768	$374,220	$7,650,036	$6,524,359

Table 2.4-2 WBS Spreadsheet (cont)

Pressure-Fed Booster System	Fac Design	Fac Const	Activation	Operations	Analysis		Totals
Integrated System			$534,600	$297,000	$29,700		$3,363,540
Test Stand	$40,000	$500,000					$1,115,744
Propellant System							0
LO2 Transfer System							0
RP-1 Transfer System							$134,000
Delivery Systems							0
Hydraulics	$2,400	$60,000					$236,600
GHe Delivery	$2,400	$60,000					$62,400
Missle Grade Air	$2,400	$60,000					$62,400
Facility GN2 Delivery	$2,400	$60,000					$62,400
Vacuum Delivery	$2,400	$60,000					$363,900
Safety Systems							0
Hazardous Gas Detection System							$167,500
Area Warning System							$100,500
Gaseous Fire Protection							$308,200
Structures							0
Flame Deflector							$53,600
Aspirator Rolling Deck							$167,500
Stand Trusses & Platforms							$237,600
Other Stand Structures							$80,400
Facility Power & Controls							0
Substations/MCC							$670,000
DC Power Systems							$737,000
Control System							$562,800
Networks Interface System							$33,500
Sound Power							$134,000
Film Camera System							$134,000
Emergency Shut Down							0
Data Acquisition							0
Block House Systems							$134,000
Stand Systems							0
High Pressure Water System							0
Firex							$402,000
Flame Deflector Water System							$402,000
Ground Service Equipment						$300,000	$300,000
Structure Simulator							$1,415,059
Cold Gas Pressurization System							$1,450,432
GN2 Control/Distribution System							0
GN2 Tankage & Manifold							$50,000
Pressure Vent/Relief System							0
Propellant Run System							$648,000
LO2/RP-1 Feedlines & Valves							0
Anti-Geysering System							0
Booster Instrumentation System							$877,824
Engine Control System							$805,000
Engine Power							0
Engine Mixture Controller							0
Booster Configured Structure							0
Tank/Tank Attachment Structure							$160,380
Tank/Stand Attachment Structure							$128,304
Engine Support Structure							$160,380
Propellant Tanks							0
Oxidizer Run Tank							$1,800,000
RP-1 Run Tank							$1,450,000
Technology Thrust Chamber							0
Hot Gas Pressurization System							0
Propulsion							$249,480
TOTAL	$52,000	$800,000	$534,600	$297,000	$29,700	GRAND TOTAL	$19,220,443

2.5 PROGRAMMATIC SUMMARY

To tie together all aspects if the program, a comprehensive spreadsheet (Table 2.5-1) was developed. This spread sheet integrates the WBS, Task assignments, schedules, budget estimates, and funding sources. This will be a valuable tool for continuing management of this program.

The management plans: quantified funding required, suggested funding sources, outlined the work to be established, detailed the schedules, optimized the cost drivers, and segregated the work into logical units. Most importantly, computer programs were developed for the continuing management effort and have been turned over to the NASA Program Manager.

Table 2.5-1 Comprehensive Spreadsheet

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window Start	Finish	Budget Estimate	Actual Budget	Funding Source
Management	11			2Q89	End	note a		
Integrated systems	01-00-00			2Q89	End			
Support NASA Major Reviews	11-01-00-00							
Coordinate A/O Activities	11-01-00-00							
Assure Contract Reqmt Delivery	11-01-00-00							
Interface With Customer	11-01-00-00							
Planning	12			2Q89	1Q92	$748k		
Integrated Systems	01-00-00			2Q89	1Q92			
Develop Test Plans	12-01-00-00							
Develop SRM&QA Plans	12-01-00-00							
DevelOp Activation Plans	12-01-00-00							
Procurement	31			2Q89	End	$150k		
Integrated System	01-00-00			1Q92	End			
Procure ILO2 and rRP-1	31-01-00-00							
Test Stand	02-00-00			2Q89	4Q90			
Procure Non-Coff Material	31-02-00-00							
On-Stand Data Acq. Equipment	31-02-06-01							
Fab./ Refurb./ Install	32			2Q89	4Q91			
Test Stand	02-00-00			2Q89	1Q91	$4,934k		
Refurb RP-1 System	32-02-01-02							
Refurb./Add Delivery System	32-02-02-00							
Refurb/Install Safety System	32-02-03-00							
Refurb/Install Stand Structures	32-02-04-00							
Refurb/Install Fac. power & Cntrl	32-02-05-00							
Install Data Acq. Equipment	32-02-06-00							
Refurb. H.P. Water System	32-02-07-00							
Note a: Management and Planning Functions Combined Under Planning								

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window		Budget Estimate	Actual Budget	Funding Source
				Start	Finish			
Fab./ Refurb./ Install (cont'd)	32							
Structure Simulator	03-00-00			2Q89	4Q91	$2,712k		
Install GN2 Cnrtl/Dist. System	32-03-01-01							
Install GN2 Press Vent/Relief Sys	32-03-01-03							
Install Propellant Run System	32-03-02-00							
Install Booster Instrument Sys	32-03-03-00							
Install Engine Control System	32-03-04-00							
Install Booster Config. Sturct.	32-03-05-00							
Install Propellant Run Tanks	32-03-06-00							
Install Tech. Thrust Chamber	32-03-07-00							
Install Hot Gas Press. System	32-03-08-00							
Activation	43			4Q90	4Q91	$535k		
Integrated System	01-00-00			4Q90	4Q91			
Test & Check-Out Integrated Sys	43-01-00-00							
Test Stand	02-00-00			4Q90	4Q91			
Test & Check-Out Propellant Sys	43-02-01-00							
Test & Check-Out Delivery Sys	43-02-02-00							
Test & Check-Out Safety Systems	43-02-03-00							
Test & Check-Out Structures	43-02-04-00							
Test & Check-Out Power & Cntrls	43-02-05-00							
Test & Check-Out Data Acq. Sys	43-02-06-00							
Test & Check-Out H.P. Water Sys	43-02-07-00							
Test & Check-Out GSE	43-02-08-00							
Structure Simulator	03-00-00			4Q90	4Q91			
Test & Check-Out C.G. Press Sys	43-03-01-00							
Test & Check-Out Propel. Run Sys	43-03-02-00							
Test & Check-Out Inst. System	43-03-03-00							
Test & Check-Out Engine Cntrl Sys	43-03-04-00							
Test & Check-Out Booster Struct	43-03-05-00							
Test & Check-Out Propel. Tanks	43-03-06-00							
Test & Check-Out Thrust Chamber	43-03-07-00							
Test & Check-Out H.G. Press. Sys	43-03-08-00							

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By-	Window Schedule		Budget Estimate	Actual Budget	Funding Source
				Start	Finish			
Operation	51			1Q92	End	$297k		
Test Stand	02-00-00			1Q92	End			
Perform Propel. Load/Dump Ops.	51-02-01-00							
Perform Delivery System Ops.	51-02-02-00							
Provide SRM&QA Ops Support	51-02-03-00							
Operate Structures	51-02-04-00							
Operate Facility Power & Control	51-02-05-00							
Operate Data Acquisition Systems	51-02-06-00							
Operate High Pressure Water Sys	51-02-07-00							
Operate Ground Support Equip.	51-02-08-00							
Structure Simulator	03-00-00			1Q92	End			
Operate C.G. Press. System	51-03-01-00							
Operate Propellant Run System	51-03-02-00							
Operate Booster Instr. System	51-03-03-00							
Operate Engine Control System	51-03-04-00							
Provide Ops Supt For Structure	51-03-05-00							
Provide Ops Supt For Propel. Tanks	51-03-06-00							
Operate hrust Chamber Assy.	51-03-07-00							
OperateH.G. Press. System	51-03-08-00							
Analysis	52			1Q92	End	note b		
Integrated System	01-00-00			1Q92	End			
Provide cursory data analysis	52-01-00-00							
Note b: Analysis Function Is Included In Planning Task								

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window		Budget Estimate	MM Budget	Funding Source
				Start	Finish			
Program Management		EP01		2Q88	END			
Management	11			2Q88	END	$998K	168	
Manage Project	11-01-00-00							
Budget Tracking & Analysis	11-01-00-00							
Coordinate Project Reviews	11-01-00-00							
Interface with Contractors	11-01-00-00							
Planning	12			2Q88	4Q88	$36K	6	
Develop Budget Plans	12-01-00-00							
Prepare Project Plans	12-01-00-00							

$1,034K 174
TOTALS

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window		Budget Estimate	MM Budget	Funding Source
				Start	Finish			
Facilities		ABxx		2Q88	2Q91			
Studies	21			2Q88	2Q89			
Perform Seismic Study	21-01-00-00					$25K		
Assess Facility Refurb Scope	21-02-00-00					$75K		
Design	41			4Q88	2Q89			
Design Coff Project	41-02-00-00					$40K		
Design Test Stand Systems	41-02-00-00					$413K	2	
Procure	31			2Q89	2Q91	$125K	21	
Procure Coff Material	31-02-00-00					$0K		
Procure B/House Data Equip.	31-02-06-01					GFE		
Procure Ground Supt. Equip	31-02-08-00					$300K		
Fab./ Refurb./ Install	32			2Q89	4Q90			
Refurb Stand Valves	32-02-00-00					$75K	13	
Refurb Simulator Valves	32-03-01-00					$50K	8.5	
Install GN2 Tank & Manifold	32-03-01-02					$50K	8.5	
Construction	42			3Q89	1Q91			
Construct Coff Project	42-02-00-00					$500K		
Furnish Delivery Sys To Base	42-02-02-00					$300K	17	

$1,953K 70
TOTALS

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window		Budget Estimate	MM Budget	Funding Source
				Start	Finish			
Simulator/ Systems		EPxx		2Q88	end			
Studies	21			2Q88	1Q90			
Study Simulator Systems	21-03-00-00					GFE		
Design	22			2Q88	4Q89			
Booster Instrumentation Sys	22-03-03-00					$65k	11	
Engine Control System	22-03-04-00					$105k	17.5	
Booster Configured Structure	22-03-05-00					$33k	5.5	
Propellant Run Tanks	22-03-06-00					note a		
GN2 Press Vent-Relief System	22-03-01-03					$104k	18	
Propellant Run System	22-03-02-00					$48k	8	
Technology Thrust Chamber	22-03-07-00					note a		
Hot Gas Pressurization Sys.	22-03-08-00					note a		
System Engineering & Integration	23			2Q88	End	$375k	63	
Develop & Maintain ICDs	23-01-00-00							
Develop Hardware Specs	23-01-00-00							
Define Test Requirements	23-01-00-00							
Help A/O Dev. Calib. Proced.	23-01-00-00							
Help A/O Dev. Inst. Meas. Prog.	23-01-00-00							
Procure	31			2Q88	End			
Procure Contractor Support	31-03-00-00					note b		
Procure Simulator Hardware	31-03-00-00					$5,630k		
Fab./ Refurb./ Install	32			4Q89	1Q90			
Fabricate Spider Structure	32-03-05-01					$148k	12.5	

Note a: Included In Hardware Estimate

Note b: Included In Facilities Procurement

$6,508k	135.5
TOTALS	

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window		Budget Estimate	MM Budget	Funding Source
				Start	Finish			
Propulsion		EPxx		2Q88	End			
Studies	21			2Q88	Q89	$250k	42	
Combustion Stability Study	21-04-01-00							
Engine Control Study	21-04-02-00							
Propulsion Control Study	21-04-03-00							
Thermal Flux Density Studies	21-04-04-00							
Vibro/acoustic Study	21-04-05-00							
Model Development	21-04-06-00							
Analysis	52			1Q92	End	$30k	5	
Provide Analysis of Run Data	52-01-00-00							
Document Analysis	52-01-00-00							

$280k 47
TOTALS

Table 2.5-1 Comprehensive Spreadsheet (cont)

Tasks/Subtasks	WBS Element	Resp. Dept.	Work Perf By	Schedule Window		Budget Estimate	MM Budget	Funding Source
				Start	Finish			
SRM&QA		CSxx		4Q88	1Q92			
Planning	12			2Q89	1Q92	$30K	5	
Help A/O Plan Activ. SRM&QA	12-01-00-00							
Study	21			4Q88	4Q89	$42K	7	
Develop System FMEA	21-01-00-00							

$72K	12
TOTALS	

3.0 PRESSURE-FED BOOSTER TEST BED SUPPORT

3.1 ANALYSIS

A report, included as Appendix E describes the stress analysis/structural design of the Pressure-Fed Booster Engine Test Bed using the existing F-1 Test Facility Test Stand at Huntsville, Alabama. The analysis has been coded and set up for solution on NASTRAN. A separate stress program was established to take the NASTRAN output and perform stress checks on the members. Joint checks and other necessary additional checks were performed by hand and are included in the analysis. The notes include a brief description of other programs which assist in reproducing and reviewing the NASTRAN results. These programs are included on the accompanying tape.

3.2 CRITERIA AND LOADING CONDITIONS

The redesign of the test stand members and the stress analysis was performed per the A.I.S.C. Code. Loads on the stand consist of the loaded run tanks, wind loads, seismic loads, live loads consisting of snow, ice and live, dead load of the steel, and loaded pressurant bottle. In combining loads, wind loads and seismic loads were each combined with full live loads. Wind and seismic loads were not combined. A 1/3 increase in member allowables was not taken for the environmental loads except at decks 147 and 214 where the increase was used when considering the stay rods, brackets and stay beams.

Wind and seismic loads were considered from each of the four coordinate directions (i.e. N,S,E,W) to give eight basic conditions. The analysis was performed with the pressurant tank mounted at level 125. One seismic condition was also run with the tank mounted at levels 169 and 214. No failures were noted with mounting at level 169, but extensive deck failure occurred when mounting the bottle at level 214. (The loadsets used are included on the tape, but no detailed results are included in the package.)

Decking support beams at levels 147 and 214 are not included in the model. The stress program thus does not reduce strut lengths to the length between deck beams (the struts are attached to the beams at intersection points) and gives stress ratios larger than one for some of the struts. The affected members were therefore checked by hand to show acceptable stress ratios.

Please note that a copy of the analysis, one (1) set of reproducible mylar drawings, and all computer loads sets and output including CAD/CAM models have been previously forwarded to NASA/MSFC for filing and records keeping. Only the analysis report is included in Appendix E.

4.0 MSFC SUPPORT

One of the PFBTB support tasks performed for the LRB Contract Extension, Task 3 was to provide certain on-site support at MSFC as requested by the NASA PFBTB Project Manager. This was Level of Effort (LOE) support under NASA direction. The two areas of support requested were a person to provide program documentation support and a test area technician to perform certain on-stand tasks. The following paragraphs outline the duties and accomplishments of these on-site support personnel.

4.1 PROGRAM DOCUMENTATION

A variety of program support and documentation tasks were accomplished, as directed by the NASA PFBTB Project Manager. Action item lists were maintained on a regular basis and appropriate status updates accomplished. Various charts, schedules and memos were prepared. Documentation responsibilities also included setting up and maintaining files. Another task performed was to keep PFBTB team members informed with project status and changes. A significant effort was also accomplished to take the PFBTB programmatics data presented in section 2.0 above and integrate it into a final NASA document "Pressure-Fed Booster Test Bed Project Plan", November 1988.

A Martin Marietta supplied Apple Macintosh was utilized to provide word processing and computer graphics support to the activities detailed above.

4.2 TEST AREA TECHNICIAN

Test area technician support for the PFBTB project was in the areas of component acquisition and refurbishment and F1 test stand support activities.

Over 300 components were accumulated for test stand reactivation. Valve Lab service request forms were filled out with specifications for servicing and repair of these components. Also an inventory control system was set up to manage components after servicing and delivery to the test stand.

Test stand support activities included removal of debris from the F1 stand first level shop and the instrumentation and control terminal room. An office was set up in the first level shop for test stand operations control. Lights were repaired and some surplus equipment was acquired to equip the shop. One of the activities accomplished to establish these shop and office areas was to reactivate potable water to the stand. Another major accomplishment was the conducting of two

(2) stand industrial water tests. The first water test was unsuccessful due to numerous leaks, water pressure could not be established at the top of the stand. Major leaks were repaired and the second water test was successful. The final test stand support activities included tasks, such as draining all water systems, to winterize the test stand.

VOLUME II PART 3

ALTERNATE APPLICATIONS

VOL II PART 3 - ALTERNATE APPLICATIONS

1.0 OVERVIEW

The LRB study program has identified three high potential future applications for the STS LRB. These future applications are; Shuttle-C; Advanced Launch System (ALS); and LRB Stand-Alone Launch Vehicle. It was determined that in a Shuttle-C program, the present baseline LRB concepts, both pump-fed and pressure-fed, could be directly substituted for SRB's and would increase payloads by 28.5 Klb over the SRB/Shuttle-C combination. A Stand-Alone including an upper stage, LRB was studied, and a preliminary concept was analyzed in a separate IR&D program, (Reference- Liquid Rocket Booster (LRB) Based Launch Vehicle M-20S S88-475201-001 Dec.31, 1988).

Application of the LRB's to the ALS program was identified as having the highest potential for evolutionary applications which would provide additional incentives for an LRB program approval. The following paragraphs present the results of the sizing and performance studies performed in support of this task. Three possible options with variations are presented with supporting data.

2.0 ADVANCED LAUNCH SYSTEM (ALS)

In order to accomplish a viable ALS/LRB launch vehicle, the combination of LRB to the ALS core vehicle must meet the stated requirements in Advanced Launch System Requirements Document, April 4, 1988. In general, the ALS baseline requirements state that the vehicle design approach and the safety factors used shall provide for improved reliability, operating simplicity, and reduced development, production, and operating cost. The specific Mission Support Requirements for payload, orbit, and inclination, are shown in Table 2.0-1.

These requirements were used to establish the size and weight of specific ALS/LRB combinations which could then be analyzed for performance Three alternative concepts (or options) evolved which show the most potential for future LRB use. The first concept utilized the recommended baseline Pump-Fed LRB vehicle with LO2/RP-1 propellants and the basic ALS core vehicle as defined by Martin Marietta Phase I ALS Study.. The second concept used a LRB design, with LO2/LH2 engines and propellants, and the basic ALS core Vehicle. The third concept used a modified LRB with LO2/LH2 propellants and the same ALS core engine with the basic ALS core vehicle. These three options then provided the configurations and performance for the ALS where the LRB was the recommended baseline LRB with no change, a modified LRB with common ALS fuel, and a modified LRB with common fuel and a common ALS engine. The third configuration has the potential to provide the lowest to possible LRB costs because the same engine is used for both core stage and the booster. A common engine would share development costs and common fuels would minimize launch facility development. One difficulty with this sharing of engines is that the proposed ALS engines are not designed to throttle. This is because an ALS goal is to reduce costs minimizing engine design complexity. The LRB engines must have throttle capability to meet the engine out requirement and STS trajectory constraints. This presents a major concern to the LRB program if common engines are required.

2.1 ALS/LRB OPTION 1 CONFIGURATION

By combining two baseline pump-fed LO2/RP-1 LRB's with the Denver ALS core vehicle, a launch vehicle was obtained that can perform both the 28.5 deg. ALS mission and the polar orbit ALS mission shown in Table 2.0-1. This configuration is referred to as the Option 1 vehicle and is shown in Figure 2.1-1. Definition and dimensions of the core vehicle were taken from Reference (1).

Table 2.0-1 Mission Support Requirements

Payload	Orbit	Inclination
Basic 100 k - 150 k	80 nm x 150 nm	28.5°
Minimum 65 k	80 nm x 150 nm	90° (Polar)
Maximum 160 k	80 nm x 150 nm	90° (Polar)

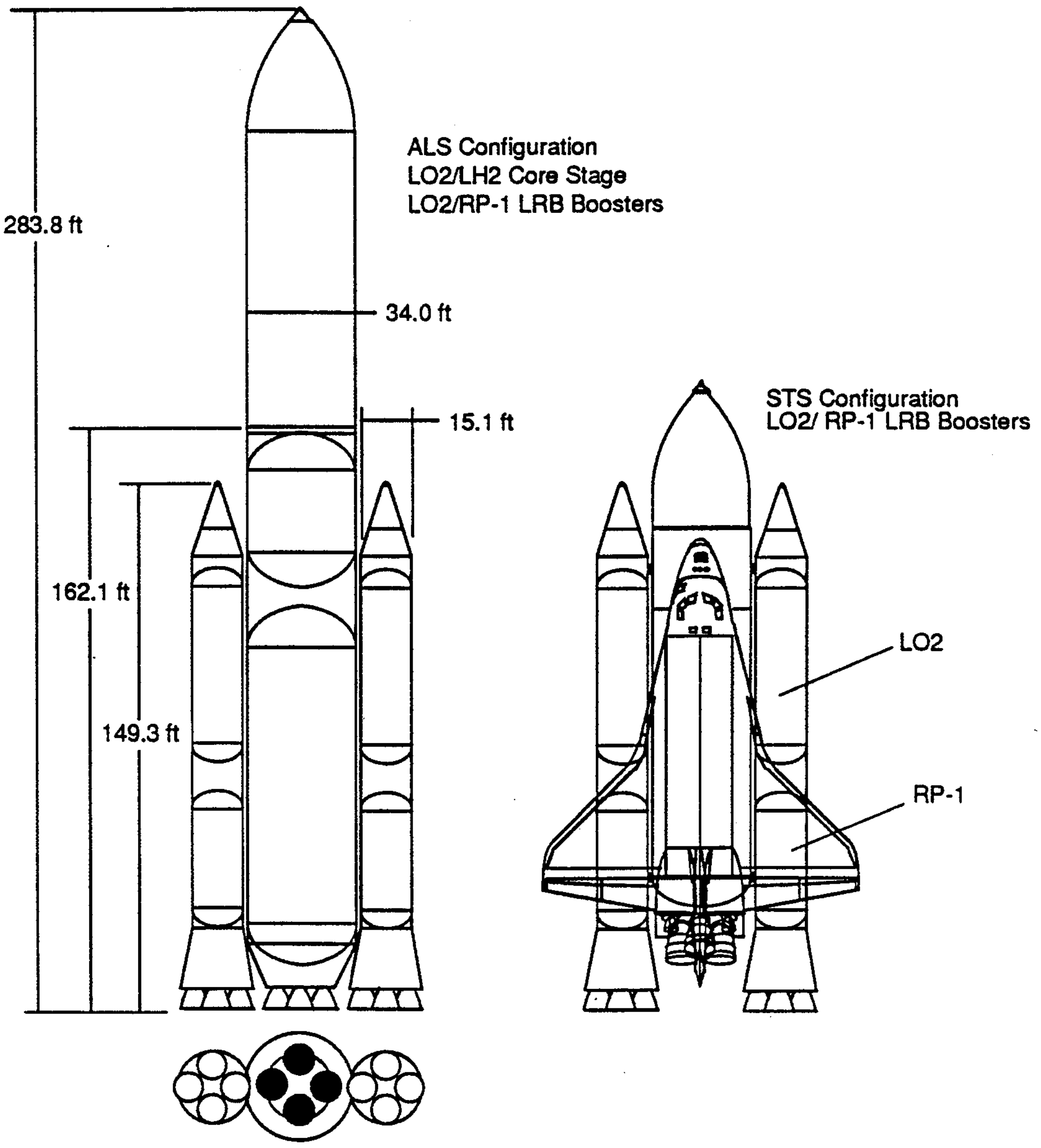


Figure 2.1-1 ALS/LRB Option 1

The core vehicle is 3406 in (283.8 ft) long and 408 in (34 ft) in diameter. It has four LO2/LH2 engines and payload capability of 110 Klbs with two LRB, LO2/RP-1 boosters attached. A view of the regular STS/LRB configuration is included in the Figure 2.1-1 for comparison.

2.1.1 Engines

Option 1 LRB engine, the baseline pump-fed engines, was described in Section 6.3 and Figure 6.3.1-2. This is a gas generator cycle, LO2/RP-1 engine of 685,000 lbf sea level thrust at full power level, shown as EPL on the chart. The normal power level, 75% of full power, is 513,000 lbf. The engine is throttleable and therefore provides one engine out capability in the four engine cluster by throttling three engines up form 75% the normal power to 100% full power.

The ALS core engine used in the option 1 configuration is a LO2/LH2 gas generator cycle engine and is described in Figure 2.1.1-1. This engine develops 584,000 lbf sea level thrust at full power and as noted in Section 1.1, is not throttleable because of cost considerations for ALS.

2.1.2 Performance

The Denver liquid/liquid expendable normal mission ALS vehicle described in Ref.(1) as concept 2A. It was sized with four liquid LO2/LH2 boosters. To meet the expanded mission requirements of 160 Klbs payload in a polar orbit, eight liquid boosters were used as shown the Ref (1) 2B concept. Concept 2B mission established the initial sizing of the ALS which was then down sized in payload compartment size, vehicle weight, and number of booster to meet the reduced payload requirements of the 2A mission.

Several approximations or allowances were made in the payload calculations as follows:

a) Engine Out Margin = 0.15 Payload Capability

b) Payload Capability = MECO Weight - Core (dry = residuals) - Engine Out Margin

It should be noted that engine out margin is a simplified calculation and is sufficient for this assessment. This does not imply that detailed engine out analysis has been performed.

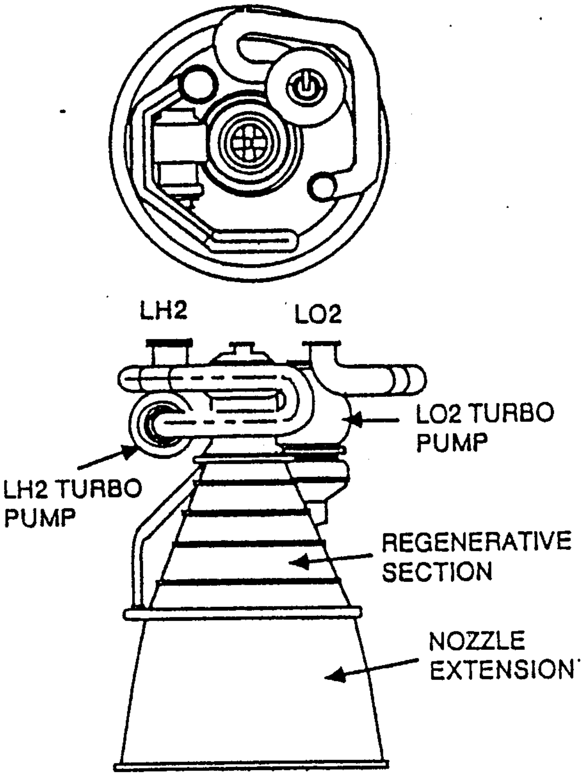
c) Flight performance reserve = 2% core ISP. This was simulated by reducing core engine ISP. - 440.6 x 0.98 = 431.8. Propellant flow was increased to accomplish this without changing the thrust.

Other groundrules and assumptions were;

d) All missions were flown to direct injection MECO target.

e) The flight path angle at MECO was 0.0 deg. and the vertical velocity target was 25,765.9 ft/sec. This provided a 80 x 150 NM equatorial orbit.

f) The first stage was flown at 0 angle of attach after the pitchover phase.



Cycle	Gas Generator
Propellants	LO2/LH2
Throttling Range	None
Mixture Ratio	6 : 1
Propellant Flow Rate	1630 lbm/sec
Engine T/W	82 (vac)
Nominal Power Levels:	
Vacuum Thrust	719 klbf
Sea Level Thrust	584 klbf
Vacuum Specific Impulse	441 sec
Sea Level Specific Impulse	358 sec
Chamber Pressure	2800 psia
Area Ratio	70
Weight	8820 lbm
Diameter	108 in.
Length	184 in.
Gimballing Rate & Pattern	Square Patterns
Burn Time	380 sec
Engine Life	1 Mission
Recovery Mode	None
Single Engine Reliability Allocation	.9935 (3 of 4)
Catastrophic Failure Correlation	.03

Figure 2.1.1-1 ALS Core Engine - Option 1 & 2

g) The pump-fed LO2/RP-1 booster followed the baseline criteria weight growth of 10% and residual propellant equalled 0.55 % of the usable propellant.

Since the ALS is an expendable unmanned vehicle, several assumptions that differ from the STS/LRB ascent flight considerations were also used

These were;

h) No maximum dynamics pressure limit to vehicle

i) No first stage acceleration limit. Second stage was limited to 7.0 g's.

The results of the analyses showed that by replacing the four pressure-fed LO2/LH2 boosters in the Denver ALS 2A concept with two pump-fed LO2/RP-1 boosters an increase of 4300 lbs payload to 110,100 lbs. was obtained in the ALS when the LRB's were flown at Full Power Level (FPL). Other results were;

Total vehicle GLOW was reduced by 400,00 lbs.

Most accelerations and dynamic pressure increased but remained within acceptable levels.

Staging altitude was lower

This could be overcome by running the engines at a slightly reduced power level so that dynamic pressures would be lowered and staging altitudes increased. A slight drop in payload would also result, however. Summary tables of performance data for STS/LRB and the ALS/LRB vehicle are shown in Tables 2.1.2-1 and 2.1.2-2 respectively.

It should be noted that the ALS core vehicle dry weight of 329,300 lbs shown in the table is a very heavy "boiler plate" design that was driven by the ALS low cost design approach. The resulting ALS/LRB configurations were not as structurally efficient as they would be with optimized, lower weight cores. Lowering the core structural weights would increase payloads significantly.

Appendix F contains a detailed summary of the performance analyses.

2.2 ALS/LRB OPTION 2 CONFIGURATION

The Option 2 vehicle is a "common fuel" LO2/LH2 configuration. In order to arrive at a common fuel vehicle a LO2/LH2 pump-fed engine was specifically designed for STS/LRB mission requirements. A LO2/LH2 baseline vehicle was then established, Figure 2.2-1, which met all if the same constraints as the LO2/RP-1 baseline except for length. Increased propellant volumes required by the LO2/LH2 combination were achieved by increasing vehicle diameter to approximately 18 ft. and extending tankage length. As shown in Figure 2.2-1, this added tank length placed the forward attach point to the ET in the middle of the forward LO2 tank sidewall.

Table 2.1.2-1 STS/LRB Performance

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

C4

Table 2.1.2-2 ALS/LRB Performance

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

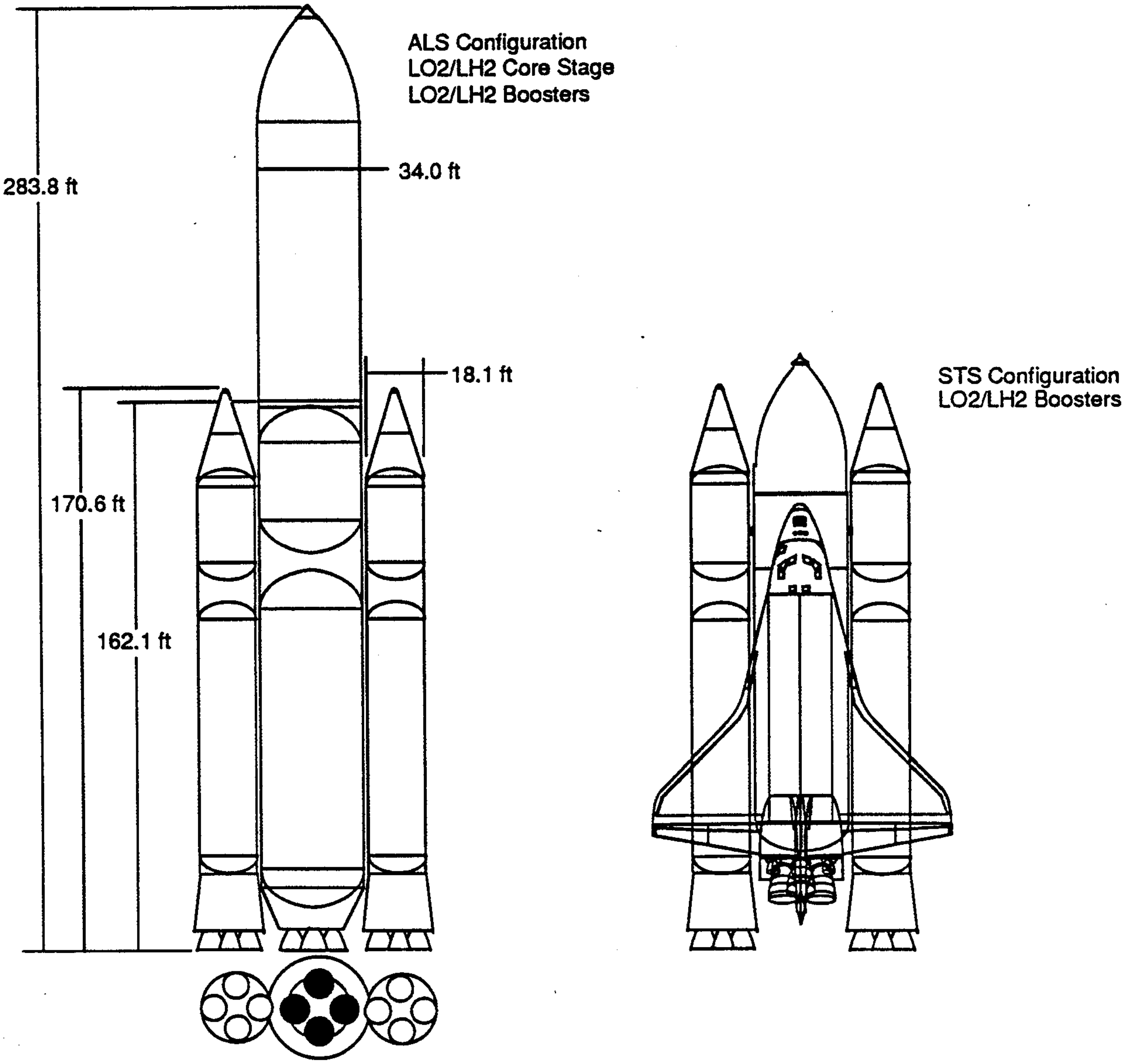


Figure 2.2-1 ALS/LRB Option 2

Due to the severity of the structural problems associated with locating this main thrust fitting on a tank wall, all previous LRB configurations had constrained tank lengths so that the forward fittings would fall on a forward shirt structure ahead of the oxidizer tank. This could not be achieved with this propellant combination and configuration.

The added length of the LO2/LH2 booster also increased aerodynamic drag ion the ET forward ogive which was accounted for in performance calculations. Figure 2.2-1 shows the LRB vehicle is 2048 in. long (170.6 ft) and 218 in. (18.1 ft) in diameter. Four pump-fed LO2/LH2 engines are required for this vehicle. Table 2.1.2-1 summarizes the STS Performance.

Combining two LO2/LH2 LRB pump-fed boosters with the Denver ALS core vehicle provided an ALS launch vehicle that meets the basic mission outlined in Table 2.0-1. Definition and dimensions of the core vehicle were taken from Ref. (1). The core vehicle is 3406 in. (283.8 ft) long and 408 in. (34 ft) in diameter and has four LO2/LH2 engines. Payload capability as shown in Table 2.1.2-2 with two LRB LO2/LH2 boosters is 102.5 klb.

Payload capability for the LRB booster in the STS/LRB mission is 71.9 klb as shown in Table 2.1.2-1.

2.2.1 Engines

Option 2 LRB LO2/LH2 engine is a derivative of the ALS core engine previously described. This engine was optimized to provide 632 klb thrust at full power sea level and thrust at full power sea level and 474 klb thrust at the 75% power level as shown in Figure 2.2.1-1.

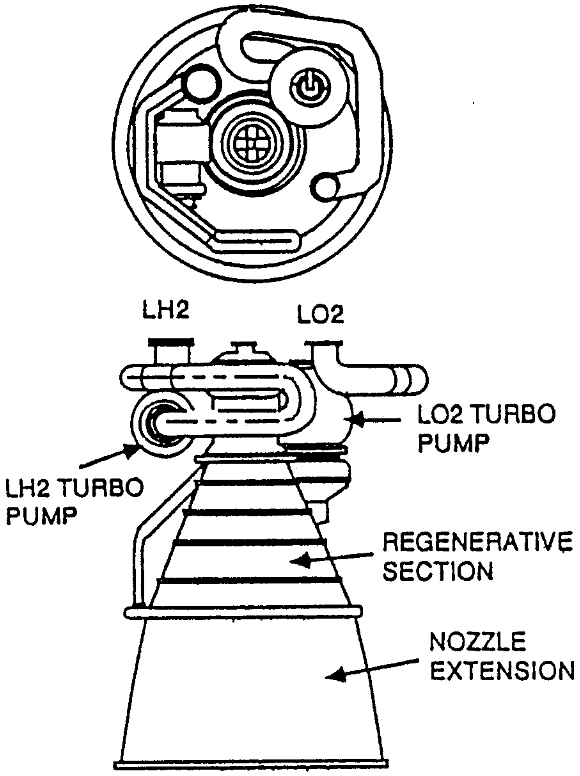
One engine out capability in the four engine cluster is provided for LRB operation by throttling the remaining three engines up from 75% thrust at NPL to 100% at EPL.

The ALS core engine was previously described in paragraph 2.1.1. As noted, the ALS core engine is not throttleable whereas an LRB engine needs throttling capability for safe operation.

2.2.2 Performance

When the option 2 LRB, as summarized in Tables 2.1.2-1 & 2, was combined with the ALS core vehicle, a launch vehicle that meets the ALS mission payload requirements was obtained. Two LRB's were used as shown in Figure 2.2-1. The resulting ALS payload for the 28.5 deg. included orbit is 102.5 klb.

Trajectory characteristics using the Option 2 LRB were similar to the Option 1 trajectory. Dynamic pressure, timeline, and booster separation conditioned were very close. For a detailed explanation of the performance analysis, see Appendix F.



	Booster Engine @	
	NPL	EPL
Mixture Ratio	6	
Propellant Flow Rate (lbm/sec)	1242	
Vacuum Thrust (klbf)	527	702
Sea Level Thrust (klbf)	474	632
Vacuum Isp (sec)	424	
Sea Level Isp (sec)	380	
Chamber Pressure (psia)	1855	
Area Ratio	25.1	
Exit Pressure (psia)	7.01	
Weight (lbm)	5755	
Throat Diameter (in.)	14.13	
Exit Diameter (in.)	70.8	
Throttle Range 65-100%		

Figure 2.2.1-1 Pump-Fed Engine LO2/LH2 - Option 2

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2.3 ALS/LRB OPTION 3 CONFIGURATION

Option 3 ALS/LRB is a "common fuel" and "common engine" launch vehicle. The basic ALS core engine was modified by removal of the nozzle extension and then used for an LRB booster. The resultant lowering of sea level thrust for the LRB engine required that six engines be placed on the core vehicle and five engines on each of two boosters as shown in Figure 2.3-1.

In order to meet STS/LRB performance with a non-optimum LRB engine, propellant volumes increased substantially so that the overall length of the LRB increased by 15 ft to 2229 in., (185.8 ft) over the Option 2 vehicle. Diameter of Option 3 LRB was held to 218 in. (18.2 ft).

The additional length required for the LRB for Option 3 placed the tip of the LRB approximately 2.3 ft in front of the nose of the ET. The resulting increase in drag had to be accounted for in performance calculations. As shown in Figure 2.3-1, the longer LRB allowed the forward ET attach point in the intertank structure, and the entire mass of the LO2 tank is forward of the ET/LRB attachment fittings.

The basic mission of the ALS for Option 3 was met with 109.1 klb of payload as shown in Table 2.1.2-2. The LRB STS mission was met with 75.0 klb payload, 4.0 klb above that of Option 2.

2.3.1 Engines

The Option 3 "common engine" for use on both the ALS core vehicle and the LRB booster is shown in Figure 2.3.1-1. This engine is a down sized ALS engine from the ALS engine shown for Option 2. It has a propellant flow rate of 1134 lbm/sec and sea level thrust of 400 klb. By removing the nozzle extension, sea level exit pressure is increased to 12.0 psia which results in a sea level thrust of 444 klb for the LRB booster. In order to achieve the require ALS/LRB mission, six of these core engines are located on the core vehicle and five on each LRB booster, as shown in Figure 2.3-1. Five engines on the LRB provide a total of 2220 klb of thrust. Since the ALS core engines are not throttleable the LRB engines are not throttleable.

2.3.2 Performance

Using a "common engine" for both the core and booster vehicles which were non-throttling required a down sized ALS engine. This was offset by using six engines on the core vehicle and five on the LRB boosters. From the STS/LRB performance Table 2.1.2-1, it can be seen that Option 2 configuration had more thrust and less useable propellant, Option 3 had a higher STS payload and a significantly lower QMAX, 612 psf. This was accomplished without a QMAX

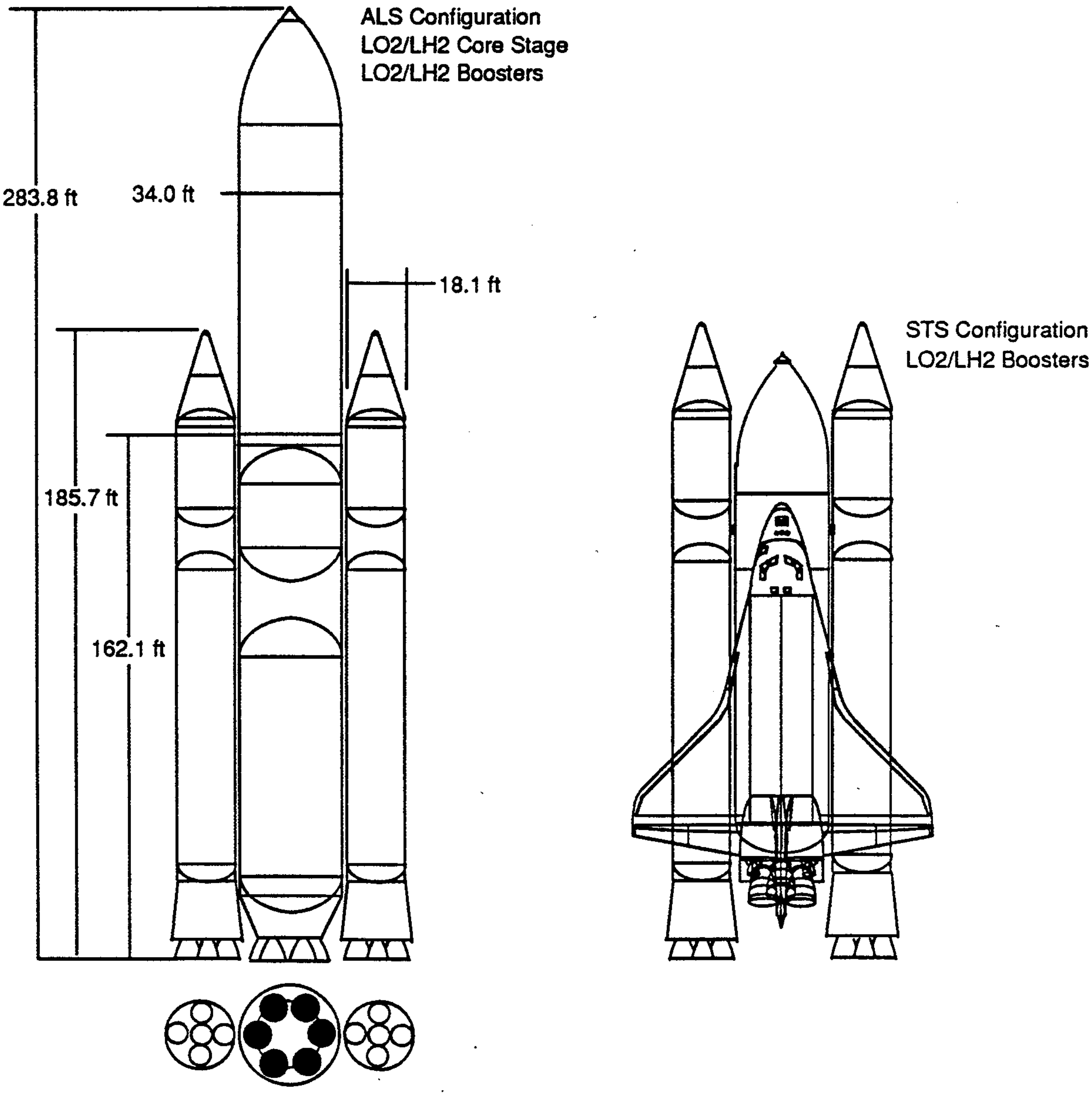
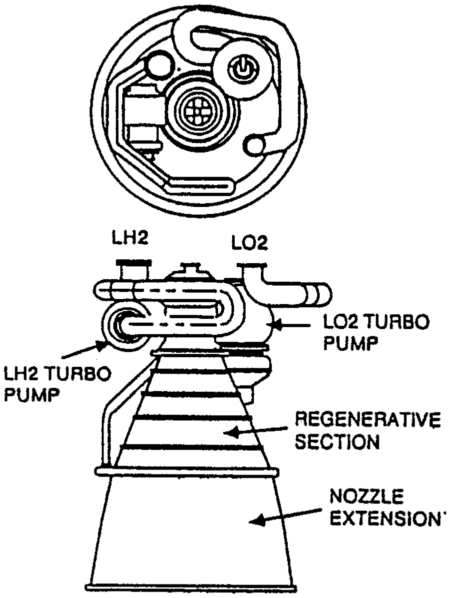
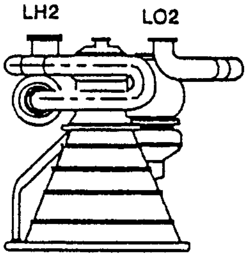


Figure 2.3-1 ALS/LRB Option 3



Core

	Common Engine	
	Core	Booster
Mixture Ratio	6	6
Propellant Flow Rate (lbm/sec)	1134	1134
Vacuum Thrust (klbf)	500	475
Sea Level Thrust (klbf)	406	443.9
Vacuum Isp (sec)	440.6	419
Sea Level Isp (sec)	358	391.2
Chamber Pressure (psia)	2800	2800
Area Ratio	69.9	24.2
Exit Pressure (psia)	3.0	12.0
Length (in.)	156	96
Throat Diameter (in.)	10.7	10.7
Exit Diameter (in.)	90	96



Booster

Figure 2.3.1-1 ALS Core/Booster Engine - Option 3 throttling which is a desirable condition. Option 3 LRB propellants, shown in the Table were increased significantly from Option 2 resulting in the longer LRB vehicle. It is interesting to note that using the maximum allowable QMAX throttling results in the smallest LRB tank sizes and a slightly higher thrust/weight ration at lift off. A detailed explanation of the performance is included in Appendix F.

Reference (1): STME/STBE Quarterly Review "Vehicle Configurations and Propulsion Requirements", Dated-September 22, 1988.