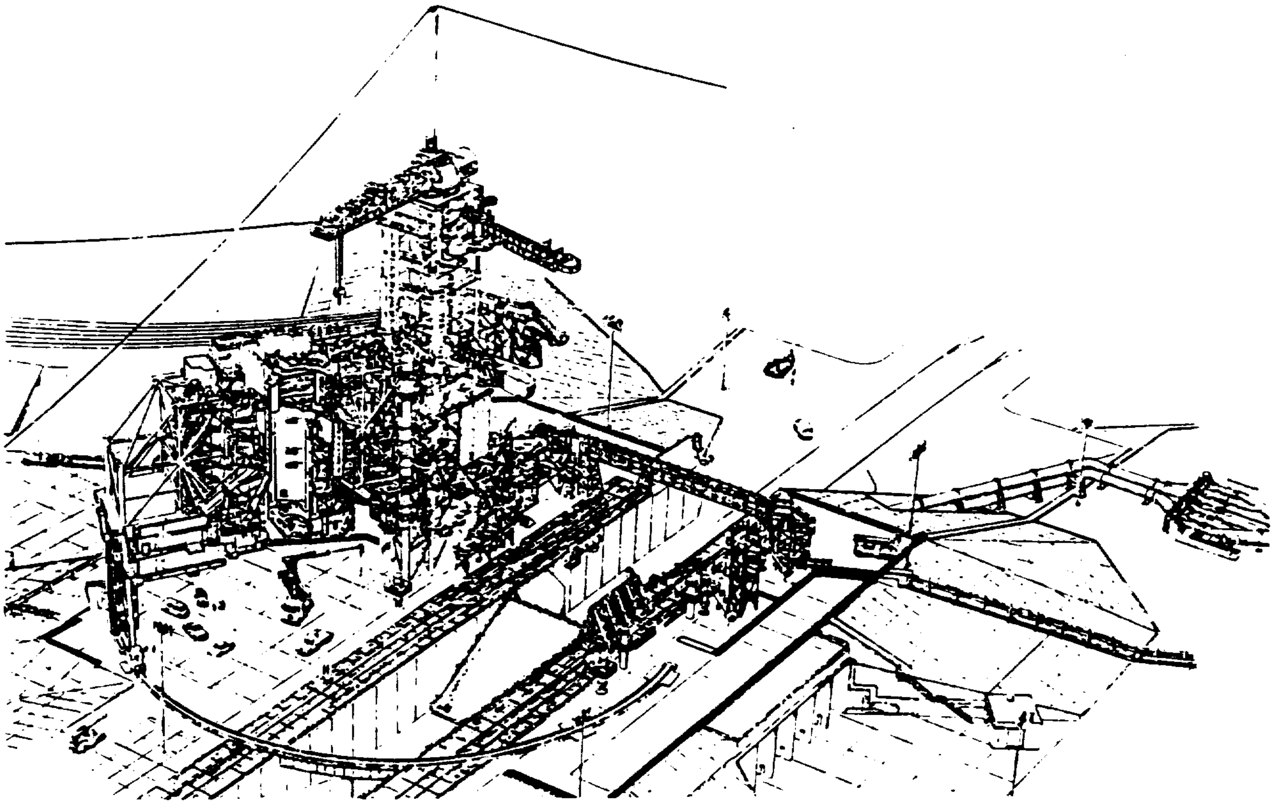
LSO-000-286-1410

KSC ADVANCED PROJECTS & TECHNOLOGY OFFICE

LIQUID ROCKET BOOSTER INTEGRATION STUDY



LRBI STUDY SYNOPSIS
VOLUME II OF V

FINAL REPORT
PHASE I

NAS10-11475

NOVEMBER 1988

Lockheed
Space Operations Company

81005-01BL3
/DY2

LSO-000-286-1410

LIQUID ROCKET BOOSTER INTEGRATION STUDY

VOLUME II OF V
STUDY TASK SUMMARY

KENNEDY SPACE CENTER
NAS10-11475

PREPARED BY:
LOCKHEED SPACE OPERATIONS COMPANY

Gordon E. Artley
Lockheed Study Manager

W. J. Dickinson
NASA Study Manager

L.P. Scott
Lockheed Deputy Study Manager

NOVEMBER 1988

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LRBI FINAL REPORT
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VOLUME II - STUDY SUMMARY

SECTION 1: LRBI Study Synopsis - An assessment of the study objectives, approach, analysis, and rationale. The study findings and major conclusions are presented.

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SECTION 3: Ground Operations Cost Model (GOCM) - The updating and enhancement of this NASA provided computer-based costing model are described. Its application to LRB integration and instructions for modification and expanded use are presented.

SECTION 4: Cost - Summary and Analysis of KSC Costs.

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The study output has been developed in the form of nineteen derived study products. These are presented and described in the subsections of this volume.

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The progress reviews and oral presentations prepared during the course of the study are presented here along with facing page text where available.

VOLUME V - APPENDICES

Study supporting data used or referenced during the study effort are presented and indexed to the corresponding study products.

LIST OF ABBREVIATIONS AND ACRONYMS

ADP	Automatic Data Processing
A&E	Architectual and Engineering
AF	Air Force
AI	Artificial Intelligence
AL	Aluminum
AL-Li	Aluminum Lithium Alloy
ALS	Advanced Launch Systems
ALT	Alternate
AOA	Abort Once Around
AOPL	Advanced Order Parts List
AP	Auxiliary Platform
APU	Auxiliary Power Unit
ARF	Assembly and Refurbishment Facility
ARTEMIS	Accounting, Reporting, Tracking, & Evaluation Management - Information System
ASRM	Advanced Solid Rocket Motor
ASSY	Assembly
ATO	Abort to Orbit
ATP	Authority to Proceed
AUTO	Automatic
AWCS	Automated Work Control System
BITE	Built-in Test Equipment
BLOW	Booster Liftoff Weight
BOC	Base Operations Contractor
BSM	Booster Separation Motor

C	Celsius
CAD	Computer Aided Design
CALS	Computer Aided Logistics System
CCAFS	Cape Canaveral Air Force Station
CCB	Change Control Board
CCC	Complex Control Center
CCF	Compressor Converter Facility
CCMS	Checkout, Control and Monitor Subsystem
CDDT	Countdown Demonstration Test
CDR	Critical Design Review
CEC	Core Electronics Contractor
CER	Cost Estimating Relationships
CG	Center of Gravity
CH4	Methane
CITE	Cargo Integration Test Equipment
CM	Construction Management
	Configuration Management
C/O	Closeout
	Checkout
CONC	Concrete
C of F	Cost of Facilities
COMM	Communications
CPF	Cost per Foot
CPF2	Cost per Square Foot
CPF3	Cost per Cubic Foot
CPM	Critical Path Management
CPU	Central Processing Unit
CR	Control Room
Cryo	Cryogenic
C/S	Contractor Support
CT	Crawler Transporter
CY	Calendar Year

dBase	Data Base - Software Program
dc	Direct Current
DDS	Data Processing System
DDT&E	Design, Development, Test & Engineering
DE	Design Engineering
DEQ	Direct Equivalent Head Count
DFRF	Dryden Flight Research Facility
DFI	Development Flight Instrumentation
DHC	Direct Head Count
DIST	Distributor
DOD	Department of Defense
DOS	Disk Operating System
DOT	Department of Transportation

ECLSS	Environmental Control & Life Support System
ECS	Environmental Control System
EL	Elevation
ELS	Eastern Launch Site
ELV	Expendable Launch Vehicle
EMA	Electrical Mechanical Actuator
EMERG	Emergency
EPA	Environmental Protection Agency
EPDC	Electrical Power and Distribution Control
EPL	Emergency Power Level
ET	External Tank
ET-HPF	External Tanks - Horizontal Processing Facility
ETR	Eastern Test Range

F	Fahrenheit
FAA	Federal Aviation Administration
F&D	Fill & Drain
FEP	Front End Processor
FLT	Flight

FMEA/CIL	Failures Modes & Effects Analysis/Critical Items List
FRF	Flight Readiness Firing
FRSC	Forward Reaction Control System
ft	Feet
FSS	Fixed Service Structure
FWD	Forward
FY	Fiscal Year

G&A	General and Administrative
G,g	Acceleration of Gravity
GAL	Gallons
GDSS(GD)	General Dynamics Space Systems
GEN	Generator
GFE	Government Furnished Equipment
GH2	Gaseous Hydrogen
GHe	Gaseous Helium
GLOW	Gross Liftoff Weight
GLS	Ground Launch Sequencer
GN2	Gaseous Nitrogen
GN&C	Guidance, Navigation & Control
GOAL	Ground Operations Aerospace Language
GOX	Gaseous Oxygen
GOCM	Ground Operations Cost Model
GPC	General Purpose Computer
GPM	Gallons Per Minute
GRD	Ground
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GTSI	Grumman Technical Services, Inc.
GUCP	Ground Umbilical Carrier Plate

H2	Hydrogen
HAZGAS	Hazardous Gas
HB	High Bay
HDP	Holddown Post
He	Helium
HIM	Hardware Interface Module
HMF	Hypergolics Maintenance Facility
HPF	Horizontal Processing Facility
HQ	Headquarters
HVAC	Heating, Ventilation, and Air Conditioning
HW	Hardware
HYD	Hydraulic(s)
HYPER	Hypergolic
Hz	Hertz
IBM	International Business Machines
ICD	Interface Control Document
I/F	Interface
ILC	Initial Launch Capability
INST	Instrumentation
INTEG	Integration
IOC	Initial Operational Capability
IPR	Interum Problem Report
IRD	Interface Requirements Document
IUS	Interial Upper Stage
JSC	Johnson Space Center

K	Thousands
K	Kelvin
KLB	Thousands of Pounds
KSC	Kennedy Space Center
KW	Kilowatt

LAC	Launch Accessories Contractor
LC-39	Launch Complex 39
LCC	Life Cycle Cost
LCC	Launch Control Center
LCH4	Liquid Methane
LESC	Lockheed Engineering and Science Company
LETF	Launch Equipment Test Facility
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
Li	Lithium
LN2	Liquid Nitrogen
LNG	Liquid Natural Gas
LO2	Liquid Oxygen
LOX	Liquid Oxygen
LPS	Launch Processing System
LRB	Liquid Rocket Booster
LRB-HPF	Liquid Rocket Booster Horizontal Processing Facility
LRBI	Liquid Rocket Booster Integration
LRU	Line Replaceable Unit
LSE	Launch Support Equipment
LSOC	Lockheed Space Operations Company
LUT	Launcher Umbilical Tower

MAX	Maximum
MECO	Main Engine Cutoff
MDAC	McDonnell Douglas Astronautics Company
MIL	Military

MIN	Minimum
MLP	Mobile Launch Platform
MMC	Martin-Marietta Corporation
MMH	Mono Methyl Hydrazine
MOD	Mission Operations Directorate
MOU	Memorandum of Understanding
MP	Manpower
MPS	Main Propulsion System
MSBLS	Microwave Scanning Beam Landing System
MSFC	Marshall Space Flight Center
MST	Mobile Service Tower
MTI	MortonThiokol, Inc.

N2	Nitrogen
NASA	National Aeronautics and Space Administration
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Test
NF	Nose Fairing
N2O2	Nitrogen Tetroxide
NPL	Nominal Power Level
NPSH	Not positive Suction Head
NRC	National Research Council
NSTL	National Space Technology Laboratories (Stennis Space Center)
NSTS	National Space Transportation System
NWS	National Weather Service

OAA	Orbiter Access Arm
OIS	Operational Intercommunications System
OJT	On-the-job Training
O&M	Operations and Maintenance
OMD	Operating and Maintenance Documentation

OMI	Operations and Maintenance Instruction
OMRF	Orbiter Maintenance and Refurbishment Facility
OMRSD	Operational Maintenance Requirements and Specifications Document
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
OPS	Operations
OMBUU	Orbiter Mid Body Umbilical Unit
ORB	Orbiter
ORD	Operational Readiness Date
ORI	Operational Readiness Inspection
OSHA	Occupational Safety & Health Administration
OTV	Operational Television

PA	Public Affairs
PAWS	Pan Am World Services, Inc.
P/A	Propulsion/Avionics Module
Pc	Engine Combustion Chamber Pressure
PC	Personal Computer
PCM	Pulse Code Modulator
PCR	Payload Changeout Room
PDR	Preliminary Design Review
PER	Preliminary Engineering Report
PGHM	Payload Ground Handling Mechanism
PIC	Pyro Initiator Controller
PIF	Payload Integration Facility
P/L	Payload
PMM	Program Model Number
PMS	Permanent Measuring System
PO	Purchase Order
POP	Programs Operations Plan
PR	Problem Report
PRACA	Problem Reporting and Corrective Action
PRCBD	Program Review Control Board Directive

PRC	Planning Research Corporation
PRD	Program Requirements Document
PRESS	Pressure, pressurization
PROP	Propellant
PRR	Preliminary Requirements Review
PSI	Pounds Per Square Inch
psia	Pounds Per Square Inch Absolute
psig	Pounds Per Square Inch Gage
PSP	Process Support Plan
PT&I	Payroll Taxes and Insurance
P&W	Pratt & Whitney Company

Q	Dynamic Pressure
QA	Quality Assurance
Q-Alpha	Dynamic Pressure x Angle of Attack
QC	Quality Control
QD	Quick Disconnect
QTY	Quantity

R	Ranking
RAM	Random Access Memory
RCS	Reaction Control System
R&D	Research and Development
RF	Radio Frequency
RFP	Request for Proposal
RIC	Rockwell International Corporation
ROM	Rough Order of Magnitute
RP-1	Propellant (Kerosene Related Petroleum Product)
RPL	Rated Power Level
RPS	Record and Playback System
RPSF	Rotation, Processing & Surge Facility

R/R	Remove/Replace
RSLS	Redundant Set Launch Sequencer
RSS	Rotating Service Structure
R&T	Research and Technology
RTLS	Return to Launch Site

SAIL	Shuttle Avionics Integration Laboratory
SAB	Shuttle Assembly Building
SCAPE	Self-Contained Atmospheric Protective Ensemble
SDI	Strategic Defense Initiative
SDV	Shuttle Derivative Vehicle
SEB	Source Evaluation Board
SEC	Second(s), Secondary
SGOS	Shuttle Ground Operations Simulator
SIES	Supervision, Inspection & Engineering Services
SIT	Shuttle Integrated Test
	System Integrated Test
SLC-6	Shuttle Launch Complex No.6
SLF	Shuttle Landing Facility
SOFI	Spray On Foam Insulation
SOW	Statement of Work
SPC	Shuttle Processing Contractor
SPF	Software Production Facility
SPDMS	Shuttle Processing Data Management System
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SRSS	Shuttle Range Safety System
SR&QA	Safety, Reliability and Quality Assurance
SSC	Stennis Space Center (NSTL)
SSME	Space Shuttle Main Engine
SSV	Space Shuttle Vehicle
STD	Standard
STS	Space Transportation System

SUBSTA	Substation
SW	Switch
S/W	Software
TAL	Transatlantic Landing
TBD	To Be Determined
T&C/O	Test and Checkout
TFER	Transfer
T-0	Liftoff Time
TOPS	Technical Operating Procedures
TPS	Thermal Protection System
TSM	Tail Service Mast
TTV	Termination/Test/Verification
TVA	Thrust Vector Activator
TVC	Thrust Vector Control
T/W	Thrust to Weight Ratio
TYP	Typical
ULCE	Unified Life Cycle Engineering
UMB	Umbilical
UPS	Unintegrated Power System
USAF	United States Air Force
USS	Utility Substation
V	Volt(s)
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VIB	Vertical Integration Building
VLS	Vandenberg Launch Site
VPF	Vertical Processing Facility

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WBS	Work Breakdown Structure
WIP	Work in Progress
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WTR	Western Test Range

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HPF	Horizontal Processing Facility
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HVAC	Heating, Ventilation, and Air Conditioning
HW	Hardware
HYD	Hydraulic(s)
HYPER	Hypergolic
Hz	Hertz

IBM	International Business Machines
ICD	Interface Control Document
I/F	Interface
ILC	Initial Launch Capability
INST	Instrumentation
INTEG	Integration
IOC	Initial Operational Capability
IPR	Interum Problem Report
IRD	Interface Requirements Document
IUS	Interial Upper Stage

JSC	Johnson Space Center

K	Thousands
K	Kelvin
KLB	Thousands of Pounds
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OJT	On-the-job Training
O&M	Operations and Maintenance
OMD	Operating and Maintenance Documentation

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OMRF	Orbiter Maintenance and Refurbishment Facility
OMRSD	Operational Maintenance Requirements and Specifications Document
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PO	Purchase Order
POP	Programs Operations Plan
PR	Problem Report
PRACA	Problem Reporting and Corrective Action
PRCBD	Program Review Control Board Directive

PRC	Planning Research Corporation
PRD	Program Requirements Document
PRESS	Pressure, pressurization
PROP	Propellant
PRR	Preliminary Requirements Review
PSI	Pounds Per Square Inch
psia	Pounds Per Square Inch Absolute
psig	Pounds Per Square Inch Gage
PSP	Process Support Plan
PT&I	Payroll Taxes and Insurance
P&W	Pratt & Whitney Company

Q	Dynamic Pressure
QA	Quality Assurance
Q-Alpha	Dynamic Pressure x Angle of Attack
QC	Quality Control
QD	Quick Disconnect
QTY	Quantity

R	Ranking
RAM	Random Access Memory
RCS	Reaction Control System
R&D	Research and Development
RF	Radio Frequency
RFP	Request for Proposal
RIC	Rockwell International Corporation
ROM	Rough Order of Magnitute
RP-1	Propellant (Kerosene Related Petroleum Product)
RPL	Rated Power Level
RPS	Record and Playback System
RPSF	Rotation, Processing & Surge Facility

R/R	Remove/Replace
RSLS	Redundant Set Launch Sequencer
RSS	Rotating Service Structure
R&T	Research and Technology
RTLS	Return to Launch Site

SAIL	Shuttle Avionics Integration Laboratory
SAB	Shuttle Assembly Building
SCAPE	Self-Contained Atmospheric Protective Ensemble
SDI	Strategic Defense Initiative
SDV	Shuttle Derivative Vehicle
SEB	Source Evaluation Board
SEC	Second(s), Secondary
SGOS	Shuttle Ground Operations Simulator
SIES	Supervision, Inspection & Engineering Services
SIT	Shuttle Integrated Test
	System Integrated Test
SLC-6	Shuttle Launch Complex No.6
SLF	Shuttle Landing Facility
SOFI	Spray On Foam Insulation
SOW	Statement of Work
SPC	Shuttle Processing Contractor
SPF	Software Production Facility
SPDMS	Shuttle Processing Data Management System
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SRSS	Shuttle Range Safety System
SR&QA	Safety, Reliability and Quality Assurance
SSC	Stennis Space Center (NSTL)
SSME	Space Shuttle Main Engine
SSV	Space Shuttle Vehicle
STD	Standard
STS	Space Transportation System

SUBSTA	Substation
SW	Switch
S/W	Software
TAL	Transatlantic Landing
TBD	To Be Determined
T&C/O	Test and Checkout
TFER	Transfer
T-0	Liftoff Time
TOPS	Technical Operating Procedures
TPS	Thermal Protection System
TSM	Tail Service Mast
TTV	Termination/Test/Verification
TVA	Thrust Vector Activator
TVC	Thrust Vector Control
T/W	Thrust to Weight Ratio
TYP	Typical
ULCE	Unified Life Cycle Engineering
UMB	Umbilical
UPS	Unintegrated Power System
USAF	United States Air Force
USS	Utility Substation
V	Volt(s)
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VIB	Vertical Integration Building
VLS	Vandenberg Launch Site
VPF	Vertical Processing Facility

WAD	Work Authorization Document
WBS	Work Breakdown Structure
WIP	Work in Progress
WSMR	White Sands Missile Range
WTR	Western Test Range

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SECTION 2

LAUNCH SITE PLAN

(NOTE: STRUCTURE PLAN AS A LEVEL 2 RESPONSE TO MSFC PROGRAM LEAD)

81005-01BM3

VOLUME II SECTION 1

LRBI STUDY SYNOPSIS

Launch site integration of liquid rocket boosters (or any new STS element) is a complex undertaking requiring early planning and coordinated integration with on-going (parallel) launch operations. The successful integration of a liquid rocket booster into the STS system can only be achieved through changes in the launch site configuration and processing procedures. The purpose of this study was the identification of all such changes and the assessment of the resulting impacts to transition the launch site and ground systems to support LRB/STS launch processing.

This KSC study was designed to complement the MSFC LRB studies in the assessment of launch site impacts, processing/launch operations, and facility requirements for the implementation of LRB at KSC. A cursory evaluation of Vandenberg Air Force Base (VAFB) as a LRB launch site was also to be considered.

This section discusses the detailed study objectives and how this study was designed to support the three-center (KSC, MSFC and JSC) NASA project teams and their LRB contractor activities. The formulation of the technical approach resulted in the breakdown of activities into a structured study plan. This plan, the resulting study products, and the task interrelationships are presented and described in this section.

1.1 BACKGROUND

1.1.1 MSFC Phase-A LRB Study

The MSFC Phase-A study contracts to General Dynamics and Martin Marietta began in October 1987. They were designed to provide the required preliminary concept studies of alternate liquid rocket boosters as a replacement for the SRBs currently used on the STS. These studies were directed toward the definition of candidate pump-fed and pressure-fed LRB configurations. The MSFC study of the LRB flight configurations was entitled "Liquid Rocket Booster for STS Systems Study". Major findings and conclusions of these studies to date are presented in Figure 1.1.1-1. Other identified issues and the final selected LRB configurations are described in Section 1.6.

MSFC LRB STUDY FINDINGS

- LRB SHOULD BE EXPENDABLE BOOSTER
- ALL CONFIGURATIONS ARE 4-ENGINED-LOX TANK FORWARD
- NEW LOW-COST ENGINE DEVELOPMENT IS REQUIRED
- LOX/RP-1 IS FAVORED PROPELLANT FOR STS
- LOX/LH2 PUMP-FED IS PREFERRED FOR ALTERNATE APPLICATIONS
- BOTH PUMP AND PRESSURE-FED OPTIONS ARE VIABLE (PRESSURE-FED REQUIRES TECHNOLOGY DEVELOPMENTS)
- ALL SELECTED CONFIGURATIONS CAN BE FLOWN WITHIN CURRENT STS CONSTRAINTS
- LRB WILL IMPACT KSC
  - BOOSTER DIAMETERS (13.9 TO 18.0 FEET)
  - BOOSTER LENGTHS (147 TO 197 FEET)
  - ET/ORBITER INTERFACES MAINTAINED
  - LIFT-OFF UMBILICALS BASELINED

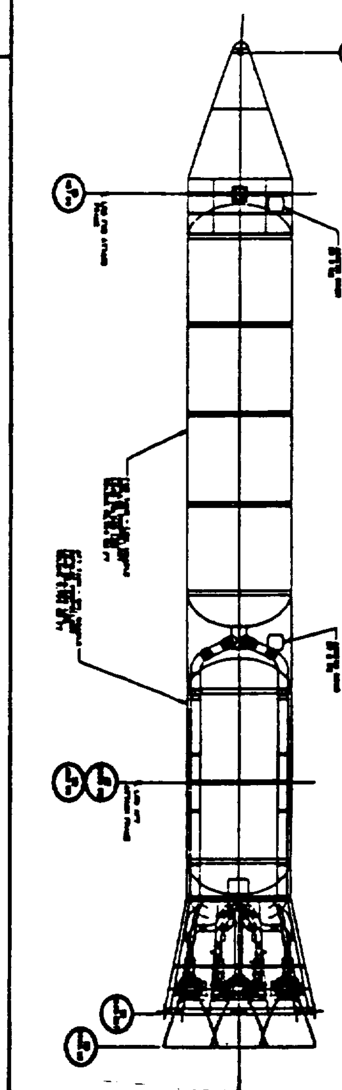

Figure 1.1.1-1. Summary of MSFC Phase A LRB Findings (Ref. GDSS/MMC).

1.1.2 KSC LRBI Study

In March 1988 Lockheed Space Operations Co. was placed under contract to perform the launch site impact evaluation effort and to participate in the LRB Technical Working Group. The LRBI Statement of Work is presented for reference in Appendix 20-7.

1.1.3 JSC LRB Integration

The third key NASA center involved with the LRB study is Johnson Space Center. JSC and their contractor, Lockheed Engineering & Science Company (LESC) performed the Level II integration function for the LRB evaluation. Figure 1.1.3-1 highlights some of the major functional areas of investigation by LESC/JSC. More detailed results of studies at MSFC and JSC can be found in the final reports and presentation materials published at the conclusion of their studies.

1.1.4 LRB Project Team

1.1.4.1 Team Members

The LRB Project was comprised of study efforts at three NASA Centers. Each of these activities supported the LRB program management function at MSFC as shown in Figure 1.1.4.1-1. The prime contractors for the MSFC system design studies were General Dynamics and Martin Marietta.

LRB Phase A flight hardware studies for MSFC were led by Tom Mobley at MMC/Michoud and Steve Seus at GDSS/San Diego. Ned Hughes, LRB Chief Engineer, coordinated these studies, reporting to Larry Wear, LRB Program Manager. In addition, MSFC provided basic wind tunnel model data to support the LRB aerodynamic design.

The Lockheed Engineering & Science Co. (LESC) study at JSC was led by Jim Mc Curry in support of Jim Akkerman, NASA/JSC in the Level II integration and system performance evaluations. The LSOC study team was led by Gordon Artley and reported to NASA, Bill Dickinson, KSC Advanced Program Office, for all of the LRB launch site integration assessments.

The total study project reported through Advanced Program Development under Darrell Branscome to the Office of Space Flight, NASA/HQ.

JSC STUDY ISSUES

- STS/LRB ASCENT FLIGHT DESIGN
  - -GDSS AND MMC CONFIGURATIONS
  - -ASCENT PERFORMANCE EVALUATIONS
  - -INTACT ABORT PERFORMANCE
- CONTINGENCY ABORT ASSESSMENTS
- LRB CONTROLLABILITY ANALYSIS
- PRELIMINARY LRB FMEA/CIL ANALYSIS
- JSC MISSION OPERATIONS DIRECTORATE IMPACTS (SOFTWARE MODS, ETC.)
- INTEGRATED AVIONICS/GN & C
- TOWER CLEARANCE STUDIES
- LRB-TO-STS INTERFACE EVALUATIONS
- LRB/STS SYSTEM LOADS/THERMAL ANALYSIS
- STAGING AND SEPARATION ANALYSIS

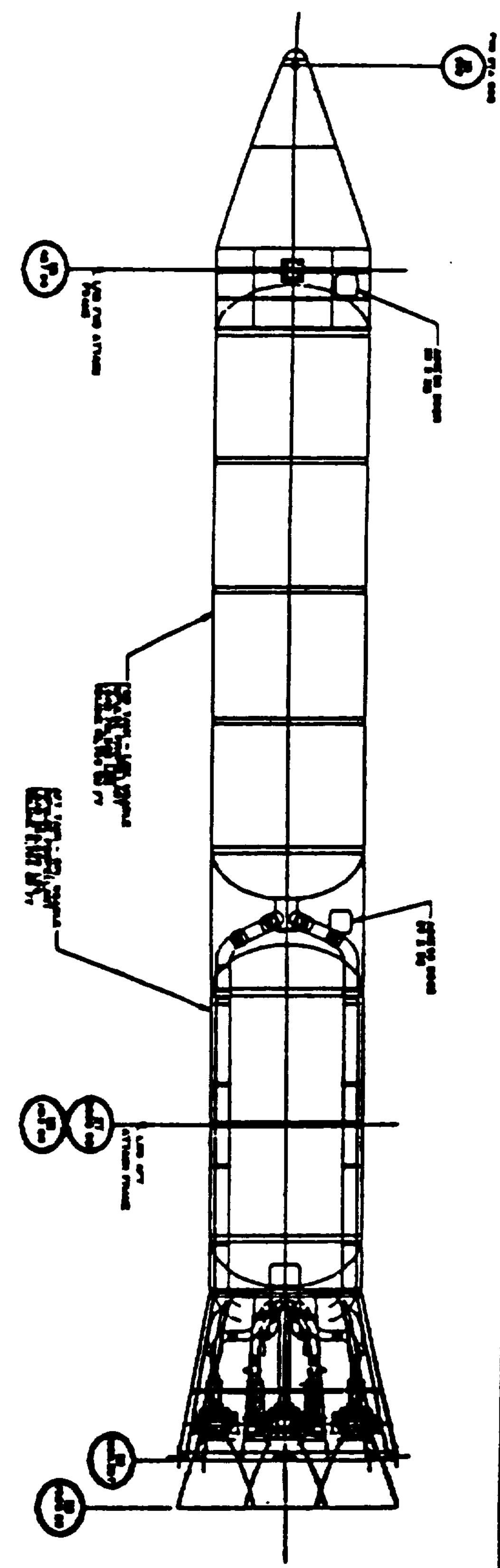

Figure 1.1.3-1. LRB/STS Integration By LESC/JSC.

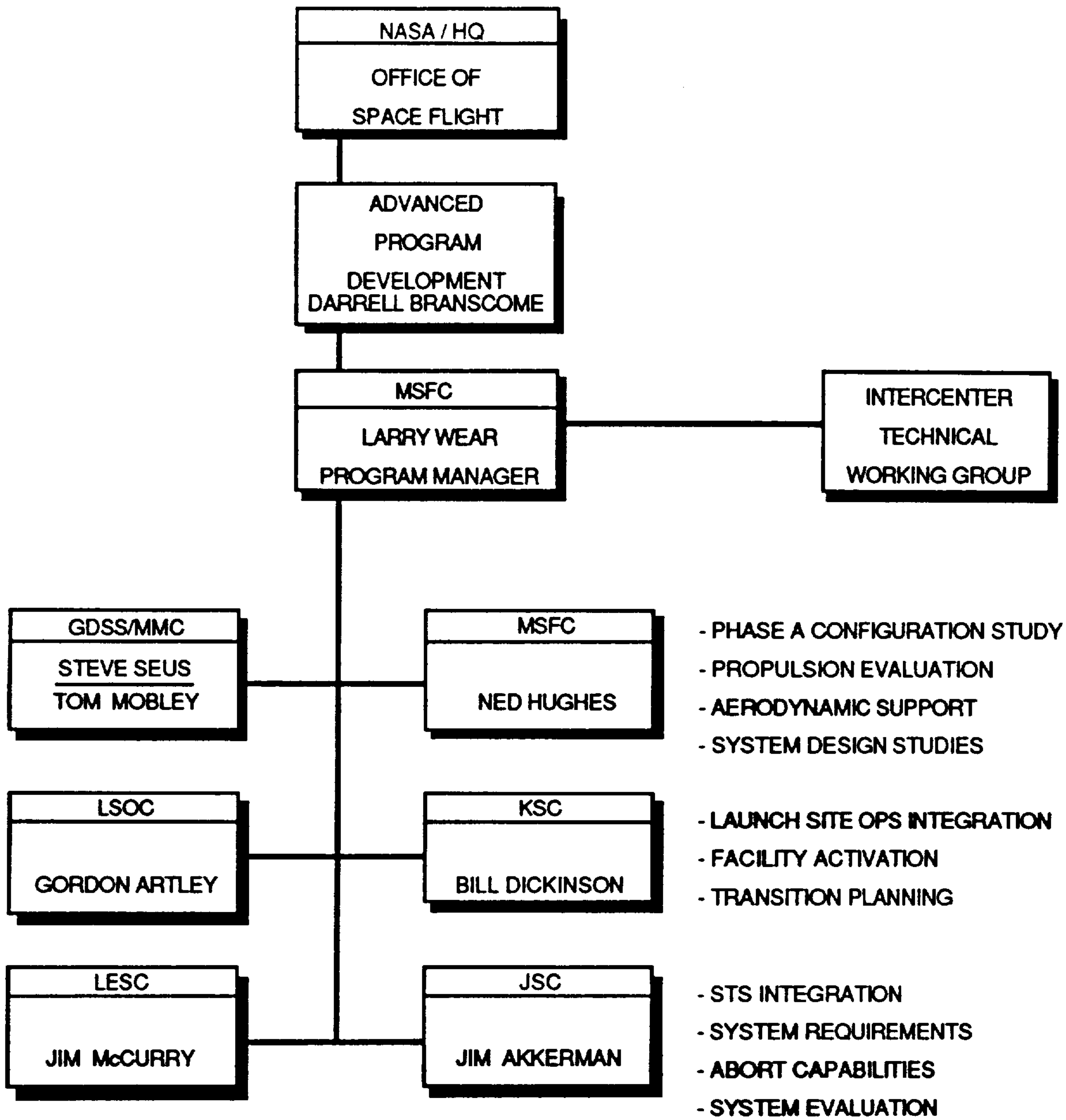

Figure 1.1.4.1-1. LRB Study Team Members.

1.1.4.2 Technical Working Group

The intercenter Technical Working Group consisted of representatives of the three involved NASA centers, contractors and subcontractors. This group met approximately every two months during the study period to assess major LRB planning, design and integration issues. This open and active communication loop made a significant contribution to the quality and maturity of the study products. Early coordination of vehicle design aspects with launch site capabilities and ground system design features enhanced the teams' ability to control life cycle costs for the planned LRB program.

1.2 LRBI STUDY OBJECTIVES

The LRB Integration Study is designed to achieve the seven study objectives summarized in Figure 1.2-1. These objectives are briefly discussed below with reference to the major contributing study products located in Volume III. The overall technical approach and associated study plan is described in Section 1.4.

1.2.1 Impacts (Operations and Facilities)

The operational impacts of the LRB program on the launch site were developed through a structured assessment; a station set by station set approach. This assessment includes evaluation of manpower, procedures, facilities and GSE/LSE requirements to support the LRB integration scenario. In addition, the major impacts to on-going launch site activities are summarized in Section 1.7.2 and Study Product 8 (Volume III).

1.2.2 Scenarios

The preliminary launch site scenarios were developed to support the selected LRB configurations from the MSFC Phase A feasibility studies. These scenarios begin with the delivery of the LRBs to the launch site and conclude after launch with booster recovery/refurbishment (pending configuration selection). Processing timelines describing the LRB scenarios and schedules for the activation/modification of all major facilities are summarized in Study Product 2 (Volume III).

	LRBI STUDY OBJECTIVES
IMPACTS	DEVELOP LAUNCH SITE OPERATIONS AND FACILITY IMPACTS FOR MSFC-SELECTED LRB CONFIGURATIONS
SCENARIOS	DEVELOP PRELIMINARY OPERATIONAL SCENARIOS FOR SELECTED LRB CONFIGURATIONS
DESIGN RECOMMENDATIONS	PROVIDE FLIGHT HARDWARE DESIGN RECOMMENDATIONS BASED ON OPERATIONAL CONSIDERATIONS
OPERATIONALLY EFFICIENT LRB	ASSIST IN THE DEVELOPMENT OF AN OPERATIONALLY EFFICIENT LRB SYSTEM
COST MODEL	UTILIZE THE GROUND OPERATIONS COST MODEL (GOCM) IN THE PREPARATION OF LRB LAUNCH SITE COST ASSESSMENTS
LSE/GSE	DEVELOP PRELIMINARY LSE/GSE CONCEPTS FOR LRB PROCESSING
LAUNCH SITE SUPPORT PLAN	DEVELOP LAUNCH SITE SUPPORT PLAN DEFINING MANPOWER REQUIREMENTS FOR LRB IMPLEMENTATION AND OPERATION

Figure 1.2-1. Study Objectives.

1.2.3 Design Recommendations

Through participation in the LRB Technical Working Group meetings and informal communications our LRBI Study Team members were given the opportunity of presenting recommended LRB flight hardware design features which would significantly enhance LRB ground processing operations and thus reduce life cycle costs. The results including discussions of the specific processing advantages are presented as Study Product 12 (Volume III).

1.2.4 Operationally Efficient LRB System

The Study Team developed a preliminary launch site plan for the LRB which, based on derived LRB processing requirements, establishes the most cost efficient and manpower efficient approach possible, while minimizing launch schedule risk. However, this plan could be significantly refined in the Phase-B preliminary design activities as more definitive requirements are developed. A combination of all study products contributed to this objective. The launch site plan is presented in Section 2 of this volume.

1.2.5 Ground Operations Cost Model (GOCM)

Launch site cost assessments for LRB integration have been evaluated using the GOCM. This computerized costing model has been enhanced and expanded for more detailed costing, and new program documentation was developed. Documentation for the improved program is described in Study Products 13, 14, and 15 (Volume III).

1.2.6 LSE/GSE

Preliminary (concept level) designs for major items of launch support and ground support equipment were developed. In a station set by station set evaluation, the required LSE/GSE designs were identified and related to cost and utility of existing designs in current use for STS processing. These concepts including MLP-mounted umbilicals and major handling GSE are documented as Study Products 4 and 5 (Volume III).

1.2.7 Launch Site Support Plan

A comprehensive launch site plan has been developed to support the implementation of LRB operations and launch site integration. This plan is described in Section 2 of this volume. The plan includes all three phases of integration: 1. Activation, 2. Transition, and 3. Operations. All related study products supporting the Launch Site Plan are presented in Volume III, Study Products.

1.3 KEY STUDY FINDINGS

Twelve key study findings are presented as a function of the above study objectives in Figure 1.3-1. These major findings are:

1. The shared facilities and manpower during transition constitute significant risk of launch delays, even though the planned LRB processing scenario is designed to minimize risks to the schedule of on-going launch activities. Schedule risk is, in general, insensitive to the selected LRB design.

2. Integration of LRB at KSC will require new and modified facilities and GSE:

   New - MLPs (2)
   - Horizontal Processing Facility for LRB and ET offline processing

   Mods - Pads (2)
   - VAB (HB-4 and HB-3)
   - LCC (and LPS)
   - LETF (mods and testing)

3. Extent of modifications to existing facilities and related costs are highly sensitive to selected LRB design characteristics (propellant, length, diameter, etc.). Major areas, of design impact are: 1) Flame deflector and flame trench requirements, and 2) Swing arm and vehicle interface requirements to accommodate vehicle excursions and launch clearances.

4. Pad modification timelines do not fit the available open windows (at 14 launches per year) for the construction to implement LRB changes. During LRB pad modification approximately eight months of exclusive access will be required. During this period all launches

STUDY OBJECTIVES	LRBI KEY STUDY FINDINGS / ACCOMPLISHMENTS
1. IMPACTS (OPS + FAC)	• SHARED FACILITIES / MANPOWER ARE SIGNIFICANT TRANSITION RISK • NEW LRB FACILITIES REQUIRED PLUS MODS TO EXISTING • MOST SCHEDULE - CRITICAL FAC. MODS ARE PADS A&B • MOST SCHEDULE - CRITICAL NEW FAC IS TWO MLPs
2. SCENARIOS	• LRB PROC SCENARIO DESIGNED TO AVOID SCHED RISK • DETAILED LRB PROCESSING TASKS DEFINED
3. LRB DESIGN RECOM	• LRB DESIGN FEATURES ID'ED FOR L.S. OPS EFFICIENCY • LOX/LH2 IS KSC PREFERRED PROPELLANT • L.S. CONSTRAINTS ID'ED TO ACCOMODATE LRB OPTIONS
4. OPER. EFF. LRB	• KEY LRB DES FEATURES ID'ED FOR L.S. OPS EFFICIENCY • L.S. PROCESSING ADVANTAGES OF LRB DEFINED
5. COST MODEL	• GOCM IMPROVED AND DOCUMENTED • LRB LAUNCH SITE PROJECTED COSTS DEFINED
6. LSE - GSE	• CONCEPT LEVEL GSE - LSE DEFINED TO ACCOM LRB
7. LAUNCH SITE SUPPORT PLAN	• MANPOWER FOR ACTIVATION, TRANSITION, OPS DEFINED • KSC NEEDS DEDICATED ACTIVATION TEAM FOR LRB INTEG

Figure 1.3-1. LRBI Key Study Findings.

are forced to the other pad. These single pad launch operations must be compressed to achieve the planned launch rates.

5. New MLP design and construction is the critical path activity to meet first LRB launch in FY96 (assumes a FY91 ATP).

6. Launch site costs are approximately $1B non-recurring and $1B recurring for a 10-year (122 mission) life cycle. Cost savings due to SRB phase-out still require further evaluation.

7. Manpower requirements will peak during FY94-FY95 at an additional 800 people to support activation, transition and operational phases of LRB implementation, plus approximately 1500 A&E and construction/installation contractor personnel.

8. The LRB has a significantly shorter integration timeline on the MLP, in the VAB, compared to SRB. This feature provides greater launch site capability to achieve a 14 per year launch rate.

9. Key LRB configuration design features were identified which result in enhanced launch site operations. These were documented and presented to the MSFC Phase-A contractors. Many, but not all, were incorporated into the LRB designs.

10. LOX/RP-1 and LOX/LH2 are both viable and acceptable propellants for the new LRB. LOX/LH2 is the preferred propellant at the launch site. Other propellants studied were less acceptable.

11. The Ground Operations Cost Model (GOCM) has been shown to be a useful parametric tool for Phase-A cost analysis. The Model was enhanced, applied to the LRB launch site integration and documented. In its current form it is ready to apply to any emerging new launch vehicle evaluation at KSC.

12. KSC needs a dedicated activation team for LRB activation and transition planning with follow-thru to implement new booster operations. This team and its responsibilities are described in the study products and the Launch Site Plan, Section 2 of this volume.

1.4 TECHNICAL APPROACH/STUDY PLAN

Our study team's technical approach consisted of the formulation of a task oriented study plan for the assessment of all LRB integration issues. The performance of these serial and interrelated tasks were designed to produce the desired study products and satisfy the objectives of the study. The study plan was implemented by a core team of dedicated specialists. This team coordinated access to LSOC resident experience in the major disciplines, operational areas and facility design groups affected by the planned LRB integration. Each of the defined tasks was assigned a task leader and the KSC Study Team became a structured entity.

1.4.1 Task Breakdown/Interrelationships

The study methodology is illustrated in the study plan presented in Figure 1.4.1-1. The study tasks were designed to progress from the establishment of baseline requirements/scenarios through the impact analysis (including MSFC project integration) to the output of the study in the form of plans, products and a cost model.

The task descriptions and functional relationships are summarized as follows:

Task 1 - Baseline
This effort was directed toward the establishment of the long range SRB/STS baseline of launch site processing operations, facilities, schedules and manpower, projected over a ten year period. This facilitated the identification of impacts and changes required for the LRB implementation.

Task 2 - LRB Requirements
Working with the LRB design teams, the selected LRB configurations were documented and the launch site processing requirements were derived. Many of these requirements are common for all booster configurations. However, several unique configuration - dependent requirements were identified; such as: ground pressurization for the pressure-fed boosters and hydrogen vent systems for the LOX/LH2 configuration. In addition, the larger LRB configurations were found to require special modifications of ground systems to accommodate their size.

Task 3 - Preliminary LRB Scenarios
Initially a "baseline" LRB launch site scenario was formulated for the pump-fed LOX/RP-1 configurations. It was designed to satisfy the defined processing and facility requirements from Task

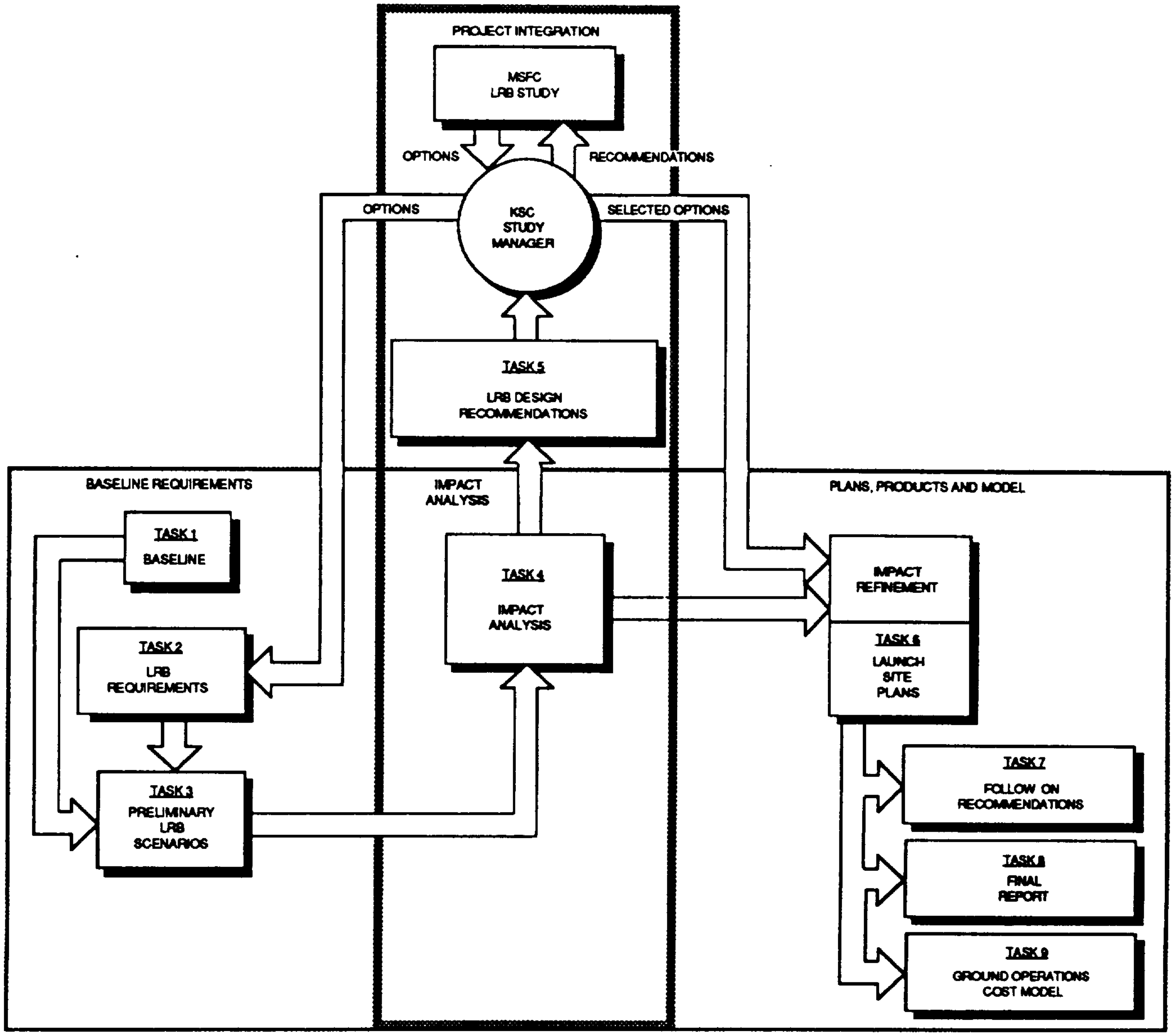

Figure 1.4.1-1. Methodology/Study Tasks.

2. The baseline scenario permitted the formulation of facility planning, processing timelines and impact analysis in the LRB assessments. The LRB scenario was merged with the STS baseline flow developed in Task 1 to construct activation, transition and operations launch site planning.

This baseline launch site scenario was refined during the study as configurations changed and requirements matured. The baseline scenario was also reviewed against the configuration unique requirements identified in Task 2 for the remaining LRB configurations; and, where necessary, amended to incorporate those requirements.

Task 4 - Impact Analysis

The performance of this task required a station set by station set evaluation of the LRB scenario and the integration of that scenario into the baseline STS processing flow. Impact evaluations spanned the design, operations and facility aspects of KSC integration. A cursory analysis of the Vandenberg launch site was developed for LRB. Results of these analysis are presented as study products and discussed in Volume III.

Task 5 - LRB Design Recommendations

Many launch site compatibility issues were identified in the development of the impact analysis of Task 4. From these definitions and the experience base of the launch site study participants, a series of LRB design recommendations were derived. These were formalized and submitted through our KSC Program Manager to the MSFC design study teams. Feedback was received through the Technical Working Group interactions and informal communication. Many, but not all, of these design recommendations resulted in changes to the flight article design which enhanced launch site processing and lowered life cycle costs for the LRB.

Task 6 - Launch Site Plan

The launch site plan for LRB implementation was developed directly from the impact analysis defined in Task 4 and for selected LRB configurations. This launch site plan provides details in the areas of facility activations, operations, schedules, costs, manpower, safety and environmental aspects. The LRB launch site plan is described in Section 2 of this volume.

Task 7 - Follow-on Recommendations

During the performance of this nine-month integration study specific areas requiring further study were identified. They are described in Study Product 16 (Volume III). These areas of study are recommended as Study Options I or II to support planning for LRB Phase B preliminary design and/or to define application of LRB to alternate vehicles.

Preliminary goals of a Phase-B program have been laid out by both MSFC contractors for the preliminary design of the LRB flight article. The primary goals of our launch site integration activity in support of Phase B will include the following:

- Refined analysis of the LRB launch site scenario and facility plan/schedules.
- Continued development of the major LRB to launch site interface definitions and required ICDs.
- Preliminary designs for new and modified facilities, GSE and LSE.
- Definition of manpower, documentation and support requirements for activation, transition and operational phases.
- Refined launch site cost projections for selected LRB configuration.

Task 8 - Final Report

The final report summarizes the results of our team's study effort and documents the developed study products.

Task 9 - Ground Operations Cost Model

NASA/KSC provided the computer-based Ground Operations Cost Model (GOCM) to LSOC for utilization in the LRB cost trade studies. GOCM is a parametric project costing model. The Study Team performed the following cost modeling actions:

1. Used GOCM and other costing techniques in the cost assessment of ground operations for the LRB integration evaluations.

2. Expanded the utility and relevance of GOCM to the KSC STS Program.

3. Evaluated and updated the Cost Estimating Relationships (CERs) resident within GOCM and incorporated cost sensitive design and support scenarios into the model.

4. Integrated lessons learned from the LRBI study.

5. Developed and delivered the following study products: 1) Detailed User's Manual for the operation of GOCM, 2) Instructions for modifying GOCM and 3) All developed software.

1.4.2 Task Schedule/Milestones

The LRB Integration contract ATP was 17 March 1988. The period of performance covered nine months. Using the earlier described task breakdown of the study plan a schedule of performance was developed as shown in Figure 1.4.2-1. This schedule has been generally followed during the course of the study; however, several of the milestones were adjusted to support the MSFC down select process as new configurations were considered or existing configurations were changed. Also noted in Figure 1.4.2-1 are the major study milestones including progress reviews and periodic reports presented during the study.

1.5 STUDY PRODUCTS

1.5.1 Task/Product Relationships

The study plan contains the planned tasks which when executed resulted in satisfying the study objectives. This process is carried out through the development of the study products. The minimum required study products identified in the contract are:

1. LRB Ground Operations Plan
2. LRB Processing Timelines
3. LRB Facility Requirements and Concepts for New Facilities
4. LRB Launch Support Equipment Definition
5. LRB Ground Support Equipment Definition
6. LRB Manpower
7. Cost Estimates Including Transition
8. Potential Impacts to On-Going Launch Site Activity
9. Preliminary Transition Plan
10. Potential Environmental and Safety Implications
11. Propellant Acquisition,Storage and Handling Requirements
12. Recommended Changes to LRB Design for Operational Efficiency
13. A detailed User's Manual for GOCM Operation
14. Instructions for Updating/Modifying the GOCM Program

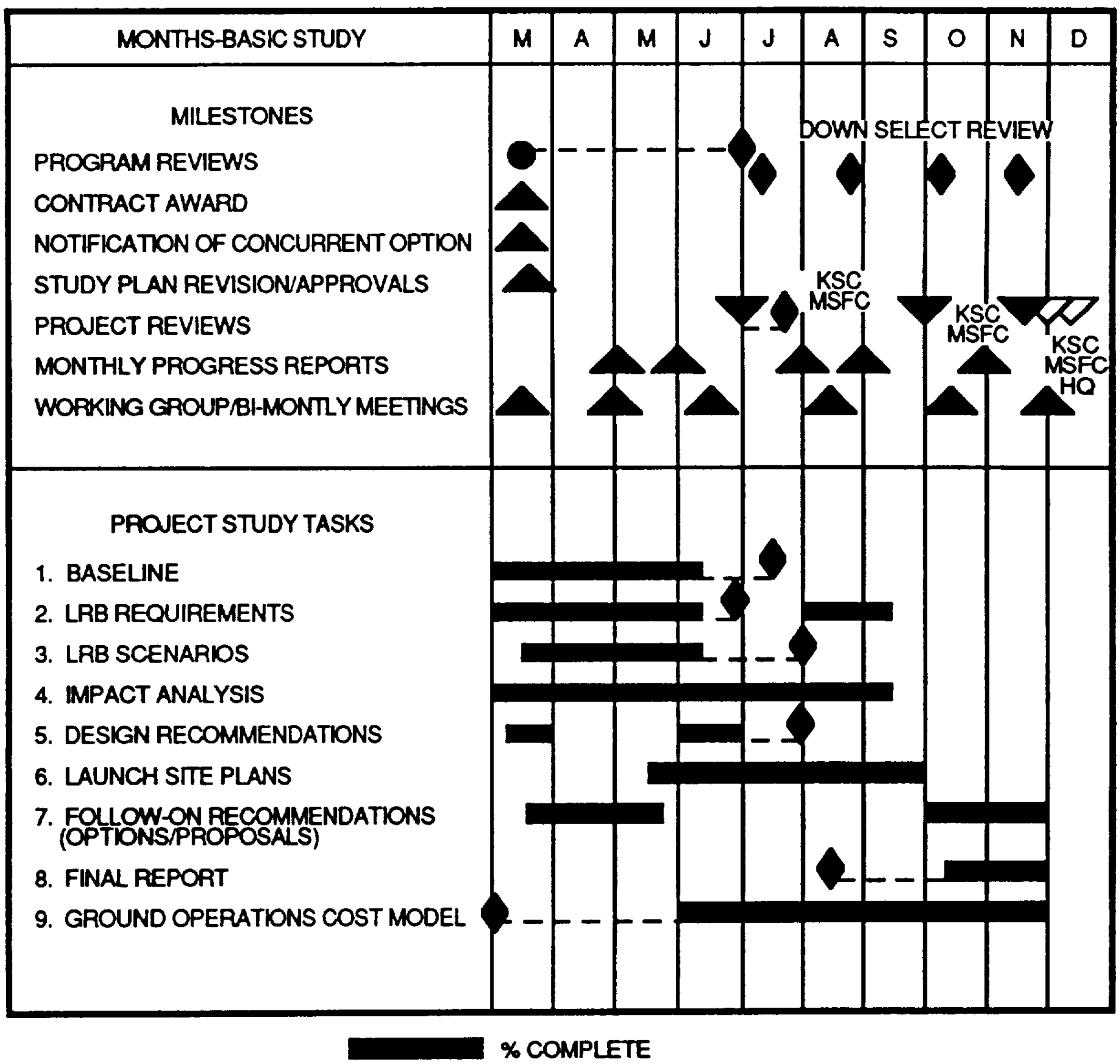

Figure 1.4.2-1. LRB Integration Study Schedule.

15. All Software Developed
16. Recommendations for Follow-on Study Activity

During the course of study activity additional products were defined by the Study Team in order to more fully meet the study objectives. These added products are:

17. VLS Assessment for LRB
18. LRB Engine Processing Study
19. Evaluation of LRB Processing and Storage in the VAB

In order to ensure the timely development of these study products a Task/Product Matrix, Figure 1.5.1-1 was developed. Here, each of the study products is represented as an output from a discrete task. In some cases, other tasks support the product development and are so noted. The study team found that assignment of each product to a defined single task resulted in better traceability of responsibility and timely study progress. Task leaders were then directly accountable for defined study products.

Volume III of this final report contains a comprehensive presentation of these 19 study products.

1.6 MSFC PHASE-A SELECTED LRB CONFIGURATIONS

1.6.1 GDSS/MMC LRB Design Approach

After the identification of selection criteria both General Dynamics and Martin Marietta proceeded with a series of trades and analyses resulting in a Phase-A down selection of the final LRB concepts. It is significant to note that MMC and GD considered launch site compatibility as a primary selection criteria and worked closely with the LRBI Study Team during the selection process.

All selected configurations were capable of STS/LRB delivery of 70,500 pounds to 150 nautical mile, 28.5 degree inclination orbit. Both pump-fed and pressure-fed configurations were evaluated. Propellants considered were RP-1, methane, propane, hydrogen and hypergols. Trade studies included recovery concepts, split expander engine designs, optimum number of engines, and launch ignition sequencing.

	STUDY PRODUCTS \ TASKS	1 SRB BASELINE	2 LRB REQUIREMENTS	3 LRB SCENARIOS	4 IMPACT / ANALYSIS	5 LRB DESIGN RECOMM.	6 LAUNCH SITE PLAN	7 FOLLOW-ON RECOMM.	8 FINAL REPORT	9 GROUND OPS COST MODEL
1	LRB GROUND OPS PLAN		S				X		X	
2	LRB TIMELINES	S		X					X	
3	FACILITY REQMTS/CONCEPTS		S		X				X	
4	LAUNCH SUPPORT EQUIPMENT				X				X	
5	GROUND SUPPORT EQUIPMENT				X				X	
6	LRB MANPOWER	S					X		X	
7	COST ESTIMATES & TRANSITION		S				X		X	
8	IMPACTS TO ON GOING ACTIVITIES	S		X					X	
9	PRELIMINARY TRANSITION PLAN	S					X		X	
10	ENVIROMENTAL/SAFETY ISSUES				X				X	
11	PROPELLANT STORAGE/HANDLING				X				X	
12	DESIGNREC/OPER EFFICIENCY		S			X			X	
13	GOCM USER MANUAL								X	X
14	GOCM INSTRUCTIONS								X	X
15	GOCM SOFTWARE								X	X
16	FOLLOW-ON RECOMMENDATIONS							X	X	
17	VLS ASSESSMENT FOR LRB		S				X		X	
18	LRB ENGINE PROCESSING STUDY				X				X	
19	LRB PROCESS/STORAGE IN VAB	S			X				X	

S = SUPPORTING INPUT (TASK/PRODUCT)
X = PRIME TASK/PRODUCT OUTPUT

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Figure 1.5.1-1. Study Tasks/Products Relationships.

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The following basic groundrules were established:

- A requirement for safe abort (or ATO) with one LRB engine out
- Minimum Orbiter and ET hardware changes
- Maintain existing Booster - ET interfaces
- Maintain or lower peak Orbiter wing loads at max Q
- Relieve SSME throttle down requirement at max Q
- Minimize changes to KSC facilities and integrated processing
- Consider design for growth and evolution to other booster applications

1.6.2 Configuration Details

The final LRB propellants for each of the Phase-A contractor configurations were selected after extensive trade studies. The primary pump-fed and pressure-fed configurations use LOX/RP-1 propellants. The GDSS alternate pump-fed booster uses LOX/LH2. The following discussions describe other configuration details for each contractor's LRB selections. Physical characteristics of each configuration, as of the June 1988 final oral reviews at MSFC, are presented in Volume V, Appendix 20-6.

Martin Marietta Configurations

The MMC pump-fed configuration is shown in Figures 1.6.2-1 and 1.6.2-2. Dual LOX external feedlines of 17-inch diameter route the oxidizer around the RP-1 tank. The forward thrust attachment to the ET is located in a reinforced forward skirt area. Elliptical bulkheads are used on all tankage. Overall dimensions are close to SRB size. Weights and volumetric data are presented in Figure 1.6.2-3.

The MMC pressure-fed configuration is shown in Figures 1.6.2-4 and -5. The feedlines are external 24-inch diameter (dual). Tank wall thickness is approximately 1-inch to contain the internal tank pressurization levels. With engine chamber pressures of 660 psi. tank pressures are in the range of 1000 psi. Full hemispherical tank bulkheads are used. Booster Gross Liftoff Weight (GLOW) is over 1.3 million pounds as shown in Figure 1.6.2-6 (SRB liftoff weight is approximately 1.25 M pounds). Also shown in this figure are the other weights and volumetric data. More definitive design details of the Martin configurations were presented in their final oral presentation charts of June 1988. All MMC engine designs for LRB were developed by Aerojet Corp. under subcontract.

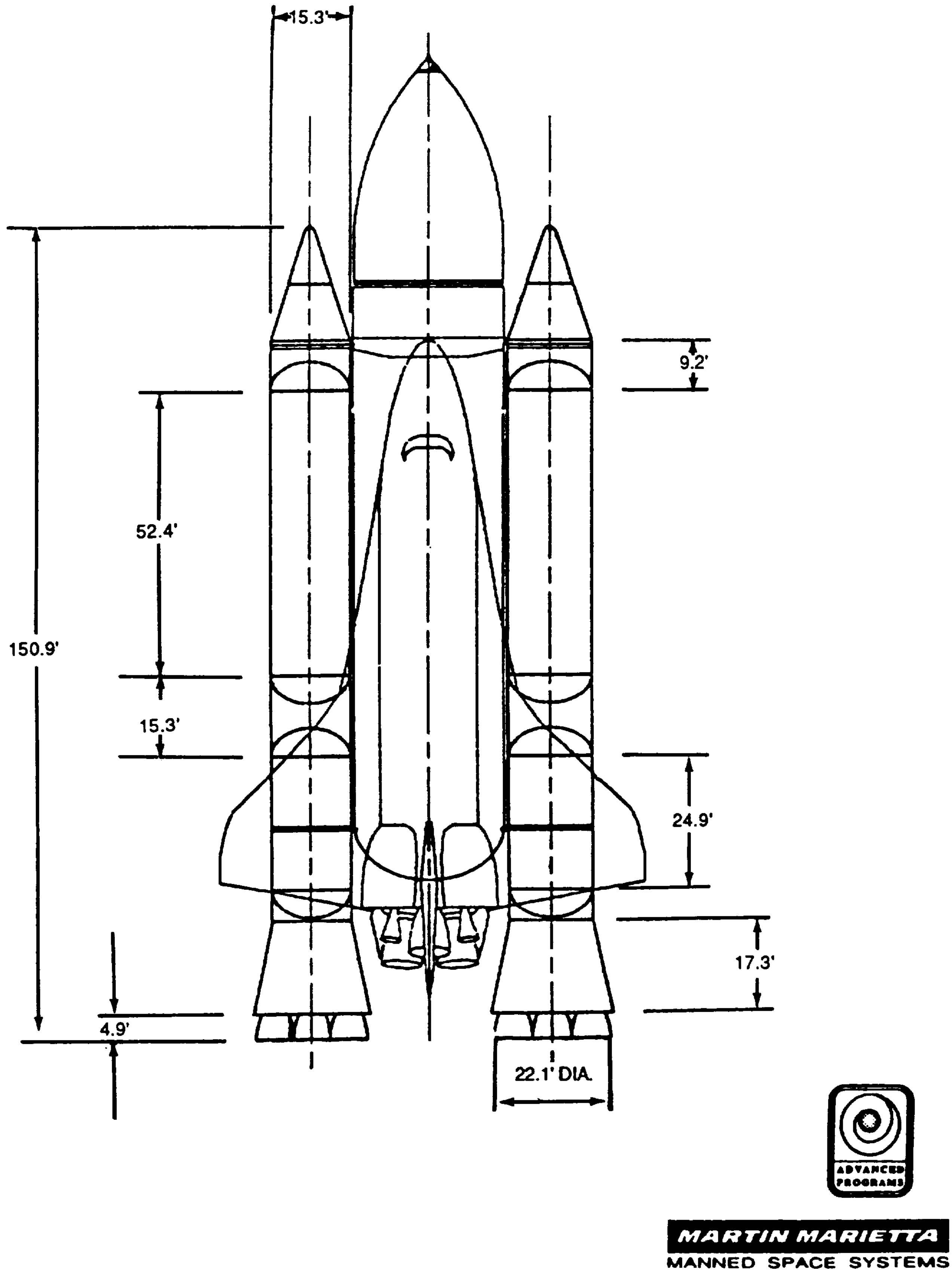

Figure 1.6.2-1. MMC Pump-Fed LO2/RP-1 Vehicle Configuration (10/6/88).

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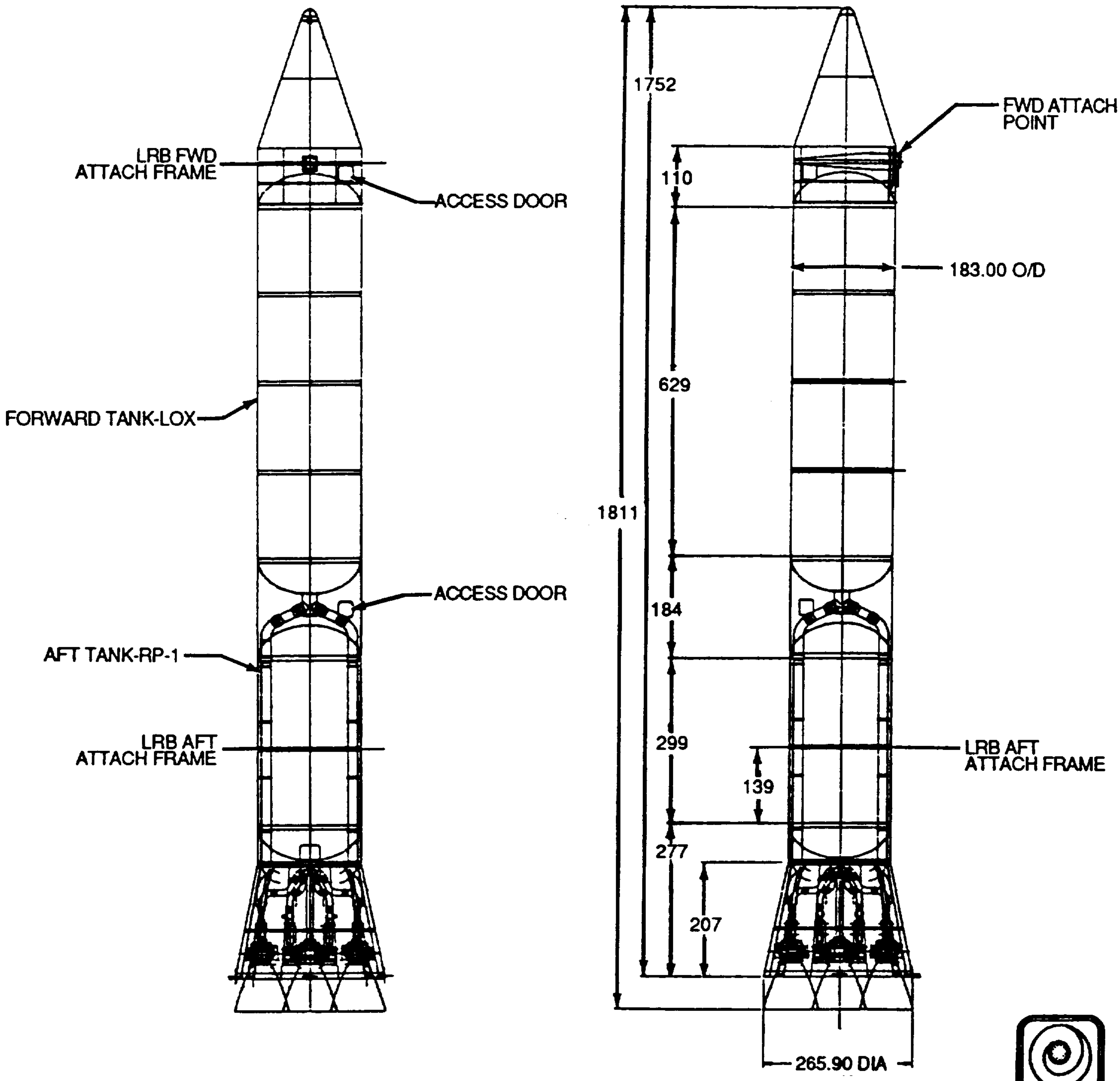

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Figure 1.6.2-2. MMC Pump-Fed LO2/RP-1 Booster Configuration.

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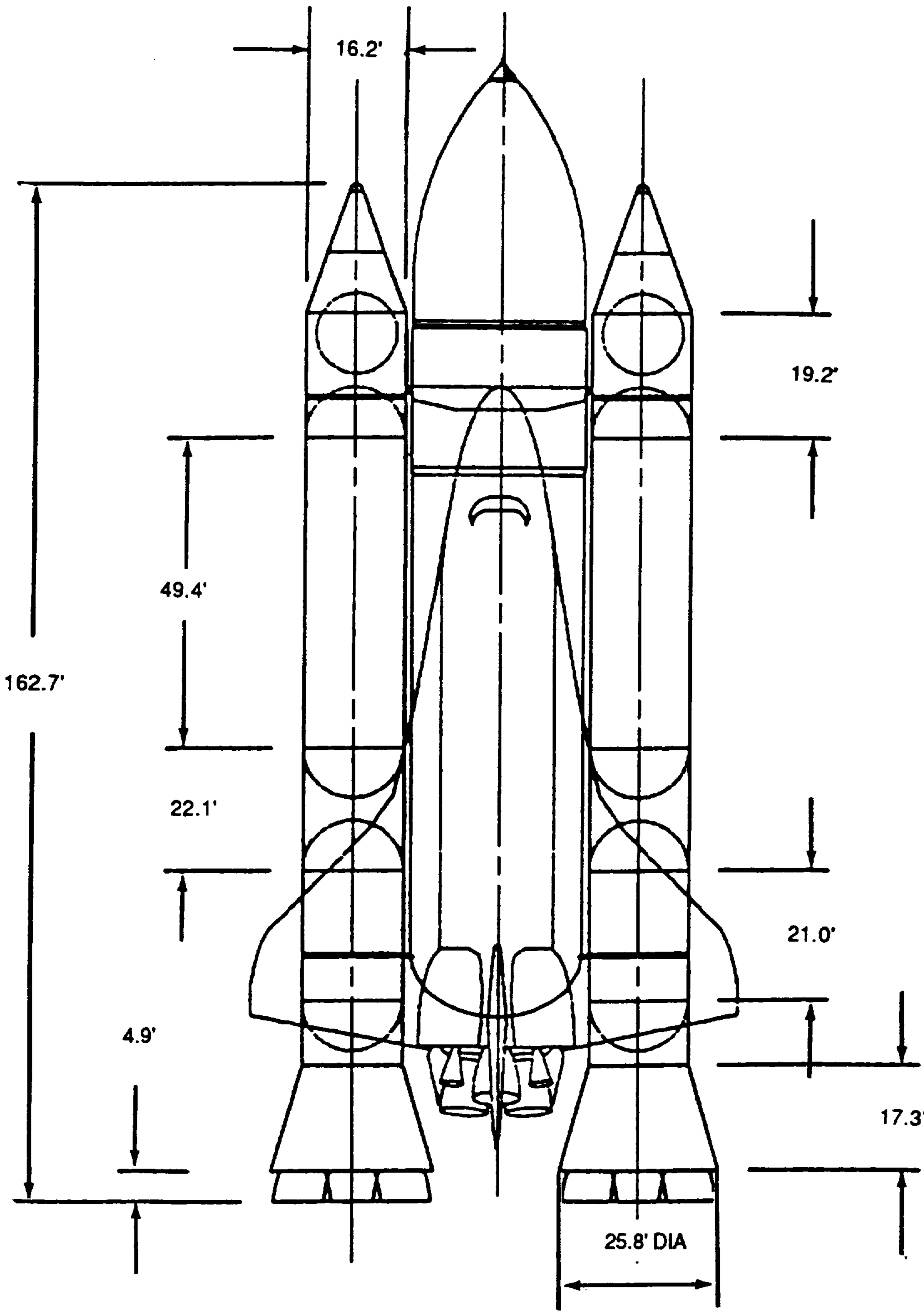
VEHICLE DIMENSIONS	
• LENGTH (IN)	1,810.7
• DIAMETER (OD - IN)	183.0
• ENGINE EXIT AREA (IN^2)	7,359
PROPELLANT VOLUMES (FT^3)	
• LO2	10,769
• RP-1	5,798
• FEEDLINES	245
WEIGHT (LB) INCLUDES 10% CONTINGENCY	
• STRUCTURE	77,840
• PROPULSION SYSTEM	34,820
• OTHER SUBSYSTEMS	11,060
DRY WEIGHT	123,720
• USABLE IMPULSE PROPELLANT	
• LO2	701,302
• RP-1	268,698
• RESIDUALS GASES AND LIQUIDS	5,335
PROPELLANTS/GASES	975,335
GLOW (GROSS LIFTOFF WEIGHT)	1,099,055

ADVANCED PROGRAMS

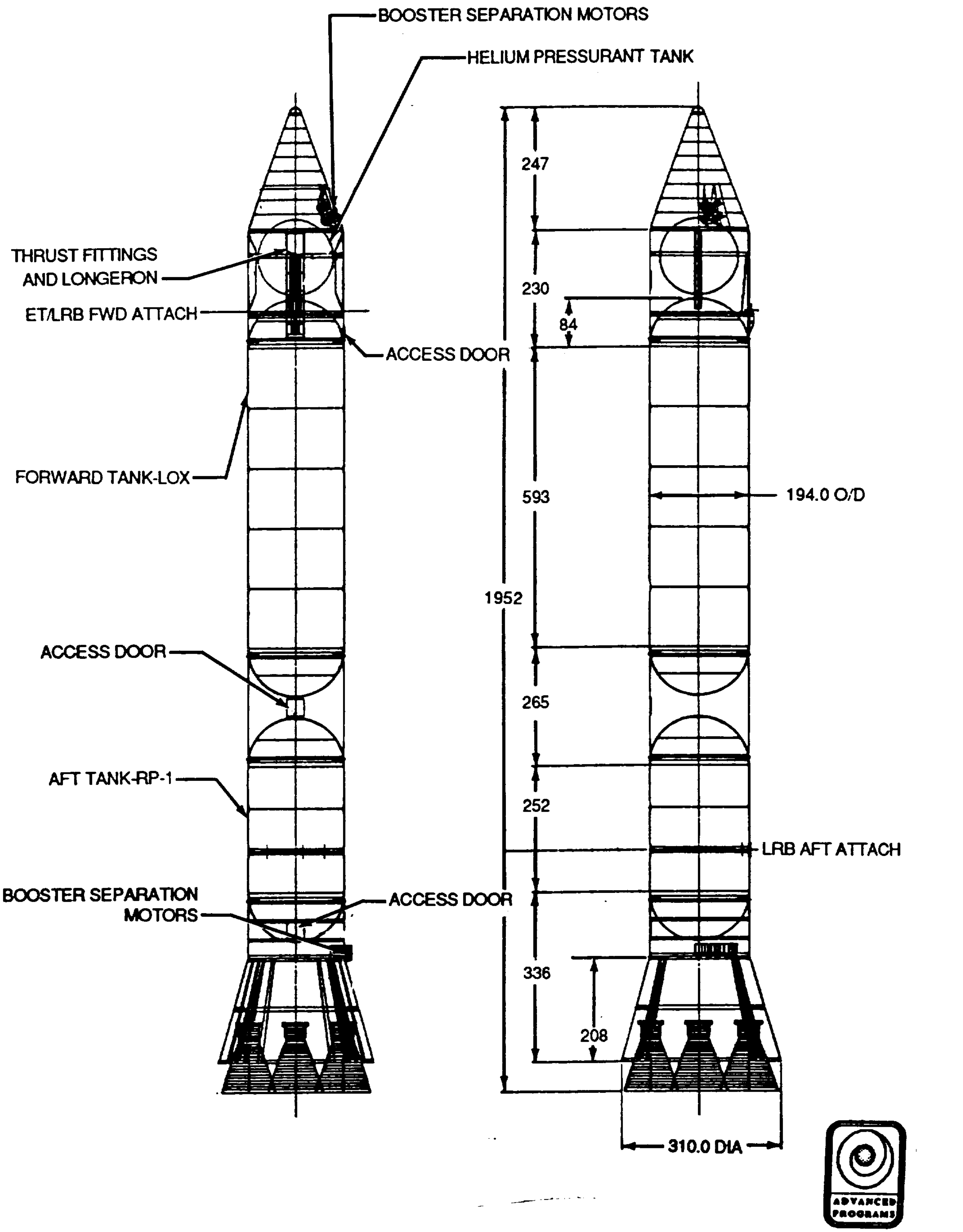
MARTIN MARIETTA
MANNED SPACE SYSTEMS

Figure 1.6.2-3. MMC Pump-Fed Vehicle Data Summary (10/6/88).



MARTIN MARIETTA
MANNED SPACE SYSTEMS

Figure 1.6.2-4. MMC Pressure-Fed LO2/RP-1 Vehicle Configuration (10/6/88).



MARTIN MARIETTA
MANNED SPACE SYSTEMS

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Figure 1.6.2-5. MMC Pressure-Fed LO2/RP-1 Booster Configuration (10/6/88).

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VEHICLE DIMENSIONS	
• LENGTH (IN)	1,952.0
• DIAMETER (OD - IN)	194.0
• ENGINE EXIT AREA (IN^2)	9,365
PROPELLANT VOLUMES (FT^3)	
• LO2	12,012
• RP-1	6,328
• FEEDLINES	214
WEIGHT (LB) INCLUDES 10% CONTINGENCY	
• STRUCTURE	166,760
• PROPULSION SYSTEM	44,030
• OTHER SUBSYSTEMS	10,730
DRY WEIGHT	221,520
• USABLE IMPULSE PROPELLANT	
• LO2	782,084
• RP-1	292,916
• RESIDUALS GASES AND LIQUIDS	5,910
• HELIUM-PRESSURE SYSTEM	11,790
• PROPELLANT-PRESSURE SYSTEM	22,560
PROPELLANTS/SYSTEMS	1,115,260
GLOW (GROSS LIFTOFF WEIGHT)	1,336,780

ADVANCED PROGRAMS

MARTIN MARIETTA
MANNED SPACE SYSTEMS

Figure 1.6.2-6. MMC Pressure-Fed Vehicle Data Summary (10/6/88).

General Dynamics Configurations

The three LRB configurations recommended by GDSS are presented in Fig. 1.6.2-7. During the final evaluation GDSS deleted the LOX/CH4 split expander configuration after studies showed no significant advantages over the basic LOX/RP-1 pump-fed option. However, the split expander engine design was considered significant and is being carried as an optional design for the LOX/LH2 configuration. The GD pump-fed and pressure-fed configurations are LOX/RP-1 designs. The LOX/LH2 configuration is proposed as an alternate pump-fed design. A unique feature of the pressure-fed design is the central 24 inch diameter LOX feedline which penetrates the lower fuel tank.

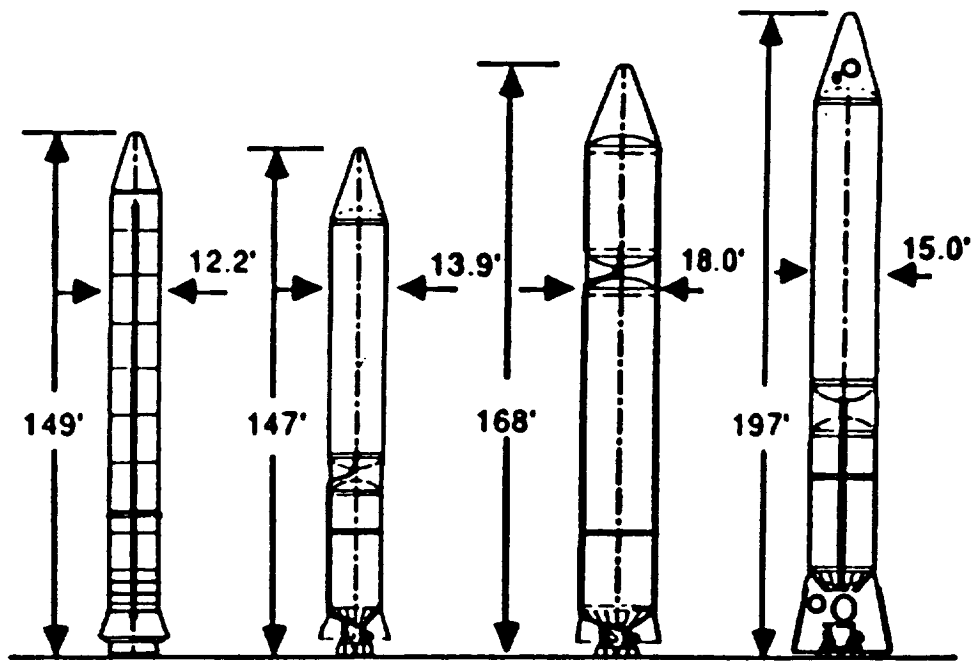
Selected data on the GDSS configurations is compared with the SRB characteristics in Fig. 1.6.2-7. More definitive design details of the General Dynamics configurations can be found in their final report presented to MSFC during August 1988. All GDSS engine designs were developed by Rocketdyne under subcontract.

At the writing of this final report GDSS was engaged in optimizing the length vs. diameter trade study for the LOX/LH2 pump-fed configuration. The current configuration shows a diameter growth to 18 feet and a shortened height of 168 feet. This length allows clearance of the ET GOX vent arm at the pad and prevents a major ground system modification. Additional size trades were in work at our print time to configure this LRB for alternate (non-STS) applications.

1.6.3 Launch Site Design Recommendations

LRB flight article design features which would enhance, simplify or streamline ground processing operations at the KSC launch site have been identified and provided to MSFC and the Phase-A contractors.

Feedback on these recommendations was provided and many features have been incorporated into the Phase-A designs. In addition, the KSC facility constraints have been identified and all proposed designs have been affected by these STS constraints. Attempts have been made to minimize the magnitude of required launch site mods (i.e. the pad flame trench) due to the extended mod period required. Impacts to on-going launch operations can thus be reduced.



DATA (ONE BOOSTER)	SOLID ROCKET BOOSTER	LO2/RP-1 PUMP FED	LO2/LH2 * PUMP FED	LO2/RP-1 PRESS FED
DRY WEIGHT (K lbs)	146	104	131	216
STRUCTURE (K lbs)	---	46.7	75.6	127
LRB GLOW (K lbs)	1,250	1,032	775	1,602
THRUST PER ENGINE (sea level)(K lbs) (nominal)	2,912	546	481	850
INITIAL T/W	1.5	1.37	1.34	1.54
BECO (sec)	120	123	126	119

* ALTERNATE: SPLIT EXPANDER CYCLE

GENERAL DYNAMICS
Space Systems Division

Figure 1.6.2-7. GDSS Selected LRB Configurations - October 1988.

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Figure 1.6.3-1 summarizes the launch site LRB design recommendations and indicates those incorporated into the Phase-A LRB designs. Question marks indicate further analysis required before incorporation, "N.A." indicates recommendation not accepted and "poss.alt." indicates possible alternate design approach under consideration.

1.6.4 KSC Requirements Checklist

Early in the LRB evaluation process our study team drafted a "KSC Requirements Checklist for LRB". This document, after review and approval at KSC, was circulated to the Martin and General Dynamics Study Teams. The checklist is designed in the form of a questionnaire on ground processing requirements for LRB. Responses were received from both of the flight element contractors and are included as Appendix 20-1 and 20-2. The format of the checklist addressed both general groundrules and specific categories of requirements. Figure 1.6.4-1 presents the organization of topics within the checklist.

During the evaluation process a series of "generic" answers to this questionnaire were developed by LSOC and LESC personnel in order to document a baseline definition of pump-fed and pressure-fed configurations for JSC and KSC integration analysis. However, because the configurations remained in a state of evolution over the study period these generic answers do not correspond to any specific selected configuration. The generic draft copy developed for launch site analysis is presented in Appendix 20-3.

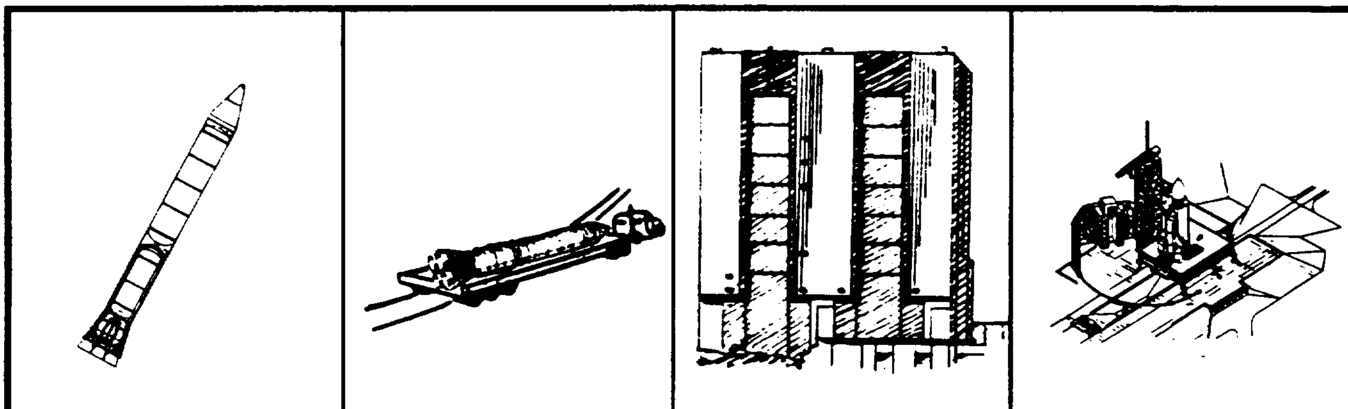
During Phase-B preliminary design it is anticipated that the requirements checklist will be updated to be descriptive of the final selected LRB configuration. A blank checklist for this purpose is presented in Appendix 20-4.

1.6.5 LRB Design Requirements Assessment

Our Study Team performed an assessment of the documented LRB Design Requirements found in the General Dynamics final report. These requirements were developed from study goals and assumptions and applicable program level requirements (NSTS 07700, etc.). This section from the GDSS final report is presented in Appendix 20-5. A summary of the findings is shown in Figure 1.6.5-1 where the total requirements in each of 5 categories is identified. The number of requirements judged to have ground system design impacts are noted in the right column. Almost 70% of these preliminary booster design requirements have ground system implications. We can see from this assessment that booster design and ground system design/redesign will be a significant integration challenge during the Phase B study. Data from the MMC requirements is expected to

INCORPORATED DESIGN FEATURE	DESIGN RECOMMENDATIONS
✓	• NO HYDRAULICS/NO HYDRAZINE
✓	• USE LIFT-OFF UMBILICALS- NO SWING ARMS OR LUT
✓	• MAXIMUM LRB DIAMETER LESS THAN 16 FEET
?	• LOCATE AVIONICS LRU's IN AFT SKIRT AREA
✓	• FACILITATE ENGINE R/R IN VERTICAL ON MLP
✓	• USE EXPENDABLE DESIGN
✓	• LOX/RP-1 PROPELLANTS HAVE MINIMUM PAD IMPACTS
?	• NO FLAME TRENCH (CONCRETE) MODS AT PAD
✓	• FACILITATE VERTICAL AND HORIZONTAL CHECKOUT
✓	• MAKE BOOSTER AUTONOMOUS WITH MINIMUM ORBITER INTERFACES
?	• USE SEPARATE BOOSTER DOWNLINK (RF)
✓	• FACILITATE SEPARATE LRB STANDALONE TEST AND CHECKOUT
✓	• ON BOARD LOX VENTS/NO BEANIE CAP
POSS. ALT.	• HARD MOUNTED ENGINES (NOZZLE GIMBALS FOR TVC)
✓	• MINIMIZE ET MODS
N.A	• ELIMINATE ENGINE PURGES, BLEEDS AND SPECIAL PREPS
N.A.	• CONSIDER EXTERNAL POD FOR AVIONICS AND BATTERIES TO FACILITATE ACCESS AND EASE OF SERVICE
✓	• AVOID ELEPHANT TRUNKS (TRAPS) IN PROPELLANT LINES THAT REQUIRE SPECIAL ATTENTION

Figure 1.6.3-1. KSC-LRB Design Recommendations.



PROPERTIES	GENERAL REQUIREMENTS	SYSTEM-SPECIFIC REQUIREMENTS
• BOOSTER PROPERTIES – PUMP-FED – PRESSURE-FED – SPLIT EXPANDER • PROPELLANTS – LOX / RP-1 – LOX / LH2	• CONFIGURATION DATA • EQUIPMENT DESCRIPTIONS • OPERATING CRITERIA • INTERFACE REQUIREMENTS • LAUNCH SITE CONSTRAINTS • HANDLING REQUIREMENTS	• RECEIVING / HANDLING • ASSEMBLY / PROCESSING • INTEGRATION • SAFETY / ENVIRONMENTAL • SPARES / LOGISTICS • TEST / CHECKOUT • PRE-LAUNCH • GROUND SOFTWARE • LAUNCH OPS • ABORT / SCRUB • RECOVERY • REFURBISHMENT

Figure 1.6.4-1. LRB Requirements Checklist Categories.

ITEM *	TOTAL	NUMBER WITH GROUND SYSTEMS IMPLICATIONS
A. GUIDELINES GOALS, ASSUMPTIONS	12	11
B. LEVEL I REQUIREMENTS (SPACE TRANSPORTATION SYSTEM)	8	7
C. LEVEL II REQUIREMENTS (SPACE SHUTTLE VEHICLE)	8	4
D. LEVEL III REQUIREMENTS (LIQUID ROCKET BOOSTER)	11	9
E. LEVEL IV REQUIREMENTS (AVIONICS / FLT CONTROLS / SEPARATION SYSTEMS)	9	2
TOTALS	48	33

* SEE APPENDIX 20-5 FOR COMPLETE LISTING OF DESIGN REQUIREMENTS FROM GDSS FINAL REPORT.

Figure 1.6.5-1. LRB Design Requirements Summary.

show the same trends. As of this report's printing time the MMC final report had not been received.

1.7 CONCLUSIONS

The LRBI Study findings and conclusions are described in Volumes I and II of this final report. Definitive reports on each of the nineteen study products are presented in Volume III. The following sections describe the major findings and conclusions in summary form and illustrate the major project planning issues for launch site integration of the LRB system. The section is concluded with a description of major issues recommended for follow-on study.

1.7.1 Processing Scenarios

The Study Team assessment of the KSC launch site integration of LRB processing and launch operations have resulted in the formulation of the launch site scenarios presented in Figure 1.7.1-1. This scenario begins with the anticipated delivery of the assembled boosters by barge to the turn basin near the VAB, followed by offload of the boosters via towed transporters. The boosters are then towed to the Horizontal Processing Facility (HPF) where all standalone checkout and flight certification activities are performed. The boosters begin the integrated part of ground processing by being towed (still on the delivery transporter) to the VAB. After all MLP preparations are completed the LH and RH boosters are rotated and lifted up into the new HB-4 integration cell where they are mated and aligned on the MLP holddown system. As noted in the figure the MLP is new and custom-built for the LRBs. The remainder of VAB operations are similar to current procedures. The ET is mated to the boosters, followed by closeout operations and preparations for Orbiter mate. Following Orbiter mate, the all-up Shuttle Integrated Test (SIT) is performed.

Transfer to the Pad via the crawler transporter is followed by standard SSV to Pad interface checks, payload ops and system readiness checks. The LRB fuel loading (if RP-1 is selected) can precede the countdown ops by several days. Existing LOX and LH2 (if selected) propellant facilities will be modified to provide adequate storage and transfer capabilities to support LRB requirements. Loading software and procedures will be updated to accommodate LRB.

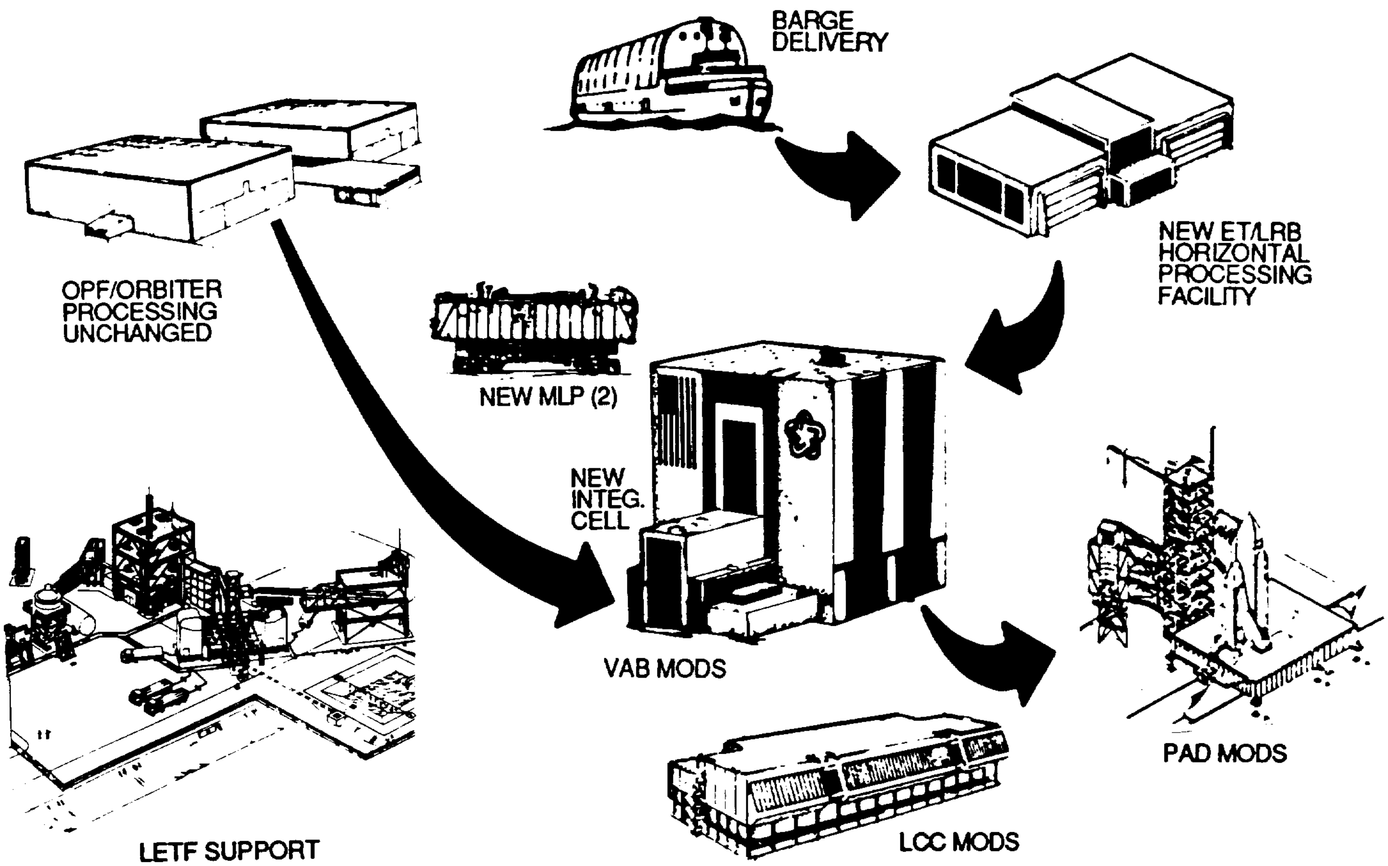


Figure 1.7.1-1. Preliminary LRB Scenario.

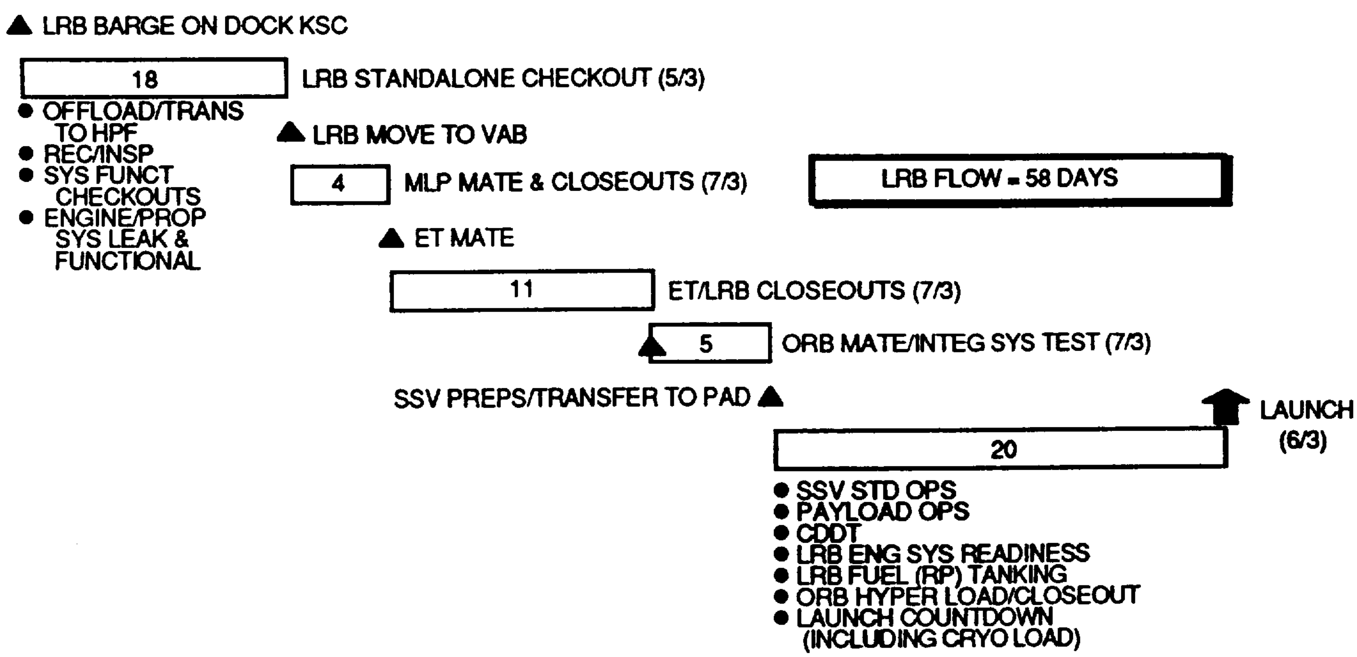


Figure 1.7.1-2. Generic LRB Process Flow.

The overall LRB scenario will incorporate planned testing support at the Launch Equipment Test Facility (LETF) and significant modification of application software and new firing room consoles in the Launch Control Center (LCC).

The timeline for a typical LRB flow through this launch site scenarios is presented in Figure 1.7.1-2 where a summary of the 130-item task processing schedule is illustrated. Flow time in work days is shown to total 58 days from receipt of booster hardware to launch. This same span for SRB is 78 days. Therefore LRB operations should result in lowered demand on launch site resources for the same sustained flight rate or, alternately, the enhanced potential for increased launch rate capability. This is illustrated in Figure 1.7.1-3 where SRB and LRB flows are compared.

Detailed timelines for LRB processing are summarized in Study Product 2, Volume III. A summary of integrated processing timelines for the transition period is presented and described in Study Product 9, Volume III, Preliminary Transition Plan.

1.7.2 Impacts to On-going Activities

Potential impacts to launch site on-going activities can be summarized in three major categories (or phases):

1. Facility Activation
   - Design/Modification/Verification
2. Transition
   - LRB start up/and increasing launch rate
3. Operational Phase
   - Mature multiflow launch rate capability with LRB

Each of these phases was evaluated to establish impacts in the attributes of manpower, schedule and costs.

The implementation of effective LRB operations will require the following major provisions:

- An activation management team to affect the facility activations, modification and verifications with minimum impacts to existing launch operations.

	WORK DAYS		% REDUCTION
	SRB	LRB	
VAB HB (INTEG CELL)	21	4	81%
MLP USE PER FLOW	55	40	27%
INTEG CRITICAL PATH (BOOSTER STACK TO ORB MATE)	32	15	53%
PAD FLOW	18	20	-11%
BOOSTER FLOW (PRE-LAUNCH)	78	58	25%

Figure 1.7.1-3. SRB/LRB Flow Comparison.

- Dedicated manpower, trained and certified for LRB processing.
- Effective planning for LRB launch rate build up and integration with on-going launch ops.
- Advanced budget provisions (C of F and R & D).
- Integrated planning with the flight hardware contractor using the assistance of a launch support services function.
- Documentation of procedures and planned support functions.
- Effective project management, timely analysis and decision making.

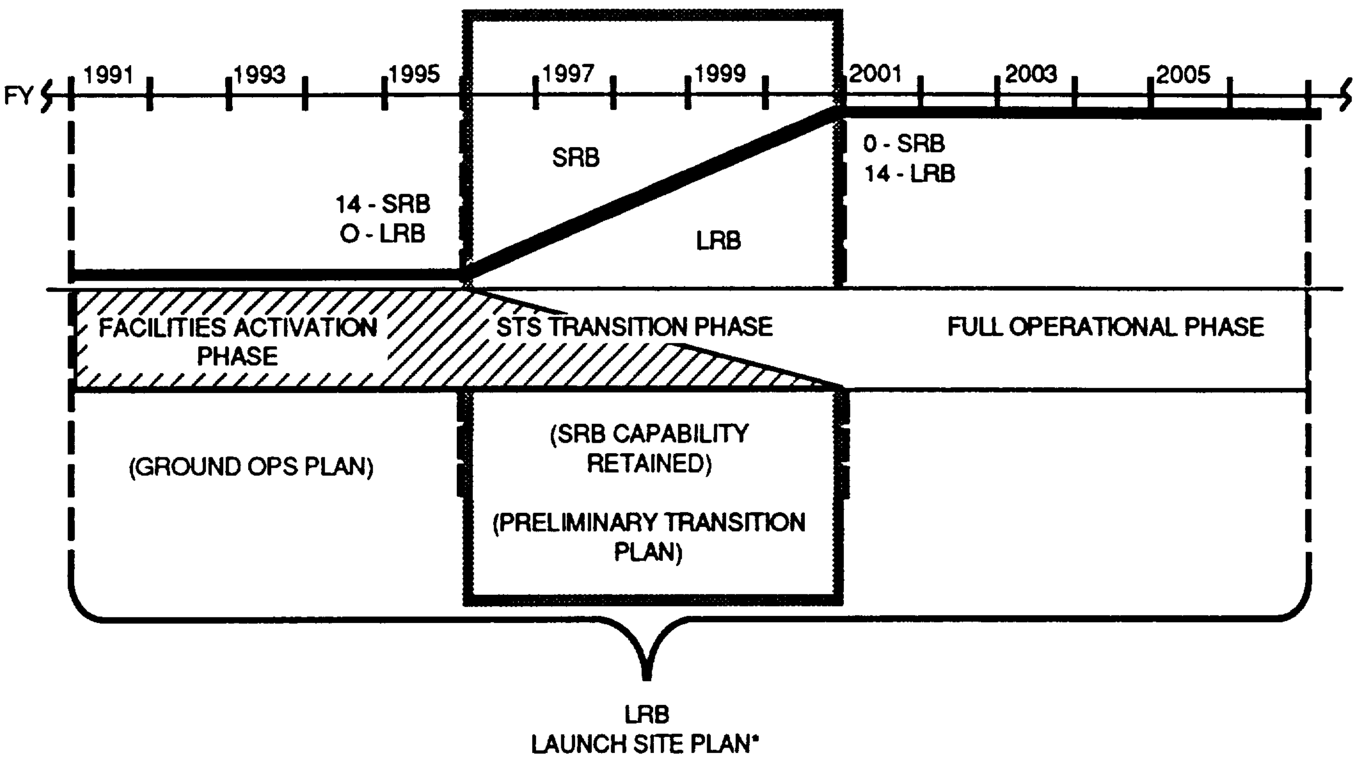
Using the overview of the launch site plan shown in Fig. 1.7.2-1 the three basic phases of the project can be seen to span a period of approximately 16 years at the launch site. The launch profile portion of the "life cycle" of the LRB program extends over 122 LRB missions. This profile was used by all LRB planners for LCC recurring cost evaluations. The major issues of facility activation and transition requirements over these launch site phases are summarized in Figure 1.7.2-2.

1.7.2.1 Facility Activation

The initial facility activation phase (FY 91 through FY 95) consists of the design, construction and modification of the first line facilities required for LRB initial launch capability (ILC). During this period the major potential for impact to KSC on-going launch operations are:

1. New Facility Construction - HPF and MLP #4 for LRB: These new facility activations will be monitored by the processing contractor. Design/construction will be by outside A & E firms. Although in the LC-39 area, the planned sites should offer no significant schedule, manpower or cost impacts to on-going launch operations. Risks of delays to LRB implementation do exist. Funding and ATP must support FY91 Phase-C/D go ahead for the design and construction of these new facilities.

2. Existing Facility Mods - VAB/HB-4 will be converted to a full SSV integration cell. New superstructure and extensible platforms would be added to support LRB/ET and Orbiter integration and test. This work will be scheduled and carried out on a non-interference basis with on-going VAB operations. Techniques such as remote platform construction and off-shift installation should be exercised to avoid schedule impacts due to safety clears etc. These mods will be designed by the processing contractor with construction performed by an outside



* TIME LINE BASED ON ACCOMPLISHING A MINIMUM OF 122 LRB BOOSTER MISSIONS IN THE PROGRAM LIFE CYCLE

Figure 1.7.2-1. Launch Site Plan Overview.

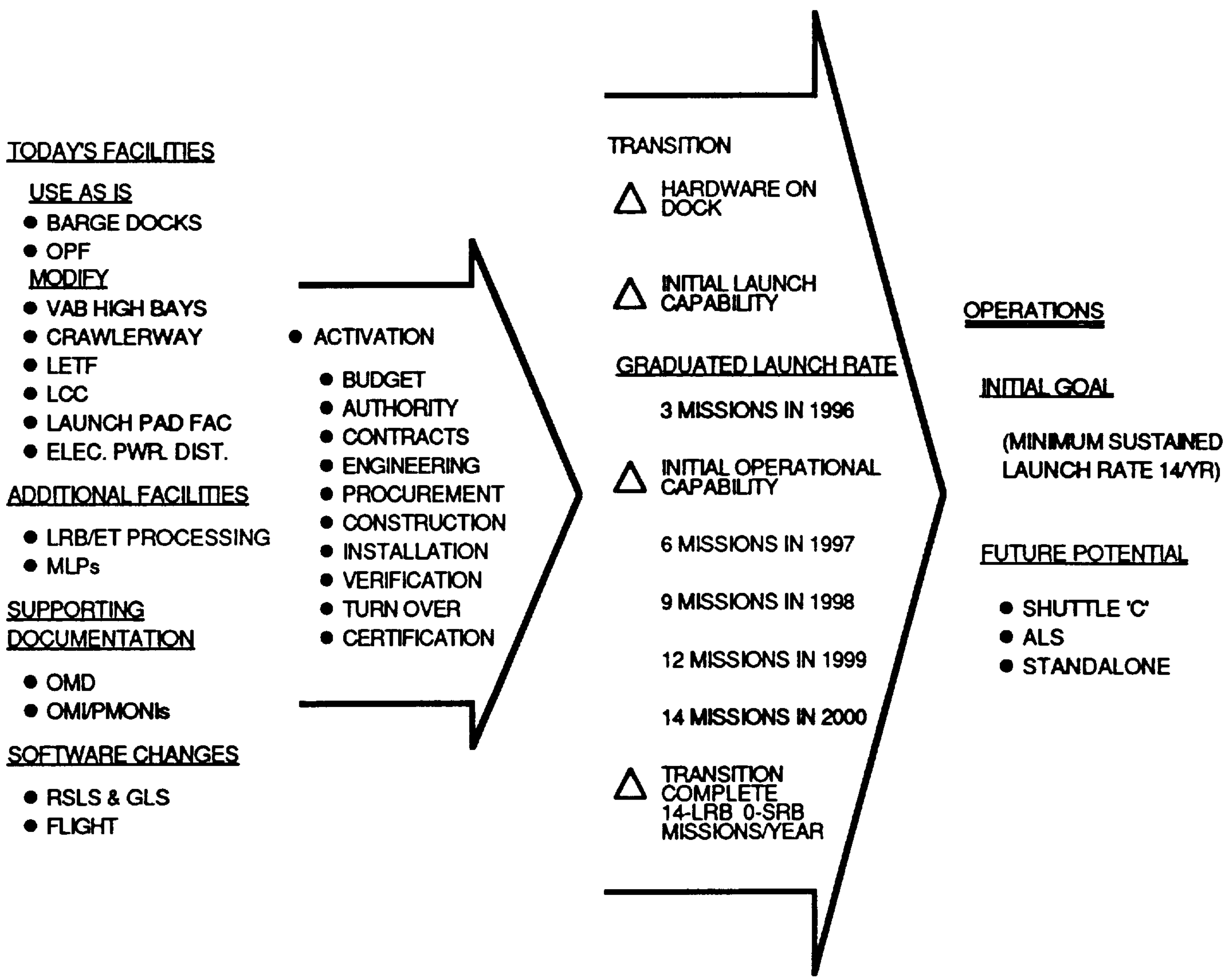


Figure 1.7.2-2. LRB Launch Site Plan Synopsis.

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fixed price contractor. Manpower and funding requirements have been identified; however, risks of schedule and cost still remain.

3. Pad B Mods - Pad B has been selected for use on initial LRB launches due to the cycles of normal mods and update intervals which places Pad B in line for an upgrade at about the timeframe of LRB activations. Impacts with planned launches at Pad B during this mod period will be avoided by diverting certain SRB launches from Pad B to Pad A. Exclusive access for the modifications is needed for the last eight months leading up to Pad certification for LRB. The diversion of on-going launches to a single Pad poses one of the highest potential risks for STS launch impact or delay in the implementation of facilities for LRB. Mods for LRB are planned to retain existing MLP-to-Pad capability for SRB/STS launches after conversion. Potential schedule impacts could occur at the Pad if required mods grow more significant. For example, flame deflector, vent arms and flame trench (concrete) mods are potential "hitters" due to the increasing diameter of recent LRB configurations. In addition, any anomalies discovered during the planned LRB "Pathfinder" flow could delay LRB implementation placing more SRB launch schedule pressure on Pad A. Manpower and funding requirements are included in our activation plan.

4. Other Facility Mods - The LETF must support the development and verification testing of all MLP mounted launch support equipment (LSE). The facility will be modified to support this testing and the manpower, schedule and funding have been identified. No other significant impacts are anticipated in this "so-called" off line facility modification. The Launch Control Center will be modified with new software and consoles for LRB processing and launch support. By specifying a standalone mini-LPS at the HPF the existing control rooms will be relieved of the need to support standalone LRB operations. However, LRB integration in the VAB will require control room interfacing with LRB systems and, of course, all pad launch operations will require this monitoring and control interface. Potential impacts to on-going LCC operations can be anticipated with four firing rooms supporting SRB launches at a rate of 14 per year while part of the system is in mod to support software and console mods for LRB. Careful scheduling of these LCC activities is required to avoid impacts. Implementation of the second generation LPS will be significant in easing the impacts of LRB activation.

1.7.2.2 Transition

The transition from SRB launches to LRB launches is planned over a 5 year period, FY 96 through FY 2000. The LRB launch rate builds up in a 3, 6, 9, 12, 14 ramp during this period and additional facilities are required to achieve these increases as illustrated in Figure 1.7.2.2-1.

This study has proposed and evaluated a five year transition period planned to avoid impacts to on-going launch operations. However, potential impacts during transition still exist and must be addressed during the anticipated Phase B activity. The major potential risks during transition are identified as follows:

1. Manpower - KSC and the Shuttle Processing Contractor must map out the manpower implementation plan for LRB and take the necessary steps before LRB introduction to hire and train an initial core LRB processing and launch team. This initial team, although small, must be "KSC-wise" and have representative talent from each of the major LRB processing and launch operations areas. The integration of this LRB team and its functions into the on-going operations during the transition period will prevent major disruption in the continuing launch processing activities. The impact to KSC will be the costs of parallel staffing initially for this dedicated function plus the potential loss of talent from existing resources when staffing from within is selected. Staffing and manpower requirements for LRB are discussed in Study Product 6, Volume III, and the Launch Site Plan, Section 2 of this volume.

2. Costs - Provisioning of the major C of F and R & D funds required to carry out the initial facility activations is crucial to the implementation of LRB initial launch capability. During transition the success of increasing launch rate for LRB will also depend on continued funding of the second line of required facilities, i.e. conversion of HB-3 to support LRB and the second new MLP and second pad modification. All launch site cost aspects for LRB implementation both non-recurring and recurring are discussed in detail in Sections 2 and 4 of this volume.

3. Schedule - The highest potential for schedule impacts during LRB transition can be found in the integrated functions of STS launch processing. Major areas are:

   VAB

   Initial integration for all LRB launches will be processed in HB-4. However, in the third year of transition near a LRB launch rate of nine per year an additional integration cell will be required to support the continued launch rate build up. Of course, by this time the SRB rate

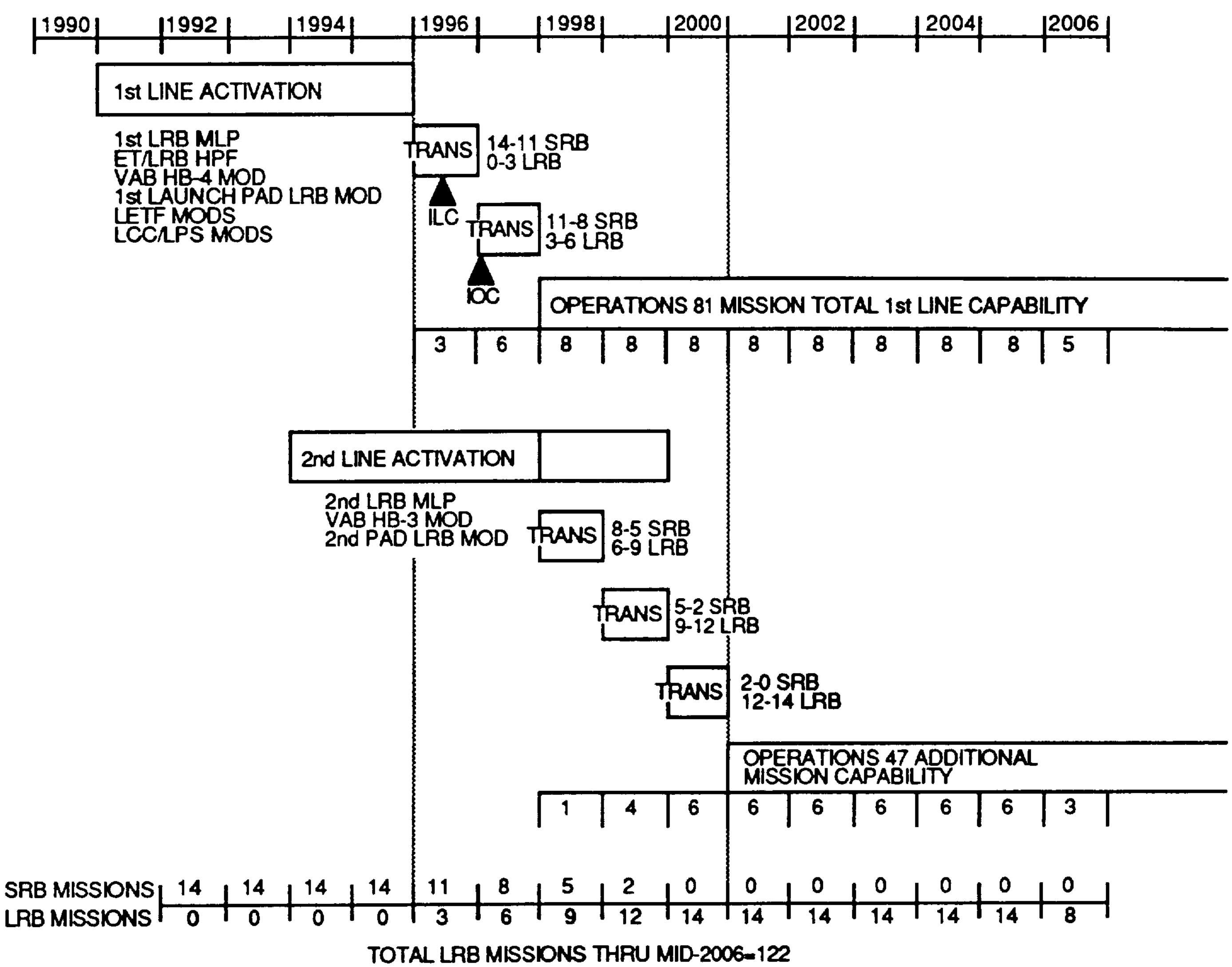

Figure 1.7.2.2-1. KSC SRB to LRB Transition Plan.

has decreased to six per year; all of which can be processed out of a single high bay. This makes HB-3 available for conversion to LRB compatibility. This conversion is planned on a non-interferance basis with on- going VAB operations. Careful integrated scheduling will be required during this period to avoid delays and schedule impacts.

Pad

Much as Pad B mods offer the highest potential schedule impact during initial activation, so do the mods at Pad A offer the highest threat to launch impact during the transition phase. During the last (5th) year of transition, in order to meet the full 14 mission goal, Pad A must be taken out of service for eight months for LRB modification. During this period all launches must be conducted at Pad B. Some added benefits will be possible due to lessons learned during the earlier Pad conversion. Although a threat to schedule, this impact can be planned with more confidence. Unique launch windows will cause added challenge for single pad support to the launch manifest.

This brief summary of transition impact issues is taken from the major findings in our preliminary transition plan described in detail as Study Product 9, Volume III.

1.7.2.3 Operational Phase

After transition to LRB the full beneficial aspects of LRB over existing SRB operations will be realized. The schedule pressure on integrated resources is significantly reduced. The increased flexibility of booster operations permits the integration of alternate vehicles such as Shuttle C, ALS and standalone ELVs with significantly lower launch site impacts.

No significant launch site schedule impacts are envisioned in the operational phase. Manpower requirements will peak during the transition phase dual (SRB/LRB) launch operations. On-going LRB processing activities are fully staffed for the planned 14 - 15 launch manifest. Costs at the launch site during the operational phase are considered to be significantly lower than that planned to support the SRB launch processing. This lower operational cost at the launch site is due mostly to the elimination of booster retrieval, disassembly and refurbishment operations. A full discussion of launch site life cycle cost issues is presented in Sections 2, 3 and 4 of this volume.

1.7.3 Major Issues for Follow on Study

During the performance of the first phase of the LRB Integration Study the study team developed analysis techniques and launch site models which are universally applicable for the evaluation of any new element integration activity.

The LRB Phase-A contractors for MSFC have moved into the definition of alternate LRB applications in their current contract extensions. In order to continue the integration of launch site aspects in the planning for these new LRB configurations, LSOC proposes to apply these newly developed techniques and models in the evaluation of launch site requirements, scenarios, impacts and costs for alternate applications of LRB. The following outline of tasks describes the approach to this optional study in two major areas: 1. Application of LRB to alternate launch configurations, and 2. Analytic Model Improvements. Detailed descriptions of approaches and subtask-breakdowns are described in Study Product 16, Volume III.

A. Application of LRB to Alternate Launch Configurations

Launch Site Requirements Definition for Alternate Configurations

Expand the dialogue with flight hardware design teams and begin merging launch site integration planning with alternate vehicle system design. This will achieve control of life cycle cost elements and will assure the satisfaction of anticipated requirements in the areas of:

- Processing/Maintainability
- Launch Operations
- Recovery Operations

Candidate Scenarios for Study

Establish candidate launch site scenarios with efficient ground operations concepts for the following:

- Payload Canister/Shroud Flow
- Core Vehicle Flow
- Booster Options/Processing Approaches
- Vehicle Integration/Launch Processing

Preliminary Facilities Plan

Evaluate horizontal vs. vertical processing for the alternate configurations. Evaluate existing facilities and required modifications vs. new facility requirements. Use of MLP vs. alternate approaches should be evaluated. Candidate design concepts at Pad "C" should be defined and evaluated for the alternate vehicle designs. Define impacts to on-going STS Operations for the transition to support the alternate applications and evaluate the envelopes of minimum impacts at each required station set. Evaluate the potential shared use of STS facilities and GSE/LSE.

B. Analytic Model Improvements

Processing Flow Model Improvements

The SRB/STS Ground Processing Flow Model is an Artemis network based planning tool. It provides timeline visibility for facility planning and utilization at the launch site in a multi-mission environment. The model is based upon a generic set of ground rules and assumptions which are incorporated as the network database. The LRBI Study Team was provided this model configured as the SRB/STS ground processing baseline. The model was manually revised to incorporate multiple LRB flows and used in mixed fleet (SRB/LRB) impact analysis.

These manual manipulations were time consuming and laborous. It is apparent that the utility of the modeling could be enhanced by the incorporation of an automatic generator for mixed fleet scenarios.

An enhanced STS Ground Processing Flow Model has the potential, to be a useful tool for advanced programs schedule and resource analysis. It can be tailored for multi-mission, mixed fleet evaluation and standardized impact analysis for any new vehicle integration at the launch site.

Modify/Update GOCM

Post 51-L ground processing environment must be incorporated into GOCM as derived from KSC ground processing operations. Simultaneously, GOCM needs to be redeveloped using a more capable software system in order to achieve greater friendliness, and application. Another proposed modification is the incorporation of a mixed fleet (STS and alternate vehicle) capability into GOCM.

The KSC Ground Operation Cost Model (GOCM) is now capable of analyzing costs of both Solid and Liquid Booster configurations launching concurrently during the same fiscal year. This capability for STS-type vehicles provides more flexibility in the model to analyze alternative scenarios. It is recommended that this enhancement be further developed to include mixed fleet capability for two alternative shuttle type vehicles such as in the Shuttle II and Shuttle C configurations. Results from these studies should be incorporated into the GOCM database.

This enhancement to GOCM would increase the utility of the cost model and allow greater flexibility in the analysis of alternate vehicle configurations at KSC. A mixed fleet analysis is essential to evaluate the phase-in of new programs while existing programs are in place, or are being phased out.

Develop GOCM II

Design and implement a ground processing cost and schedule assessment system which will serve future program planning at KSC. The ability to tailor a GOCM type modeling system to a specific application and phase of study requires the concept of modularity to be employed. Many GOCM features today would just as easily handle parameters developed from accounting techniques, as well as the current configuration which was developed parametrically. Therefore, with further refinement, GOCM could span the vast needs for costing over a wide range of study phases. Both types of costing could be performed 1) the quick broad response obtained from parametric assessment and 2) the focused, detailed accounting cost technique. These capabilities would be available in various mixes for each application.

VOLUME II SECTION 2

LAUNCH SITE PLAN

This plan summarizes the costs, implementation plans for the facilities and manning, and identifies the support requirements at Kennedy Space Center (KSC) to integrate the Liquid Rocket Booster (LRB) into the STS program. Information is presented on the facilities, types and numbers of personnel, scheduling and costs associated with LRB implementation. This information was developed from the analyses performed by the Study Team in separate studies to activate the facilities, process the LRBs, perform the phased replacement of LRBs for SRBs on planned shuttle launches and provide an ongoing LRB/Shuttle launch capability for the total life cycle of the LRB program. An overview of these study results is contained in Volume II, Section 1 of this report. The detailed analyses, results and recommendations of the LRB integration studies are described in Volume III, Sections 1-19.

2.1 OBJECTIVE

The costs and implementation plans contained in this report describe the impact that the LRB integration will have on the current STS ground operations at KSC.

The level of detail pursued in this Phase-A study is sufficient to determine impacts to launch site facilities with the corresponding cost estimates and implementation plans. However, due to the undetermined final configuration or hardware contractor for the LRB, the study was not taken to a level sufficient to actually implement the program at KSC.

2.2 APPROACH AND RATIONALE

A baseline configuration was assumed to be the pump-fed LOX/RP-1 option proposed by the two contractors. Any significant cost differences of the other proposed options are stated where applicable. Life Cycle Costs are depicted which include the up-front non-recurring costs and the learning curve of the first three LRB launches at the beginning of transition.

All costs in this report are Rough Order of Magnitude (ROM) and are presented in FY 1987 dollars. The implementation schedules for proposed modifications, new construction, manning and support requirements are presented so that costs can be determined by fiscal year.

Facility costs estimates were developed using a "bottoms-up" approach. Costs for each item were estimated using the Means Construction Estimating Guide. Similar items, buildings or systems already designed and built for the STS were also used and costs were adjusted for size and location where applicable.

Manpower costs and numbers were based on skills being used for similar activities on current contracts and processing activities at the launch site.

2.3 GROUNDRULES AND IMPLICATIONS

2.3.1 Groundrules/Assumptions

The following groundrules and assumptions were used in developing this implementation plan:

- Launch sites are the existing STS/SRB sites at KSC, including currently existing capabilities as well as programmed improvements.

- The "KSC Flow Model" developed in ARTEMIS was used to project Shuttle missions throughout the 15-plus years of this program. This model is based on the March 1988 NASA manifest.

- Construction and modification during the activation phase is based on providing capability to support processing and launch in early 1996 of the first LRBs delivered in 1995.

- This plan is baselined on the pump-fed LOX/RP-1 configuration submitted by the two LRB hardware contractors.

- Planned activities during the activation and transition phases are designed to minimize the impact to the ongoing SRB processing/launch program and any joint use of personnel or equipment is on a non-interference basis to the SRB operations.

- o The plan lists only the costs attributed to integration of LRBs.
- o Management/manning from the existing NASA Contractor Community required for support to this program has been identified but not priced.
- LRBs are assumed to be expendable.
- A sustained launch rate of 14 SRB/Shuttle launches per year is assumed to be ongoing at the start of LRB launches.
- No other emerging launch vehicle programs are reflected in this study.
- All SRBs launched during the transition to LRBs will be recovered and refurbished.

2.3.2 Environmental and Safety Implications

The environmental and safety implications of the LRB Integration Study were developed using data provided by MSFC LRB systems studies conducted by General Dynamics and Martin Marrietta Corporations. The full report on the environmental and safety impacts is presented in Volume III, Section 10. The results of that report indicate that the LRB offers significant environmental and safety improvements over the current SRB operations. The conclusions of Section 10 are listed below.

A. There will be less impact on operations in the VAB since no live propellants are being handled. This will eliminate the need for establishing many of the control zones currently required when processing the SRBs.

B. The hazardous operation of processing live SRB segments in the Rotation, Processing and Surge Facility (RPSF) will be eliminated.

C. The ability to abort after ignition provides added safety features should problems arise after ignition and prior to launch.

D. Ignition by-products from the LRB are less damaging to the environment than those of the SRB.

E. Launch vehicle safety concerns on the PAD are reduced since no propellant is introduced into the LRB until launch countdown.

F. The ability of the LRBs to be drained and inerted following an on-Pad emergency significantly reduces the hazards posed to safing and securing crews entering the blast area.

The analyses and findings of the Environmental and Safety Study were used to develop the data in this Implementation Plan.

2.4 IMPLEMENTATION PLAN AND PHASES

The overall launch site plan to implement the LRB program at KSC is depicted in Figure 2.4-1. In order to begin LRB processing and accomplish the first LRB mission in 1996 as shown, the required facility work and OMD development must begin concurrent with ATP. This will necessitate early funding and preparation of Program Operating Plans (POPs) during the Phase-B Study in 1989. Cost data for the POPs is supplied in Paragraph 2.9 and accompanying figures.

All of the activities depicted here are dependent upon timely completion of any preceding milestones with a minimum amount of schedule slippage allowed in any area. An extensive amount of coordination among all involved agencies will be needed to accomplish these tasks. Written agreements and Memoranda of Understanding will be needed between Shuttle processing agencies and numerous contractor agencies coming on site. Additional manning and/or reassignments of current manpower will be required in NASA and SPC organizations to manage/monitor various engineering, construction and installation activities. Additionally, increased support requirements in areas such as parking, badging, security, food service, utilities and etc., will be needed. The new construction and facility modifications will use outside contractor organizations. An impact of as many as 2000-3000 additional people working in the launch site area during peak activity of the facility work should be anticipated.

The LRB program has been grouped into three phases to support the construction, modifications and preparations for the first LRB/Shuttle launches in 1996, the incremental replacement of SRBs with LRBs, and the full-up LRB operational phase to complete 122 LRB launches. These phases are defined as: Facilities Activation, Transition and Operational (see Figure 2.4-2). 2.4-5

The activities in the first two phases are planned to yield minimum impact to the ongoing KSC launch operations with SRBs until the SRB launches have been phased out. A synopsis of the planned activities is shown in Figure 2.4-3.

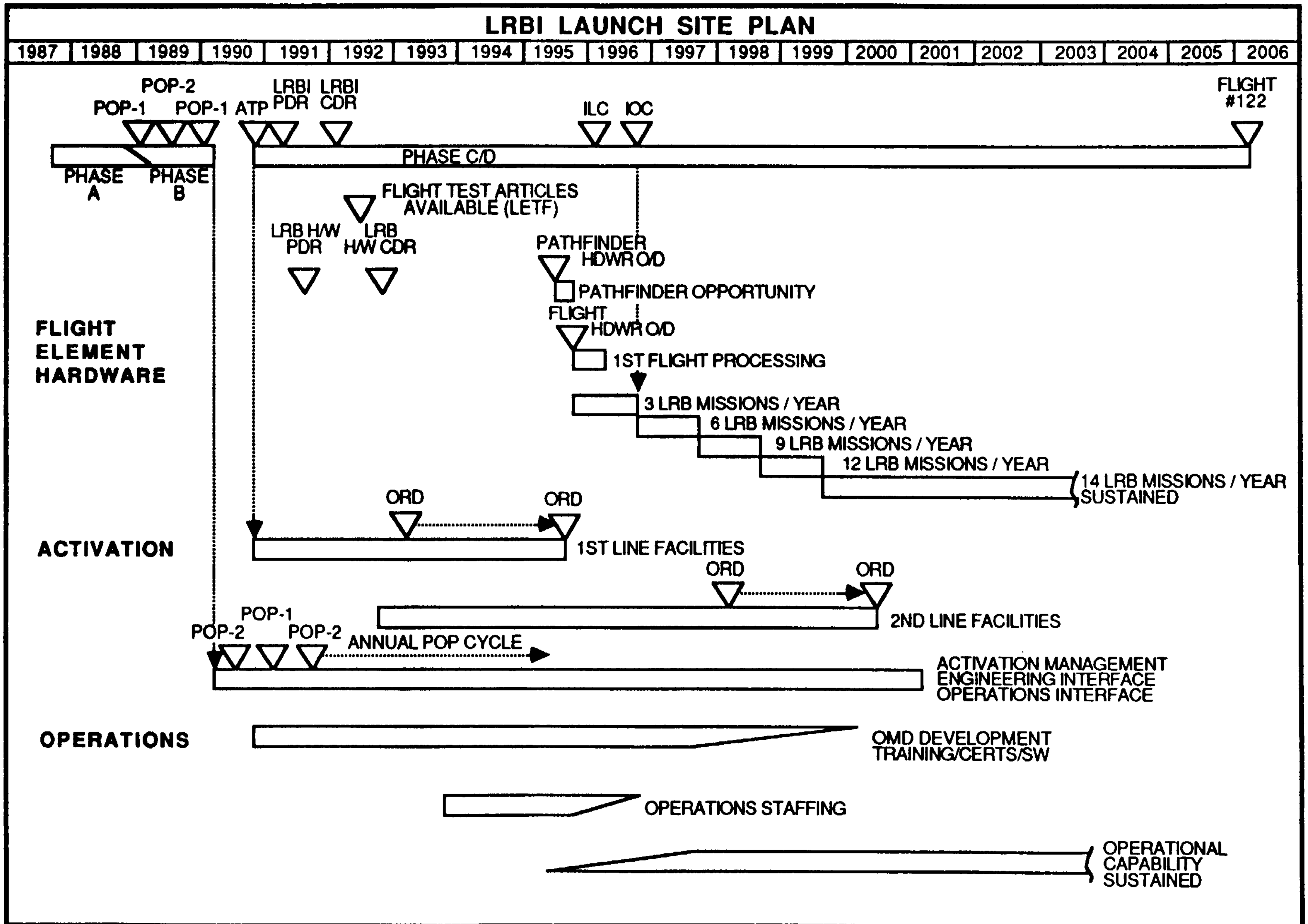

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Figure 2.4-1. LRBI Launch Site Plan.

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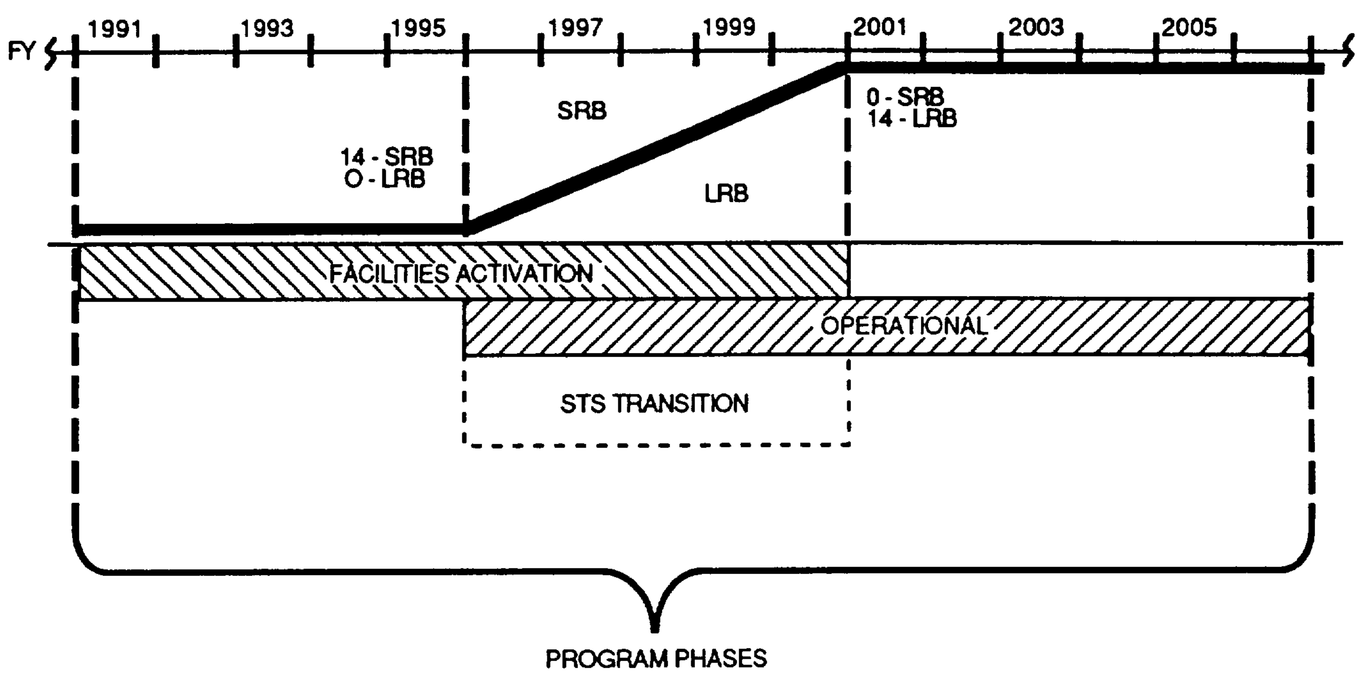

Figure 2.4-2. LRB Launch Site Phases.

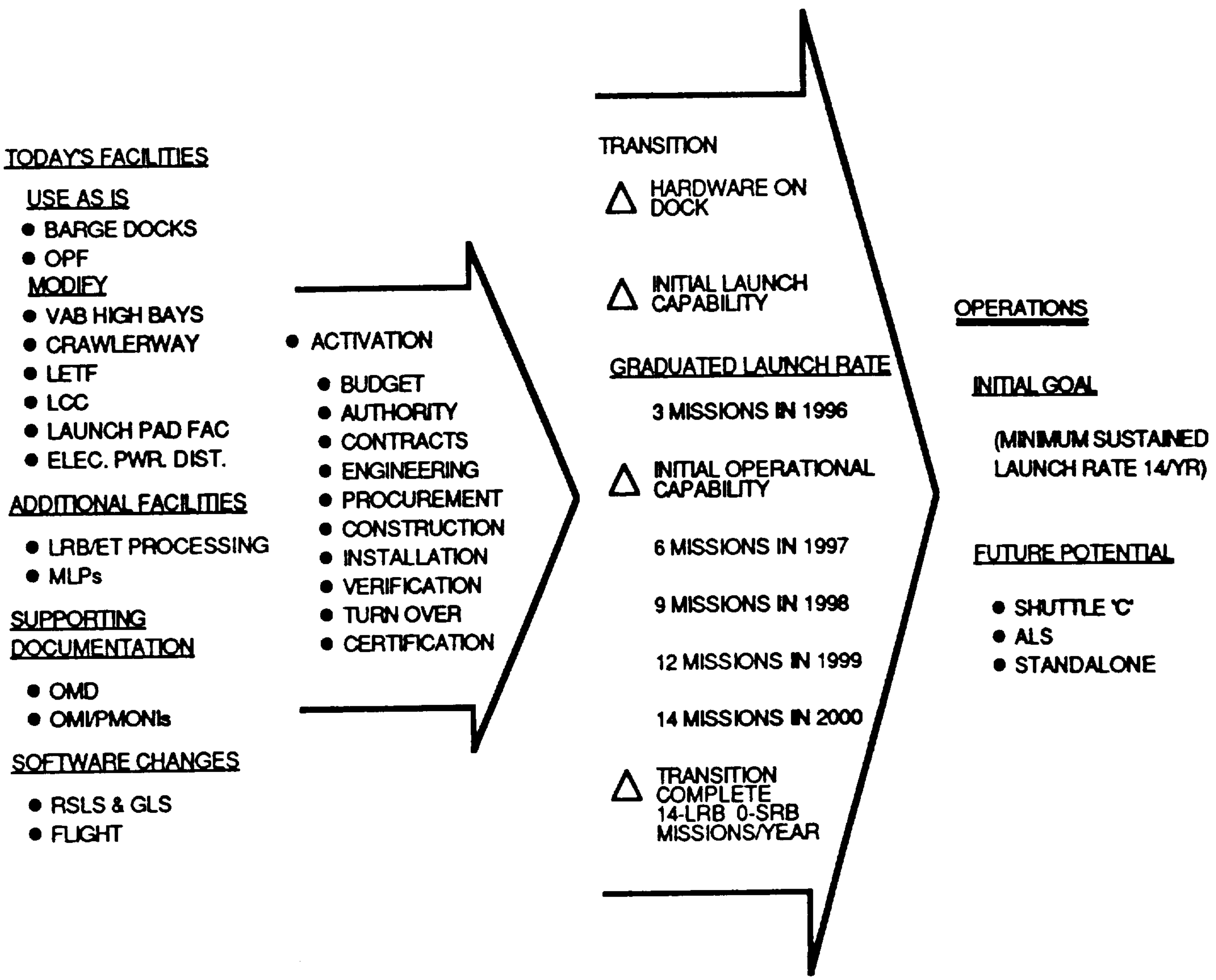

Figure 2.4-3. LRB Launch Site Plan Synopsis.

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2.4.1 Activation Phase

This phase is planned for a ten-year period from the beginning of FY 1991 until the end of FY 2000. Activities in this period include design, construction and activation for the first launch in early FY 1996; preparation of O&M documents; training/certification of personnel; demonstration tests and an FRF with the pathfinder hardware; and completion of the facilities work in the latter half of the phase.

The duration of the early facility work in this phase is based on the arrival of the first LRBs in FY 1995 from one of the manufacturing contractors and back filled to include time to prepare the facilities to support first LRB launches. This will require an Authority To Proceed (ATP) no later than the beginning of FY 1991. This schedule may necessitate some budgeting, contracting, and engineering activities prior to the start of the phase.

2.4.2 Transition Phase

This phase is planned for the five-year period from the beginning of FY 1996 until the end of FY 2000. This includes the overlap period of the last half of the activation phase and the first half of the operational phase. Activities in this period include completion of the remaining facility preparations to support sustained operational LRB launches; receipt of the first operational hardware; graduated increase in the LRB launch rate with a corresponding decrease in SRB launches; ILC at the first LRB launch; IOC at the fourth LRB launch; and phaseout of SRB launch capability in FY 1999.

The phased LRB launches consist of three in FY 1996, six in FY 1997, nine in FY 1998, 12 in FY 1999, and 14 in FY 2000. At this time the SRB launches will be phased out and the LRBs will be the only Shuttle launches being conducted. This will result in 44 LRB launches during this phase.

A detailed study on this phase is presented in Volume III, Section 9.

2.4.3 Operational Phase

This phase is planned for the ten-plus year period from the beginning of FY 1996 until the latter part of FY 2006. A sustained launch rate of 14 LRBs per year is expected during the latter part of this period. This decreases to eight launches during FY 2006 if the program is terminated. This will complete the total of 122 launch missions projected for the life cycle of the LRB program.

2.5 FACILITY IMPACTS

Concurrent with the development and production start-up of the LRB hardware, the launch site facilities must be prepared for LRB processing. In order to support the first launch of LRBs in early 1996, a facility activation conceptual plan has been developed. The minimum facility changes, new and modified, conducted during the activation phase to support early LRB launches during the transition phase, are designated as first line facility activities. The additional facilities required to support the LRB launches during the latter stage of the transition phase and the remainder of the operational phase are designated as second line facility activities. These are activated during the latter part of the activation phase. A detailed analysis and discussion of the facility requirements and concepts for new facilities is covered in Volume III, Section 1.

Facility requirements were developed from LRB requirements checklists completed by General Dynamics and Martin Marrietta and from their interim reports. The requirements checklist covered the following items:

1. General configuration of each booster option
2. Ground equipment description and requirements based on differences to existing Shuttle equipment design
3. General operating criteria
4. Nozzle configuration details to determine flame deflector and trench impacts at the PADs.
5. LRB component weights, diameters and hard points
6. Receiving/handling requirements
7. Assembly requirements
8. Integration requirements
9. Test/Checkout Requirements
10. Launch Requirements
11. Abort/Scrub Requirements

12. FRF Requirements
13. Recovery Operations (If Applicable)

The detailed checklist and contractor responses are shown in Volume V, Appendix 20.

2.5.1 New Construction

To avoid impacts to the ongoing STS/SRB launch program and provide compatibility with the new size/shape of the LRBs, selected new facilities must be designed and constructed. These consist of two new MLPs and a new ET/LRB Processing Facility designated as the Horizontal Processing Facility (HPF). The HPF will also contain an LRB engine shop and a processing control center. Summaries of these facilities are presented in the subparagraphs below.

The schedule for these new facilities is shown in Figure 2.5.1-1 and 2.5.1-2. Scheduled work timelines are shown based on the latest start and latest finish times required to meet ILC. The float timelines represent the earliest opportunities upon which facility implementation is initially planned.

2.5.1.1 LRB MLP #4 And #5

To avoid impact to the ongoing STS/SRB Launch Program, consideration was initially given to construction of one new LRB MLP and the modification of an existing SRB MLP. Further analysis revealed that it was impractical to modify an existing MLP since a primary structural girder must be cut or modified to provide proper exhaust flame holes for all of the proposed LRB contractor configurations. Additionally the estimated cost and time involved in the modification effort and the potential impact to STS/SRB launches was more significant than the construction of a new LRB MLP. Details of MLP construction and considerations are discussed in Volume III, Section 3.

The construction of MLP #4 must begin at ATP to support pathfinder activities and ILC. This approximate 5 year effort, starting at the beginning of FY 1991, must be completed in the fourth quarter of FY 1995. MLP #5 construction can start in the second quarter of FY 1993 and must be completed at the end of the third quarter of FY 1998. Due to the similarity to MLP #4 and overlap of some construction activities, MLP #5 is programmed for a slightly less than 5 year

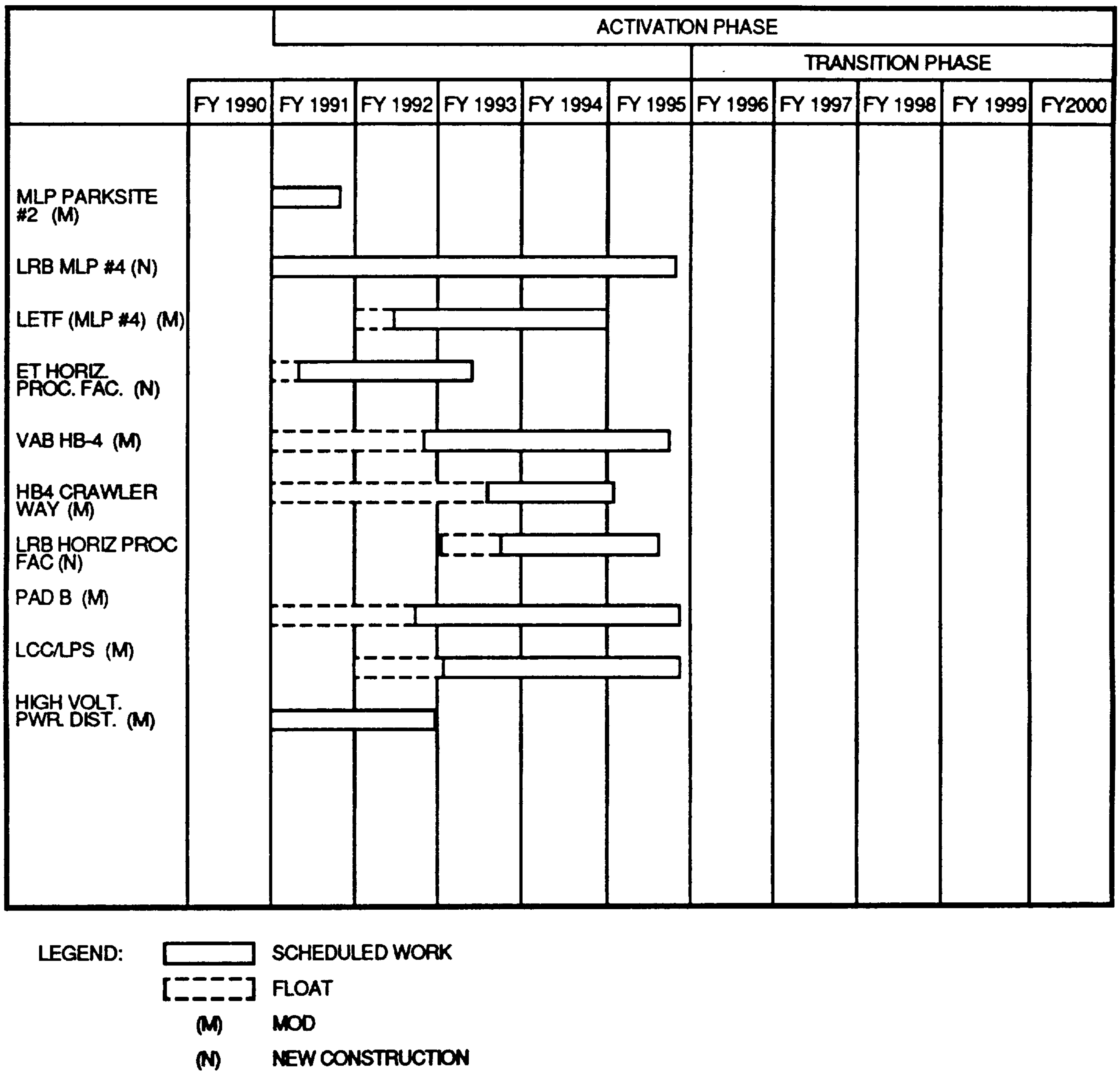

Figure 2.5.1-1. First Line Facility Activities.

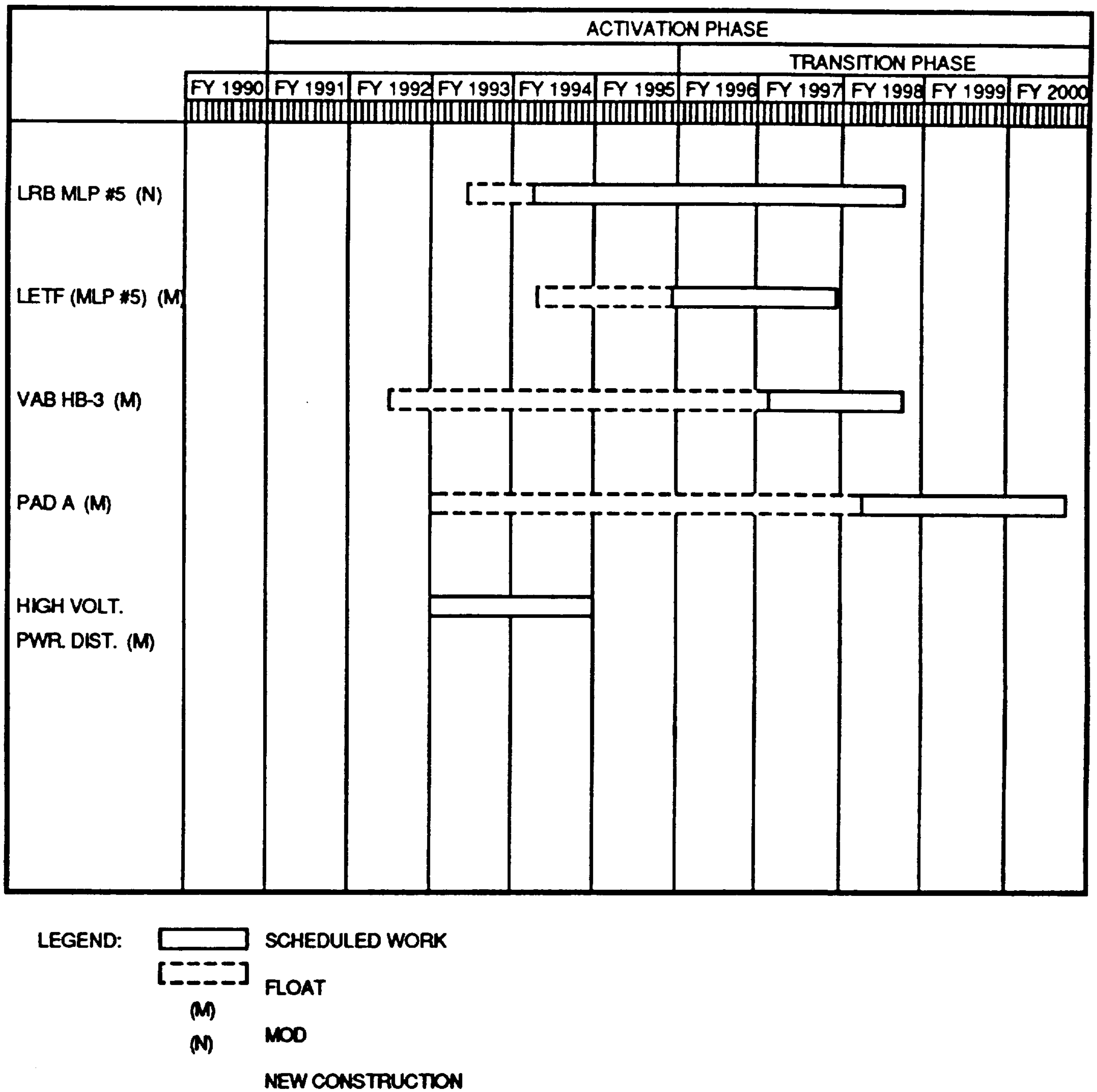

Figure 2.5.1-2. Second Line Facility Activities.

effort. Summary schedules for MLP #4 and MLP #5 are shown in Figures 2.5.1-1 and 2.5.1-2 respectively, and detailed schedules are in Volume III, Section 1.

The ROM cost for MLP #4 is $153.3M and MLP #5 is $120.7M. These costs include design by an A&E firm, construction by an outside contractor, the LSE/GSE, TTV and initial spares but do not include the Activation Management Team. Part of the efforts of the Activation Management Team as described in Section 2.8, have been apportioned to this effort at a cost of $22.9M and $18.1M respectively. This equates to the equivalent services of head counts of 85 and 72 team members respectively for each MLP for each full year of construction activity.

2.5.1.2 ET Horizontal Processing Facility

To provide a location for STS/LRB integration without impacting STS/SRB integration currently conducted in the VAB HB-1 and HB-3, VAB HB-4 was selected for modification to accommodate LRBs. This selection necessitated moving the ET storage and processing from HB-4 to an off-line facility. The proposed new facility can be combined with the new LRB Horizontal Processing Facility which also contains the LRB Engine Shop. These functions will have separate processing areas but can share the office space, shops, and storage space. Most operations currently performed on the ET can be accomplished in a horizontal position.

The construction of this facility must be in the early part of the activation phase to permit ET processing to move out of HB-4 and allow modification of HB-4 in time to support the planned first LRB launch in early 1996. Construction of this facility can start at the beginning of FY 1991 at the earliest and must be completed in the second quarter of FY 1993. The summary schedule for this approximate two year effort is shown in Figure 2.5.1-1 and a detailed schedule is in Volume III, Section 1.

Since this facility will be part of a joint use facility as described above, pricing was included in the ROM cost of $73.3M for the ET/LRB HPF. This includes the complete implementation under a design/build contract. Part of the Activation Management Team as described in Section 2.8, has been apportioned to this effort at a cost of $11.0M. This equates to the equivalent services of 51 team members for each full year of construction activity.

2.5.1.3 LRB Horizontal Processing Facility

To provide necessary space and facilities and to prevent impact to the SRB processing, a new LRB Horizontal Processing Facility will be constructed. This facility will be attached to the ET HPF as described in Paragraph 2.5.1.2. Details on this facility can be found in Volume III, Section 3.

The construction of this facility can begin during the latter part of construction on the ET HPF. The earliest start is programmed for the first quarter of FY 1993 and latest finish in the third quarter of 1995. The summary for this approximate 2.0 year effort is shown in Figure 2.5.1-1 and a detailed schedule is in Volume III, Section 1.

Since this facility is also part of the ET/LRB HPF the ROM cost is included in the $73.3M total for the ET/LRB HPF.

2.5.1.4 LRB Engine Shop

A facility is required to support the engine related and contingency processing activities of the LRB similar to the SSME processing shop. This facility should provide for the receipt, storage, installation/removal, modification, checkout and maintenance of the LRB engines and any relocated operations associated with the GSE needed for engine processing. The engine shop is also part of the ET/LRB HPF.

The construction of this facility is concurrent with, and a part of, the LRB HPF. The construction schedule is included in the same schedule as the LRB HPF discussed above and shown in Figure 2.5.1-1.

Pricing was done separately on this facility as discussed in Volume III, Section 7. The ROM cost is $29.0M. This includes the GSE and initial spares. The design and facility implementation are included in the ET/LRB costs above.

The part of the Activation Management Team apportioned to the LRB HPF is the same for this facility.

2.5.1.5 ET/LRB HPF Control Center/LPS

To avoid an LCC impact to SRB processing during LRB standalone processing, an independent control room concept for the LRB processing is proposed. This is included as part of the ET/LRB HPF to conduct ET and LRB component and system checkout without using the LCC facility. Each operations system engineer will have a console to perform functional testing of LRBs. Checkout will include engine, avionics, instrumentation, power and gimbaling tests. ET horizontal processing can also be supported from this facility.

The costs of this facility are included in the ET/LRB HPF cost breakout with the major part consisting of equipment.

2.5.1.6 ET/LRB Processing Facility Siting

A siting selection study was accomplished to determine the most optimum location for this facility. The selection criteria included the following considerations:

A. VAB proximity
B. Turn basin proximity
C. Blast danger area (quantity/distance)
D. Launch Danger Area
E. Environmental Impacts
F. ET and LRB tow routes
G. LC-39 Area Congestion
H. Availability of utilities/services
I. Demolition and relocation of existing facilities
J. Site preparation costs

The primary site chosen that best meets this criteria is located in the vicinity of the existing press site (see Figure 2.5.1.6-1). This site is in close proximity to the barge terminal and tow route. Safety concerns are eliminated since the site is beyond the VAB quantity/distance zone. Environmental concerns are minimized since an existing location is being converted.

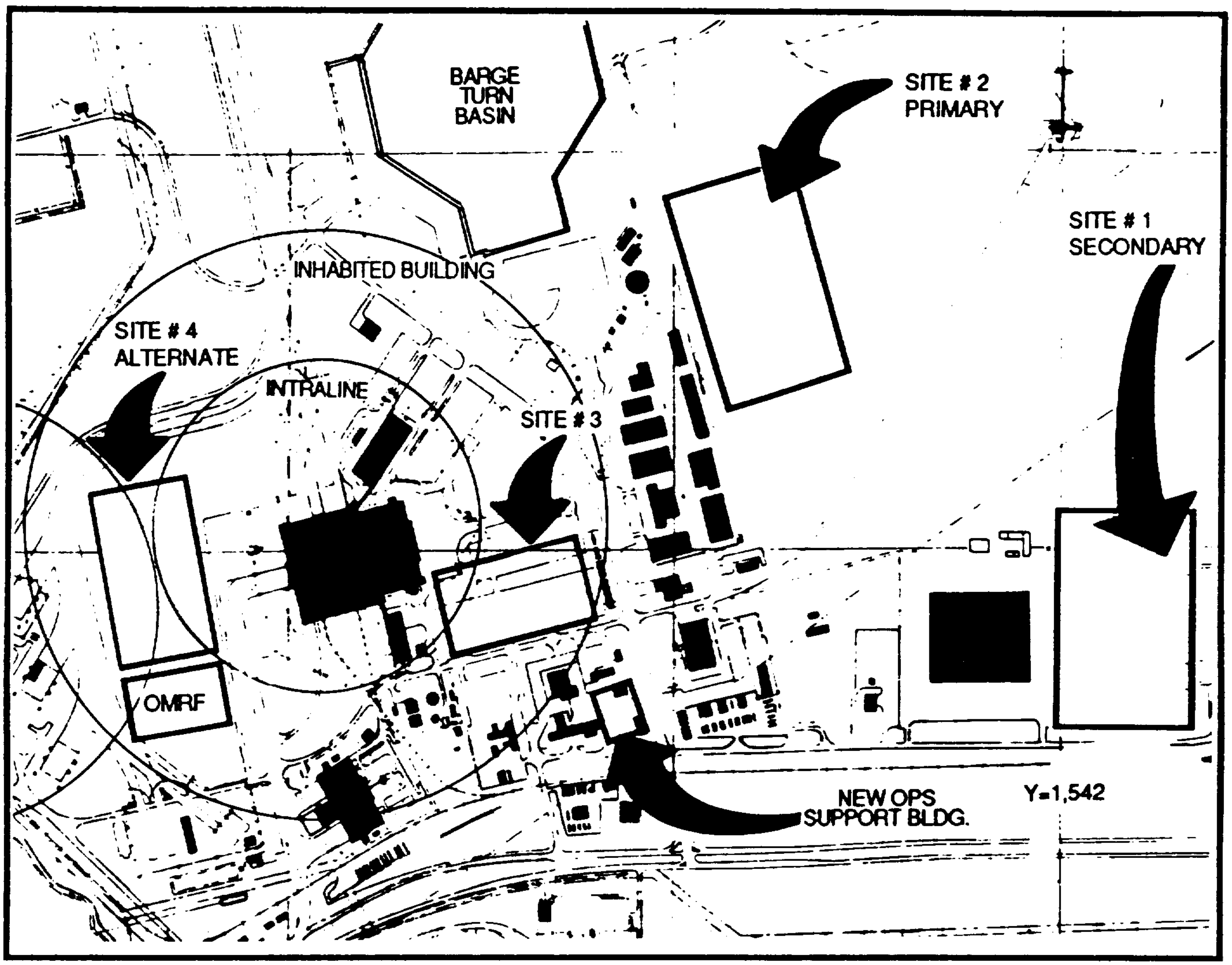

Figure 2.5.1.6-1. ET/LRB Processing Facility - Site Plan.

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2.5.2 Modifications

Some of the existing KSC facilities used for STS/SRB processing must be modified to accommodate the LRB processing. These modifications have been planned to provide minimum impact to the ongoing SRB processing. Facilities requiring modification are as follows:

A. MLP parksite #2 - Required to support construction and operation of new LRB MLPs. (Implementation time - 0.85 years, cost $2.6M)

B. LETF (MLP #4 and MLP #5) - Required to provide functional checkout and verification of new MLP #4 and MLP #5. (Implementation times - 2.6 and 2.1 years, costs $11.1M and $9.0M)

C. VAB HB-4 - Required to stack/mate LRBs/ET/Orbiter without impacting ongoing SRB operations in HB-1 or HB-3. (Implementation time - 2.85 years, cost $25.9M)

D. HB-4 Crawlerway - Required for access to HB-4 for roll out to the PAD (Figure 2.5.2-1) (Implementation time -1.4 years, cost $5.1M)

E. PAD A and B - Required to accommodate the new requirements of LRBs for structural, communication, data transfer and propellant connections. (Implementation times - 2.7 and 3.15 years, costs $69.2M and $70.8M respectively)

F. LCC/LPS - Required to provide new computer hardware and software to support the LRB. (Implementation time - 2.75 years, cost $14.3M)

G. VAB HB-3 - Required to stack/mate with LRBs or SRBs during the transition phase and LRBs only during sustained operational phase. (Implementation time - 1.6 years, cost $10.2M)

H. High Voltage Power Substation - Required to distribute and supply electrical power to the new facilities and support increased demands at modified facilities. (Implementation time - 4 years, cost $18.4M)

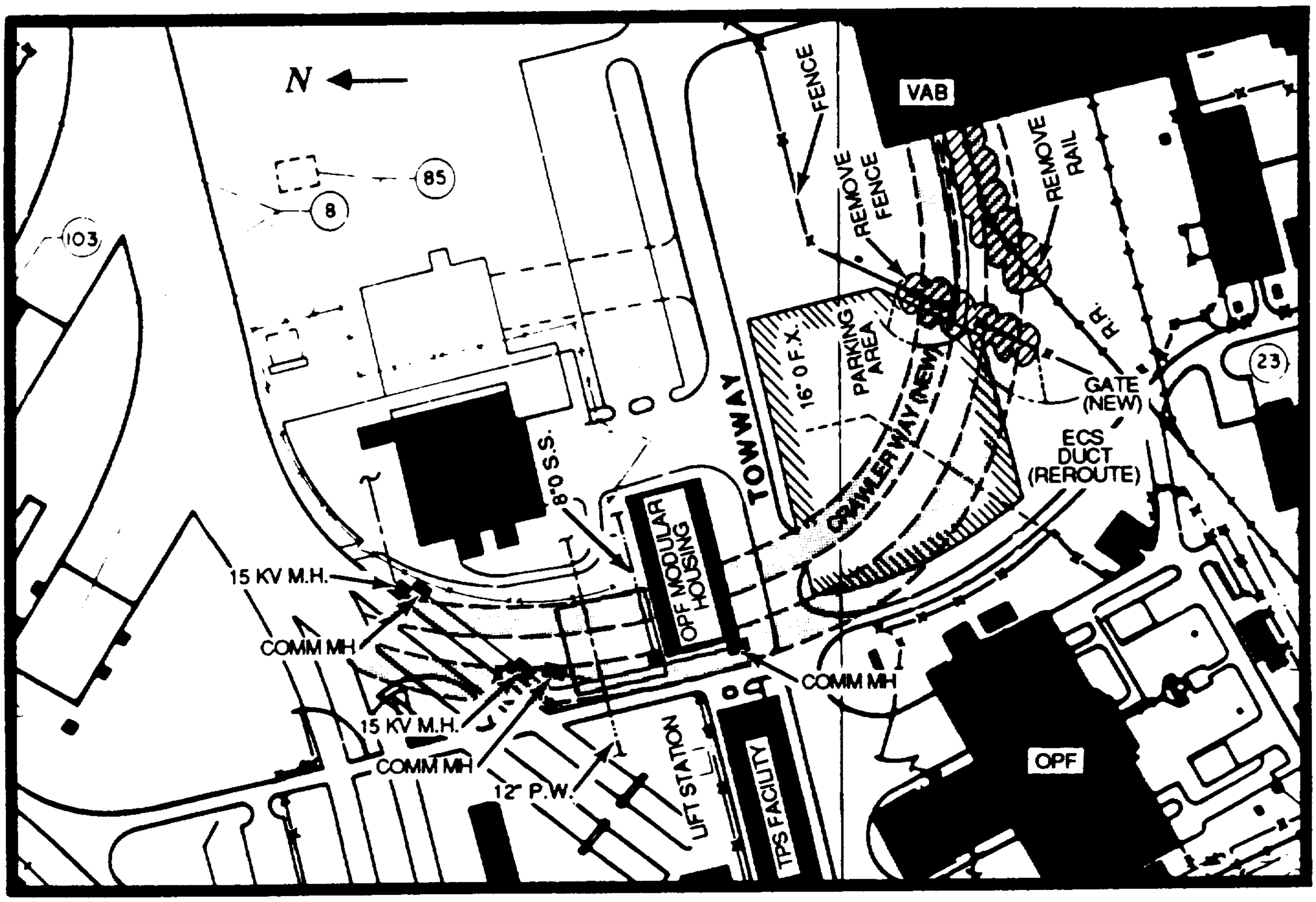


Figure 2.5.2-1. VAB High Bay 4 Crawlerway.

2.6 INTERFACE REQUIREMENTS

Since the LRB integration at the launch site represents a significant change to the current booster processing operations, other agencies and their relationships to KSC will be affected. These changes will affect manpower, procedures and equipment at other government, contractor and commercial organizations as well as at KSC. A KSC NASA LRB program/project office should be established to manage these interfaces. The specific interface support requirements to integrate the LRB program were not defined during this Phase-A study. However, similarities to the existing SRB and SSME processing requirements as defined in the Launch and Landing Program Requirements Document/Processing Support Plan (PRD/PSP) were used to estimate comparable support required. The additional staffing of an LRB program/project office to provide the launch site interface support to the LRB integration are included in the management/manning data in Section 2.8 of this plan. An explanation and concept of these interface requirements for the major affected organizations is presented in the subparagraphs below.

2.6.1 Johnson Space Center (JSC)

The introduction of the LRB processing and launches into the ongoing STS/SRB program will create new interface requirements with JSC. The most significant of these will be the additional performance data on the LRBs that will be transmitted to and monitored by JSC during launch and new flight software development for LRB. New ground software will have to be tested and certified at KSC to support these requirements. This will necessitate additional support at KSC over and above the STS/SRB support which will still be ongoing during the activation and transition phases. This type of launch site support has been factored into the manloading in Section 2.8.

2.6.2 Marshall Space Flight Center (MSFC)

A significantly increased load of requirements will be placed on MSFC since the contractual link to the LRB hardware contractor will be through MSFC. New tasks at the launch site will require support in areas such as: 1) Barge delivery and transport to the ET/LRB HPF 2;) processing requirements for flight; 3) Comprehensive instrumentation and performance data collection; 4) ET mockup tool development for the pathfinder LRBs; and 5) All associated tasks to support a new concept booster throughout its checkout and integration.

2.6.3 Department Of Defense (DOD)

Support required from DOD agencies, including the Eastern Test Range (ETR), (range tracking, range safety, camera and telemetry data coverage, weather support, etc.) are expected to be similar to those for the SRB program. A slight increase in KSC support for these new requirements during the transition phase has been factored into the manloading in Section 2.8.

2.6.4 KSC/Other

The introduction of the LRB program at KSC while maintaining an uninterrupted SRB program will create additional interface support requirements at KSC due to increased construction, facility modifications, and new products/methods being used. These requirements are discussed in Section 2.7. Other agencies which may require coordination for the LRB program are the Goddard Space Flight Center (GSFC) and the National Weather Service (NWS). This type of interface support is also factored into the management/manning data in Section 2.8.

2.7 SPECIAL KSC REQUIREMENTS

The increased activity at the launch site to support LRB integration will in some way affect almost every agency operating at KSC. Until an LRB hardware contractor is selected and the configuration is determined, the actual impacts cannot be completely defined. However, based on experience with other systems integrations, current Shuttle processing operations and the requirements listed in the Launch and Landing PRD/PSP, a general concept of activities can be estimated.

The introduction of a new system into an ongoing operation, without impacting the ongoing operation, will require separate teams of management/monitoring personnel. These personnel, typically government managers/monitors/engineers or designated contractors will need to be thoroughly knowledgeable of the new system as well as the operations of the current system. In order to perform LRB integration without impacting the STS/SRB program, these types of dual assigned personnel must be kept to a minimum, but must be maintained in the key coordination roles of integrated scheduling and planning.

2.7.1 SRB/LRB Joint Activities

These LRB activities are those that potentially interfere with the ongoing STS/SRB operations and could cause downtime, area clear, schedule delays, special permits, sharing of tools, personnel, and space,etc. These types of activities will require comprehensive coordination and scheduling throughout all KSC areas. These tasks have typically been performed under the auspices of KSC/NASA operations and O&M personnel. This activity has been included in the management/manning data in Section 2.8.

2.7.2 Facility Contractor Support

In addition to the interface activities discussed above, numerous activities will be accomplished on a standalone basis. These are primarily the facility modifications and new construction to be handled by outside contractor firms. The facilities involved are summarized in Section 2.5 and discussed in detail in Volume III, Section 3.

KSC activities to support this effort are typically controlled through the KSC/NASA DE/vehicle engineering organizations. This effort will consist of design, development, procurement, engineering review, contract monitoring, facility inspection, test termination and verification (TTV), activation, and acceptance/turn over activities. Extensive coordination must also be maintained among all other KSC agencies to keep impacts to the on-going SRB program to a minimum.

To enable the Shuttle processing contractor to assume operation and maintenance responsibilities of the facilities after they have been certified, teams of activation personnel must be involved throughout the activation process. These personnel will work closely with the A&E firms conducting the facility modifications and new construction. Details of this manning are covered in Volume III, Section 6. These facility activities are included in the management/manning data in Section 2.8. As part of the activation management team, personnel will be needed for the management/monitoring of numerous logistics and material handling functions during the TTV phases of construction and modification. These personnel, typically government or contractor designated, are covered in the management/manning data in Section 2.8.

2.7.3 LRB Launch Support Services (LSS)

The LRB hardware contractor will require office and equipment storage space at KSC. This dedicated space will be in addition to the current SRB contractor requirements since there will be a dual LRB/SRB program during the activation and transition phase. This new space requirement will increase during the latter part of the activation phase and early part of the transition phase to support increased efforts of the LRB facilities start up, checkout, FRF, and other efforts in support of the initial LRB flights. Requirements should be somewhat greater than the SRB contractor's current support for booster activities.

2.7.4 Recovery Requirements

Recovery of expended LRBs similar to SRBs was considered by the study team and element contractors but was not recommended. The up-front costs to develop the concept and the operational risks of the concept were greater than the Life Cycle Costs to use non-recoverable LRBs. However, the option is still open to further study the feasibility of a water, land impact, or mid air intercept recovery. If a decision is made to retrieve the LRB for salvage or reuse of components, additional facilities will be required.

The water recovery docking area must be expanded to accommodate the LRBs if ocean recovery is selected. An additional facility would be needed to disassemble, clean and refurbish LRB reusable parts since the existing facility would be supporting SRB retrieval/disassembly. Consideration might be given to barging the expended LRBs back to the manufacturer or other commercial facility for rework. After the transition phase when SRBs are phased-out, the SRB retrieval/disassembly facility could be modified to accommodate LRB rework. The existing recovery ships could probably be used for LRB recovery with some level of modifications. These modifications were not evaluated in this study.

A land recovery, although not fully studied or defined, would require specialized equipment to accomplish the landing, recover the LRBs, and transport them to a rework facility on a suitable roadway.

2.8 MANAGEMENT/MANNING

2.8.1. LRB Processing

The significant differences between LRBs and SRBs will necessitate a totally different type of processing and therefore different skills of manpower. Although the SRB technicians can eventually be cross-trained and transitioned to LRB activities, the initial phases of LRB work will require additional LRB dedicated personnel to avoid impact to the on-going SRB activities. A generic SRB Baseline Study, described in Volume V , Appendix 6, was conducted to determine the types and numbers of technicians needed to support the processing of LRBs. A determination of numbers and types of SPC support personnel involved in LRB processing is also included in the Baseline Study.

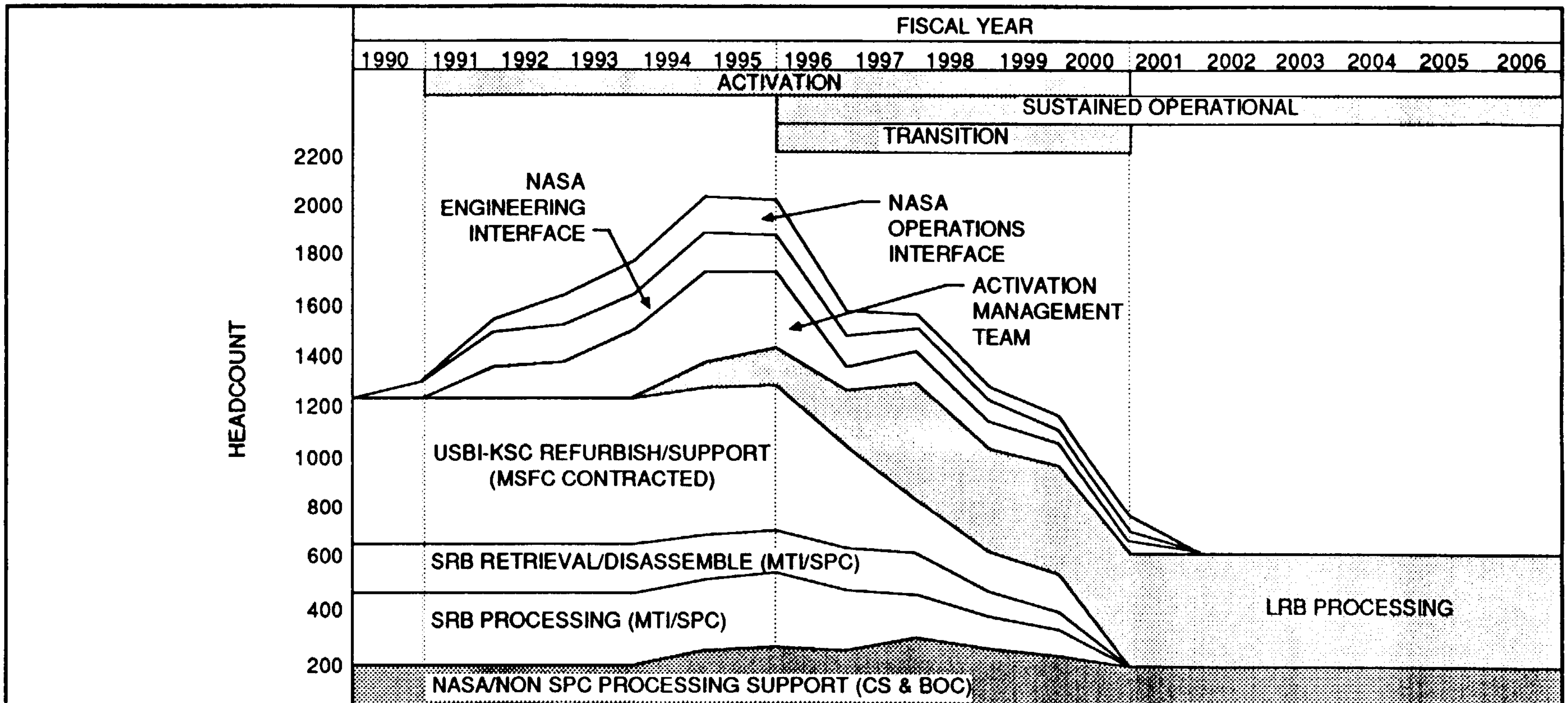
The manning in this group consists of those personnel directly involved in the hands-on processing of LRBs. These include the technicians and their direct support from Engineering, Facility/Ground Support, Logistics, Quality, Safety, Operations Planning and Control, Overhead, and LPS. The head count of these types of personnel was derived in Volume III, Section 6 and is shown in Figure 2.8-1.

2.8.1.1 Non-SPC SRB Processing Support

Additional manning linked to the LRB processing include personnel from the Base Operations Contractor and NASA. These are part of the LRB processing team but are shown separately as NASA/Non-SPC Processing Support in Figure 2.8-1 since they are also part of the SRB Processing Team. These personnel are identified in the Generic SRB Baseline Study.

2.8.2 NASA Operations Interface

In addition to the hands-on LRB Processing and Activation Personnel, support will be required from the NASA/Contractor Community similar to that currently provided to the on-going KSC operations. These personnel must be dedicated to the LRB Program, especially in the early phases of activation and transition. Whether or not these are actually additional personnel or reassigned/cross-utilized personnel cannot be determined in this study.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
TOTAL	1342	1597	1704	1789	2050	2024	1603	1546	1295	1145	719	608	608	608	608	608	608
NASA OPERATIONS INTERFACE		36	123	145	145	145	116	58	44	44	15						
NASA ENGINEERING INTERFACE	79	157	142	135	127	127	102	64	57	51	44						
ACTIVATION MGMT. TEAM		141	176	246	363	286	83	96	133	69	52						
LRB PROCESSING					110	147	221	441	441	441	441	441	441	441	441	441	441
USBI REFURB/SUPPORT	600	600	600	600	600	600	474	342	216	200							
SRB RETRIEVAL/DISASSEM.	160	160	160	160	160	160	126	91	57	50							
SRB PROCESSING	336	336	336	336	336	336	264	192	120	100							
NASA/NON-SPC PROC. SUPP.	167	167	167	167	209	223	217	262	227	190	167	167	167	167	167	167	167

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Figure 2.8-1. Time Phased LRB Integration Headcount.

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This organization from the NASA/Contractor Community consists of direct operational/interface support from Ground Engineering, Vehicle Engineering, Shuttle Logistics Project Management Office, Shuttle Operations Office, Center Support Operations, Safety and Reliability Office, and the LRB Project Office. Functional support of these organizations is described in Volume III, Section 6. The time phased head count required to support LRB integration is shown in Figure 2.8-1.

2.8.3 NASA Engineering Interface

These personnel, also from the NASA/Contractor Community, are involved in all areas of engineering support/management for LRB Operations. These personnel must be dedicated to the LRB during activation and transition and may be additional personnel or reassigned/cross-utilized personnel.

This organization will provide engineering/management interface support from Engineering Development, STS Management and Operations, Ground Engineering, Vehicle Engineering, Shuttle Operations, Shuttle Logistics Project Management, Safety and Reliability, Quality Assurance, Environmental Impacts and the LRB Program Office. Functional support of these organizations is described in Volume III, Section 6. The time phased head count required to support LRB Integration is shown in Figure 2.8-1.

2.8.4 Activation Management Team

The facility construction and modifications will be performed by outside A&E/construction firms. This activity will require direct interface support from a designated Activation Management Team. This team, consisting of NASA and/or Contractor personnel, will be the link between the construction firms and all of the launch site coordination activities to ensure the finished product meets the requirements of LRB Integration. Details of this organization and their functions are covered in Volume III, Section 1 and Section 6. The time phased head count required to support LRB integration is shown in Figure 2.8-1.

2.8.5 SRB Manning

The non-LRB manning covered in this Section includes SRB processing personnel and their direct support similar to that described for LRB processing in paragraph 2.8.1 above. The generic SRB

Baseline Study in Volume V, Appendix 6, also included information on SRB retrieval/disassembly personnel and the USBI refurbishment operations at KSC of approximately 600 people under the MSFC contract. The Baseline Study reflected an estimated 400 head count for USBI-KSC in 1985 and was updated to the more current 600 headcount used here.

The total head count for Morton Thiokol SRB Processing technicians is 221 which includes 62 for SRB retrieval and disassembly. To permit a closer comparison with the LRB Processing Technicians, the total technician count was reduced by 62 leaving a total of 159. Additionally, 59 technicians support both ET and SRB processing. Fifty percent of these (29) have been allotted to ET functions and are also subtracted leaving a total of 130. The factors used to determine the direct support for LRB technicians from Engineering, Facility/Ground Support, Logistics, Quality, Safety, Operations Planning and Control, Overhead, and LPS were also applied to the SRB processing technicians to arrive at total of 336. This is the steady state head count for SRB processing used in Figure 2.8-1.

Since the LRB will not be retrieved, the refurbishing functions at KSC will decrease as SRB launches decrease and phaseout. The steady state head count for retrieval and disassembly technicians and their support is 160 based on the same factors used above. Additionally, the MSFC contracted SRB refurbishment process by USBI at KSC will phaseout with SRB launches. These time phased head counts are also shown in Figure 2.8-1.

SRB processing is also supported by the Base Operations Contractor and NASA similar to that described in Paragraph 2.8.1.1 for LRB. This support is shown in Figure 2.8-1 to increase with LRB phase-in and return to prior levels after SRB phaseout.

2.8.6 LRB Versus SRB

After SRB phaseout, the LRB Processing and NASA/Non-SPC Support (LRB) personnel total 608. These are essentially replacements to the SRB Processing, NASA/Non-SPC Processing Support (SRB), SRB Retrieval/Disassembly, and the MSFC funded USBI Refurbishment/Support personnel totaling 1263 (Ref. Fig. 2.8-1). This indicates a net decrease of 655 personnel due to the replacement of SRBs with LRBs.

2.9 LAUNCH SITE IMPLEMENTATION COSTS

This section summarizes costs by major category of activities involved at the launch site. The subsections below cover cost summaries for facilities with selected equipment, recurring material and commodity costs, and management/manning costs. Time phased summaries are included to identify fiscal year costs by major category. All costs are Rough Order of Magnitude (ROM) in 1987 dollars. These data will support early POPs preparation during Phase-B. Summary data for the baseline configuration POP is shown in Figure 2.9-1.

2.9.1 Facilities and Equipment

The costs of the new facilities and modification of existing facilities discussed in Section 2.5 of this plan are covered in this section. Figure 2.9.1-1 lists the costs for the first line facilities which total $397.7M. Figure 2.9.1-2 lists the costs for the second line facilities, totaling $215.2M. Costs are shown for design, facility, equipment (LSE and GSE), TTV and initial spares and do not include the Activation Management Team. Figure 2.9.1-3 is a breakout of these costs time phased by fiscal year. These costs are a straight line breakout by fiscal year of the totals based on the facilities schedules shown in Figures 2.5.1-1 and 2.5.1-2. A more rigorous cost analysis could be done in follow-on work during Phase-B which would better allocate the cost throughout the time periods. Volume III, Section 7 contains details of facility and equipment costs.

2.9.2 Recurring Material and Commodity Costs

This subsection summarizes the major costs of expendable commodities (fuels, gases, oxidizer) and the spares for LSE/GSE required for the facilities discussed in Section 2.5. Figure 2.9.2-1 lists the costs for these items by category, time phased by fiscal year. Volume III, Section 11 contains details of commodity costs.

Propellant and gas consumptions per load-and-launch of two LRBs were used for the highest priced and lowest priced options for the two contractor's LOX/RP-1 versions. These options yield a lowest cost of $490.4K for the MMC pump-fed version and $610.4K for the General Dynamics pressure-fed version. The other two LOX/RP-1 versions fall between these costs and are not discussed here since differences are minimal. Additionally the General Dynamics LH2/LOX version yields a per load-and-launch cost of $678.8K. Each of these costs includes the fuel RP-1 (or LH2), oxidizer LOX, and the increase in purge/pressurizing gases GN2 and GHe over that

FY	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
PROGRAM PHASES	FACILITY ACTIVATION															
						OPERATIONAL										
						TRANSITION										
RECURRING																
PROCESSING				5.50	7.35	11.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05
SPC/BOC/SUPT	8.35	8.35	8.35	10.45	11.15	10.85	13.10	11.35	9.50	8.35	8.35	8.35	8.35	8.35	8.35	8.35
COMMODITIES					.49	1.47	2.94	4.41	5.88	6.86	6.86	6.86	6.86	6.86	6.86	3.92
SPARES/MAT'L			1.09	2.49	21.33	21.33	22.73	27.81	27.81	33.47	33.47	33.47	33.47	33.47	16.73	8.37
SUB TOTAL	8.35	8.35	9.44	18.44	40.32	44.70	60.82	65.62	65.24	70.73	70.73	70.73	70.73	70.73	53.99	42.69
NON-RECURRING																
1ST LINE FAC	52.62	65.53	88.95	112.08	78.56											
2ND LINE FAC			3.05	23.17	27.46	31.11	36.32	49.26	25.63	19.22						
ACTIVATION MGMT TEAM	7.90	9.86	13.78	20.33	16.02	4.65	5.38	7.45	3.86	2.91						
SUB TOTAL	60.52	75.39	105.78	155.58	122.04	35.76	41.70	56.71	29.49	22.13						
TOTALS	68.87	83.74	115.22	174.02	162.36	80.46	102.52	122.33	94.73	92.86	70.73	70.73	70.73	70.73	53.99	42.69

* NUMBERS ARE '87$M

Figure 2.9-1. LO2/RP-1 Pump-Fed Booster POP

NON-RECURRING FACILITY COSTS		DESIGN	FACILITY	TTV LSE GSE	INITIAL SPARES	TOTAL COST 1987 $ M
FIRST LINE FACILITIES	MLP PARKSITE #2 (M)	0.4	2.2	—	—	2.6
	LRB MLP #4 (N)	20.9	51.9	76.1	4.4	153.3
	LETF MLP #4 (M)	—	—	11.1	—	11.1
	ET/LRB HORIZ PROC FAC (N)	9.9	46.4	15.6	1.4	73.3
	VAB HB-4 (M)	4.1	20.0	1.6	0.2	25.9
	HB-4 CRAWLERWAY (M)	0.8	4.3	—	—	5.1
	LRB ENGINE SHOP (N)	—	—	26.6	2.4	29.0
	PAD B (M)	10.0	14.5	42.8	3.5	70.8
	LCC/LPS (M)	0.3	1.7	12.3 (S/W)	—	14.3
	HIGH VOLT PWR DIST (M)	1.9	10.4	—	—	12.3

LEGEND: (M) MOD
(N) NEW

TOTAL = 397.7

Figure 2.9.1-1. LRB First Line Facility - Non-Recurring Cost Summary.

NON-RECURRING FACILITY COSTS		DESIGN	FACILITY	TTV LSE GSE	INITIAL SPARES	TOTAL COST 1987 $ M
SECOND LINE FACILITIES	LRB MLP #5 (N)	13.9	51.9	53.0	1.9	120.7
	LETF MLP #5 (M)	—	—	9.0	—	9.0
	VAB HB-3 (M)	1.4	7.5	1.2	0.1	10.2
	PAD A (M)	8.4	14.5	42.8	3.5	69.2
	HIGH VOLT PWR DIST (M)	1.0	5.1	—	—	6.1

LEGEND: (M) MOD
(N) NEW

TOTAL = 215.2

Figure 2.9.1-2. LRB Second Line Facility - Non-Recurring Cost Summary.

FY	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
PROGRAM PHASES	FACILITY ACTIVATION (1991–2000)															
						OPERATIONAL (1996–2006)										
						TRANSITION (1996–2000)										
						ILC	IOC									
1ST LINE																
MLP PARKSITE #2 (MOD)	2.60															
LRB MLP #4 (NEW)	31.94	31.94	31.94	31.94	25.55											
LETF (MLP #4) (MOD)		2.56	4.27	4.27												
ET/LRB HORIZ PROC FAC. (NEW)	11.93	18.35	11.37	19.78	11.87											
LRB ENGINE SHOP (NEW)			3.92	15.68	9.41											
VAB HB-4		0.91	9.09	9.09	6.82											
HB-4 CRAWLERWAY (MOD)			1.46	3.64												
PAD (B) (MOD)		5.62	22.48	22.48	20.23											
LCC/LPS (MOD)			4.42	5.20	4.68											
HIGH VOLTAGE PWR. DIST. (MOD)	6.15	6.15														
1ST LINE TOTAL	52.62	65.53	88.95	112.08	78.56											
2ND LINE																
LRB MLP #5 (NEW)				20.12	26.82	26.82	26.82	20.12								
LETF (MLP #5) (MOD)					0.64	4.29	4.08									
VAB (HB-3) (MOD)							5.42	4.79								
PAD (A) (MOD)								24.35	25.63	19.22						
HIGH VOLTAGE PWR. DIST. (MOD)			3.05	3.05												
2ND LINE TOTAL			3.05	23.17	27.46	31.11	36.32	49.26	25.63	19.22						
TOTALS	52.62	65.53	92.00	135.25	106.02	31.11	36.32	49.26	25.63	19.22						

* NUMBERS ARE '87$M

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Figure 2.9.1-3. Life Cycle LRB Facility Costs.

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FY	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
PROGRAM PHASES	FACILITY ACTIVATION (1991–2000)															
						OPERATIONAL (1996–2006)										
						TRANSITION (1996–2000)										
FUELS																
RP-1 (MMC PUMP)					.26	.78	1.56	2.34	3.12	3.64	3.64	3.64	3.64	3.64	3.64	2.08
RP-1 (GD PRESS)					.35	1.05	2.10	3.15	4.20	4.90	4.90	4.90	4.90	4.90	4.90	2.80
LH2 (GD PUMP)					.46	1.38	2.76	4.14	5.52	6.44	6.44	6.44	6.44	6.44	6.44	3.68
GASES/OXIDIZER																
GHe (ALL)*					.10	.30	.60	.90	1.20	1.40	1.40	1.40	1.40	1.40	1.40	.80
GN2 (ALL)*					.06	.18	.36	.54	.72	.84	.84	.84	.84	.84	.84	.48
LOX (MMC RP-1 PUMP)					.07	.21	.42	.63	.84	.98	.98	.98	.98	.98	.98	.56
LOX (GD RP-1 PRESS)					.11	.33	.66	.99	1.32	1.54	1.54	1.54	1.54	1.54	1.54	.88
LOX (GD LH2 PUMP)					.07	.21	.42	.63	.84	.98	.98	.98	.98	.98	.98	.56
LSE/GSE SPARES																
MMC RP-1 PUMP			1.09	2.49	21.33	21.33	22.73	27.81	27.81	33.47	33.47	33.47	33.47	33.47	16.73	8.37
GD RP-1 PRESS			1.09	2.49	21.54	21.54	23.32	28.40	28.40	34.27	34.27	34.27	34.27	34.27	17.12	8.59
GD LH2 PUMP			1.09	2.49	26.24	26.24	28.27	34.80	34.80	43.30	43.30	43.30	43.30	43.30	21.65	10.83

* NUMBERS ARE '87 $M
* PURGE / PRESSURIZATION GASES ARE INCREASES OVER SRB ACTIVITIES.

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Figure 2.9.2-1. Life Cycle LRB Recurring Material and Commodity Costs.

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being used for SRB activities. These costs account for average waste/loss for each launch but do not include any scrub/abort/recycle missions.

The cost of LSE/GSE spares for each year of the life cycle is based on 14% of the initial cost of the equipment. The first set of spares for each facility is assumed to be purchased during the last year of initial construction or modification and continue each year through the life cycle. This factor was phased down by 50% and 75% in the last two years of the life cycle to phaseout the program. Figure 2.9.2-1 includes these costs for the three options discussed above.

2.9.3 Management/Manning Costs

This subsection summarizes the manpower costs for the manning discussed in Section 2.8 for the LRB integration operations. The head counts developed in Figure 2.8-1 for LRB and SRB processing, SRB Retrieval/Disassembly and their support personnel were multiplied by $50K to arrive at the estimated costs per year. For the fiscal years 1994 and 1995 when LRB personnel are entering training/certification and no launches are being performed, a ramp-up head count was used to arrive at the costs. A ramp-down head count is used to phaseout SRB personnel. The USBI-KSC Refurbishment/Support data used from the generic SRB Baseline Study was included in the head count in Paragraph 2.8 to reflect total booster population at KSC but is not priced in this section since it is not a KSC cost. Figure 2.9.3-1 lists costs for each type of personnel, time phased through their period of activity.

The activation management team consists of approximately two-thirds engineering type skills and one-third procurement/material management skills. Annual costs used for these personnel was estimated at $60K and $48K per year respectively for each type and averaged to $56K for the team. This was based on averages from similar types of activity on other projects.

The manning categories of NASA Operations Interface and NASA Engineering Interface discussed in Paragraphs 2.8.2 and 2.8.3 are not included in the cost data. These two organizations consist of personnel who will most likely be reassigned or cross utilized from existing Shuttle related functions on the launch site and, therefore, would not be an added cost to the LRB program.

FY	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
PROGRAM PHASES	FACILITY ACTIVATION															
						OPERATIONAL										
						TRANSITION										
RECURRING																
LRB PROCESSING				5.50	7.35	11.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05	22.05
NASA/NON-SPC PROC SUPPORT (CS & BOC)	8.35	8.35	8.35	10.45	11.15	10.85	13.10	11.35	9.50	8.35	8.35	8.35	8.35	8.35	8.35	8.35
SRB PROCESSING	16.80	16.80	16.80	16.80	16.80	16.80	13.20	9.60	6.00							
SRB RETRIEVAL/ DISASSEMBLY	8.00	8.00	8.00	8.00	8.00	6.30	4.55	2.85	2.50							
USBI-KSC REFURB/ SUPPORT		NOT PRICED														
TOTAL	33.15	33.15	33.15	40.75	43.30	45.00	52.90	45.85	40.05	30.40	30.40	30.40	30.40	30.40	30.40	30.40
NON RECURRING																
ACTIVATION MGMT TEAM	7.90	9.86	13.78	20.33	16.02	4.65	5.38	7.45	3.86	2.91						
NASA ENGINEERING INTERFACE		NOT PRICED														
NASA OPERATIONS INTERFACE		NOT PRICED														
TOTAL	7.90	9.86	13.78	20.33	16.02	4.65	5.38	7.45	3.86	2.91						

* NUMBERS ARE '87$M

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Figure 2.9.3-1. Life Cycle LRB Management/Manning Cost Summary.

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2.9.4 Major LRB Life Cycle Costs

Figure 2.9.4-1 presents a diagram of the life cycle non-recurring and total costs for the LRB Program. The costs for three different booster options is also shown. Non-recurring totals include the facility costs and Activation Management Team costs.

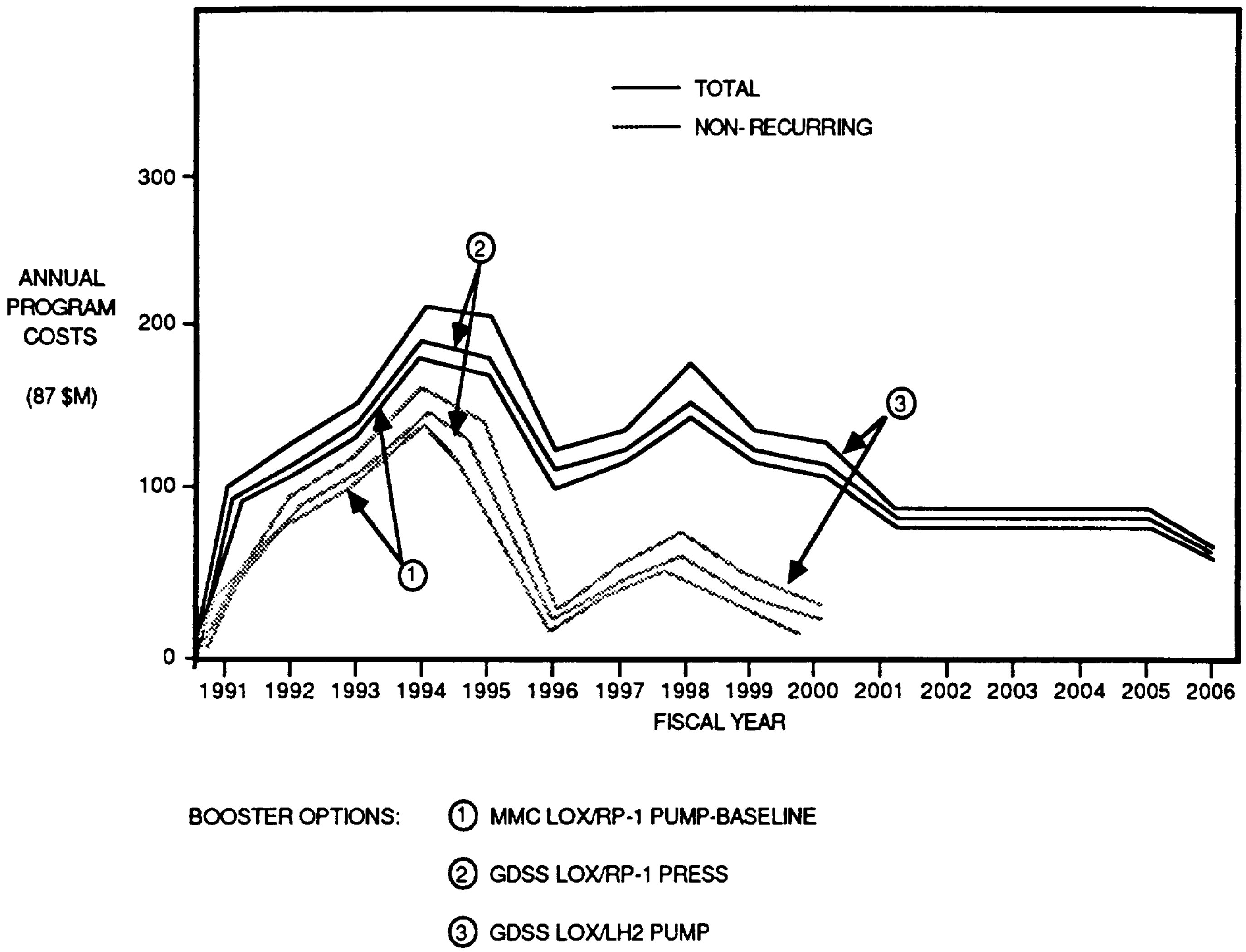

Figure 2.9.4-1. LRB Integration Costs.

VOLUME II

SECTION 3

GROUND OPERATIONS COST AND MODEL

(GOCM)

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SECTION 3
GROUND OPERATIONS COST MODEL

Three independent KSC LRB cost estimates were performed, and are reported in Volume II, Section 4. One of the estimates employed the use of the Ground Operations Cost Model (GOCM). GOCM is a NASA developed parametric cost model which develops Ground Processing Cost, and was provided to the study group for use in the LRB program.

In addition to utilizing GOCM to estimate LRB costs, the study team was instructed to study and evaluate GOCM and to provide updates to the software and its documentation. This section reports the GOCM study findings and the work accomplished to enhance GOCM.

The GOCM was provided to the study team by KSC under contract NAS10-11475 dated April 15, 1988. In accordance with the Statement Of Work, the study team was to:

- Utilize GOCM and other costing techniques as appropriate in the preparation of cost assessments of ground processing operations conducted in support of the Liquid Rocket Booster (LRB) configurations trade-studies.

- Expand and enhance the utility and relevance of GOCM to the KSC STS program and incorporate lessons learned from the LRB integration study.

- Evaluate and update GOCM Cost Estimating Relationships (CERs) and incorporate detail design and alternative support scenarios that are cost significant and sensitive into GOCM as a module.

- Develop and deliver the following products: GROUND OPERARATIONS COST MODEL USER'S MANUAL (Vol III Sec 13), INSTRUCTIONS (Vol III Sec 14) for updating and modifying GOCM, and DEVELOPED SOFTWARE (Vol III Sec 15).

GOCM as provided by KSC is hereafter called the baseline. The baseline was enhanced to make it more user friendly and expansion ready without altering its CERs and methodology. This version of GOCM is called the enhanced version. It provides a good framework for the construction of future GOCM derivatives and revisions. The enhanced GOCM is the subject to which the study team has applied the Statement Of Work. A variant of the enhanced GOCM called the enhanced modified GOCM was also developed. It incorporates the lessons learned from the LRBI which have resulted in CER additions and modifications. (See Figure 3.0)

GOCM was found to be an excellent macro level cost generation tool which is suitable for pre-Phase A and Phase A studies. GOCM also provides an effective framework for processing more discrete CERs which would span over to the micro level and be useful in Phase A, Phase B and Phace C trade studies.

While proving to be limited in applicability to Phase A trade studies, GOCM has performed some very important functions. They are:

- Identifying ground processing sensitivities and shortfalls
- Providing a cost reference
- Macro budget planning
- Initial cost estimates
- Identifing major cost drivers

This report provides the LRBI GOCM user's experience, STS calibration/modifications to GOCM, explains model enhancements made by LSOC, explains the application and the role GOCM had in the LRBI, explores GOCMs potential and recommends future direction for GOCM.

The LRBI provided an ideal opportunity to evaluate GOCM and apply the lessons learned to simplify its operation, expand its utility and enhance its relevance.

3.1 USER'S EXPERIENCE

3.1.1 New User Impressions

Initial impressions of GOCM were overwhelming. The baseline model was large, nearly utilizing the total capacity of an IBM PC AT computer. Model operations were slow and difficult at first. The user's operations manual was terse and incomplete. Early GOCM operations proved to be a formidable task.

It was initially recognized that a comprehensive knowledge of ground processing and space craft configurations was needed in order to ascertain the functional relationships of each GOCM cost element. This could have been made simpler with a more comprehensive user's manual. This

GROUND OPERATIONS COST MODEL EVOLUTION

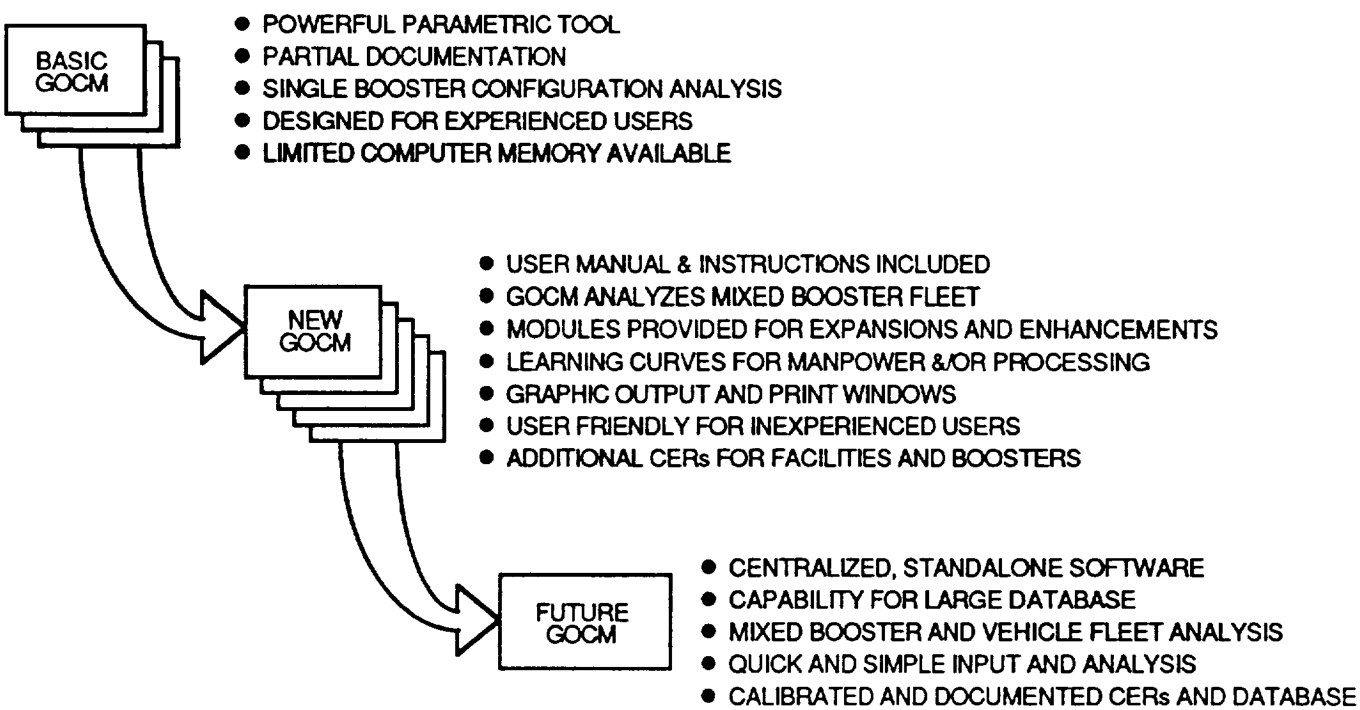

Figure 3.0. GOCM Evolution.

manual should be written to a technical audience but one with little space operations and launch preparations knowledge. The new user also needs a model dictionary which should be carried over into the Instruction Manual. The dictionary should contain STS ground processing and GOCM peculiar terms.

The instruction manual will become very important to the user as he becomes proficient in operating GOCM. He naturally wants to know how GOCM generates those fascinating costs! Here is where the user becomes lost. There is no place he can currently turn to except the model's code, which is a very difficult to interpret. The Instruction Manual provided as a result of this study will simplify this situation. It provides direction and guidance to the user for accomplishing model integration and for incorporating updates and changes. Using the instruction manual the GOCM user can probe GOCMs CERs and understand their operation.

It was the above experiences and impressions that provided guidance in the creation of the GOCM USER'S MANUAL, the INSTRUCTIONS MANUAL, and the software enhancements contained in the enhanced version of GOCM.

3.1.2 Early Model Evaluation

3.1.2.1 Strengths and Weaknesses

GOCM is very flexible. The flight element configurations can vary, their size can vary, Mission profiles is a variable and the cost due to learning has been accounted for in this model. This flexibility allows the user to evaluate a multitude of flight hardware types and mission scenarios. For instance, GOCM can be used to estimate the ground processing cost for the Shuttle, Shuttle II, Shuttle "C", small expendable rockets, and the proposed ALS.

GOCM was developed in three parts; Processing, Operations and Facility models (see Figure 3.1.2-1). This allowed it to be partitioned in order that it would fit into the available PC memory. Each model part has a very distinct purpose, and the combination generates the overall cost projections. LSOC has taken this concept of modularization even further in its development of the enhanced version, and in the process provided more available memory. The additional available memory was partially used to maximize user friendliness and to provide model growth potential.

Early in using GOCM, certain shortcomings were recognized. GOCM did not break out costs by flight element. Only the system level processing cost were provided. Therefore cost assessments of various subsystems within the overall system could not be evaluated. This was the case with the

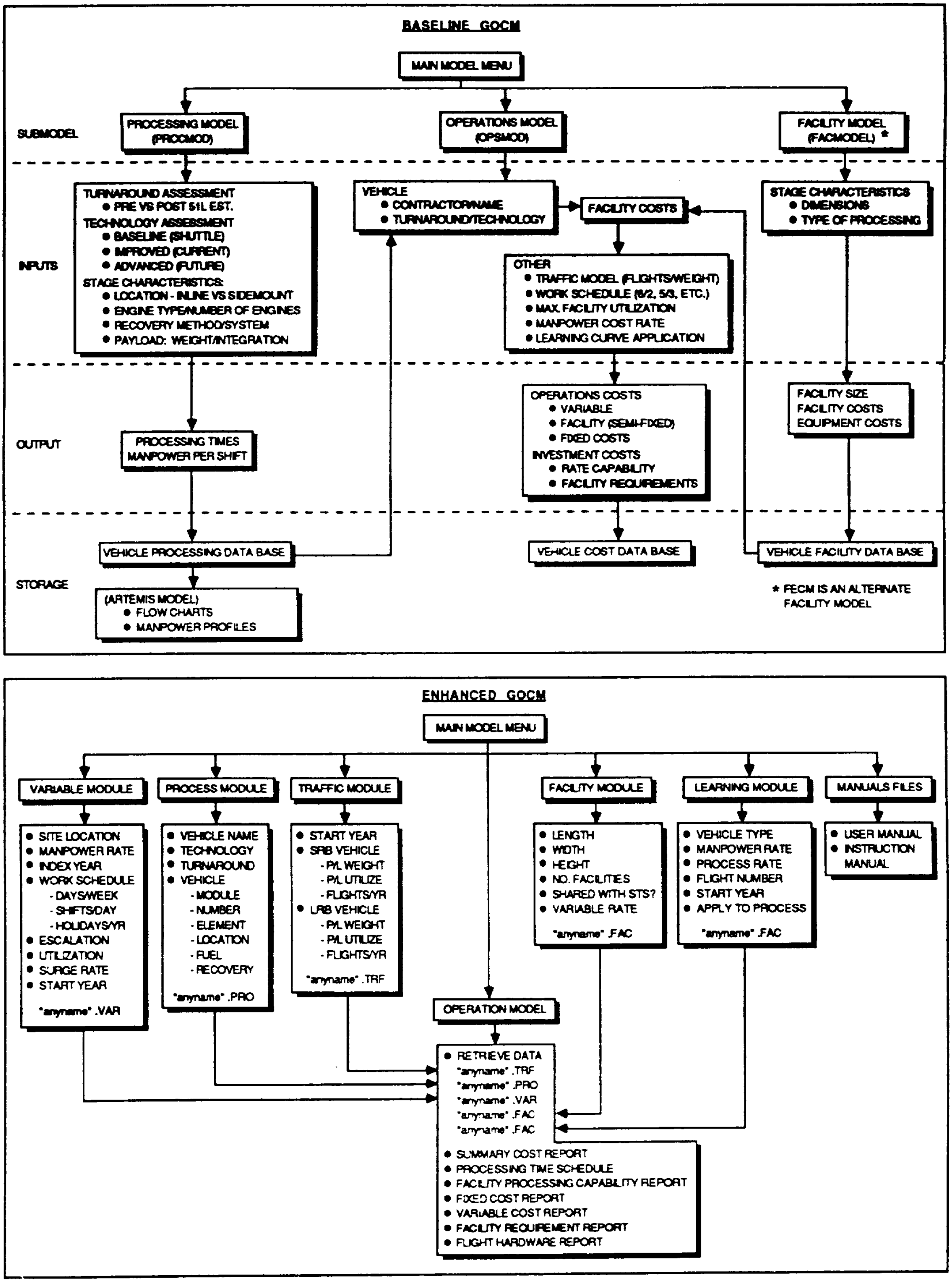

Figure 3.1.2-1. GOCM Modularization.

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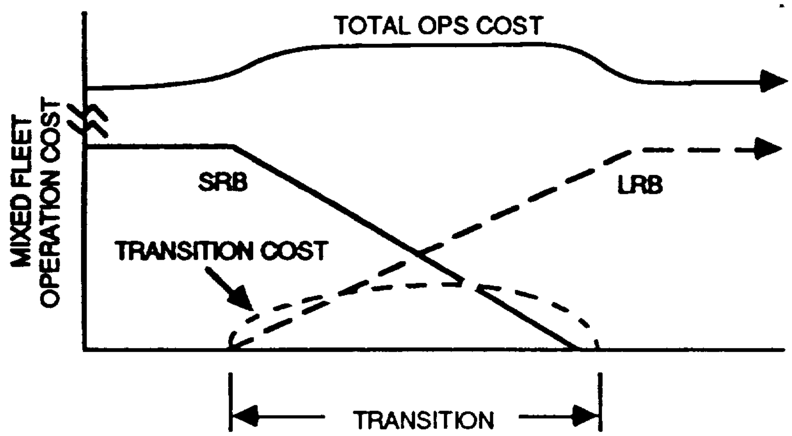
LRB. Another feature which was desirable for the LRB study and not available was the ability to conduct Mixed Fleet cost projections. The LRB is envisioned in this study to be phased into operation while the SRB is phased out. Therefore, there is a period of mixed booster fleet operations. The mixed booster fleet operations complicates the foreseen ground operations. Concurrent with SRB operations, facilities and equipment used will be subject to modifications to support LRB processing. LRB preparations and site activations will be occurring simultaneously with SRB operations during the transition (see Figure 3.1.2-2). Therefore, scheduling the use of facilities is not only dependent on their recurring utilization capability, it is also dependent on their downtime for the non-recurring modification activity. This is something that the current model is incapable of handling. GOCM also does not estimate facility modification costs. Most of the current in place facilities are being considered for use in the LRB program after the appropriate modifications are performed. Outside techniques will need to be employed to incorporate these cost elements into the overall cost. Currently, GOCM will derive the "new" facility requirements and their associated costs when required to meet the desired launch schedule. These costs, however, are not flowed backwards from the date the facility is needed to accommodate budget development. Furthermore, only facilities that are in the modules repertoire can be added. That is, GOCM can only increase the quantity of in place facilities or build similar new replacement facilities for a new vehicle configuration. New type facilities in addition to the modification of existing facilities must be handled elsewhere.

These shortcomings do not detract from GOCM's utility. They simply reinforce the belief that no model can be fabricated for universal application. Cost development usually requires a user's expertise that can not be totally captured in the cost model's logic. The user must know the limits of this model and understand its application. In this light, we view the projection of ground processing cost to require a dynamic system of interactive cost models, cost modules, and cost databases (see Paragraph 3.3.2), where the user is as an important part of the cost generation process as the tools he uses. GOCM, in its baseline form, is an excellent beginning in the development of a ground processing cost generation tool kit.

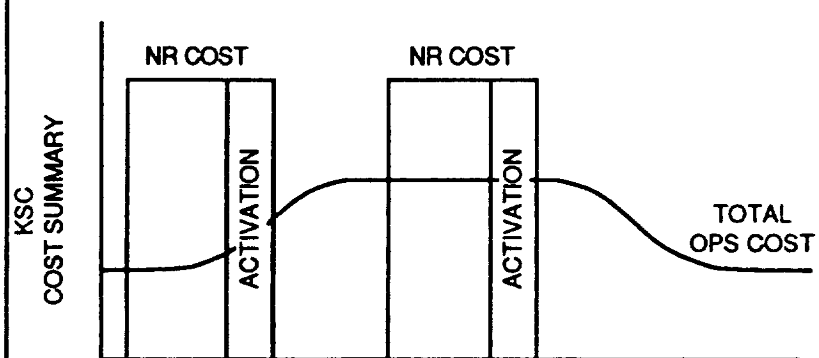
It is believed that further progress beyond the enhanced version of GOCM is severely limited by the architecture employed. The systems approach advocated elsewhere in this report (see Paragraph 3.3.2 and 3.5) requires the use of different software and hardware systems. It also requires the development of resident expertise and a systematic program of development, maintenance, and use. It is the conclusion of this study that the evolutionary improvements are coming to an end and the next generation redesign of GOCM is needed.

One of the prime limitations of a parametric model is the insensitivity it has to detail design fea-



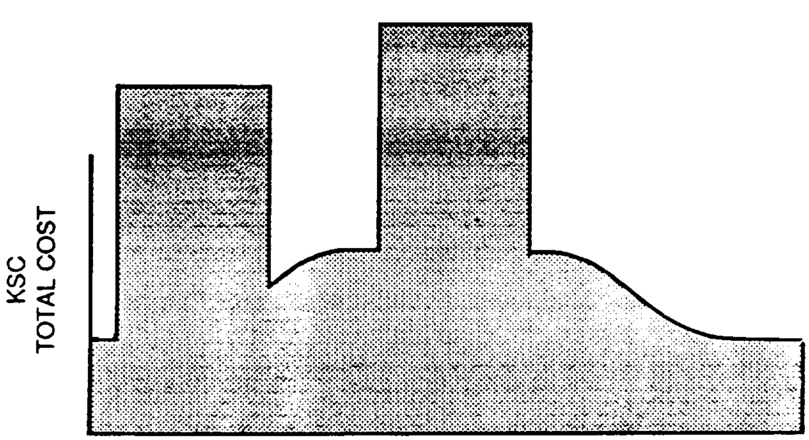
Mixed Fleet Operations Conceptual Cost at KSC.

- MIXED FLEET LRB FLIGHT HARDWARE AND GROUND PROCESSING SYSTEM DEVELOPMENT CONCURRENT WITH SRB OPERATION.
- TRANSITION LRB INITIAL OPERATIONS, TEST AND EVALUATION CONCURRENT WITH COMBINED LRB/SRB OPERATIONS.
- TRAINING TAKES PERSONNEL OUT OF THE CONCURRENT COMBINED OPERATIONS, NECESSITATING MORE PERSONNEL TO SUSTAIN OPERATIONS.
- ANOTHER TRANSITION COST ELEMENT IS DUPLICATE BOOSTER MANUFACTURER ON SITE REPRESENTATION DURING CONCURRENT COMBINED OPERATIONS.



KSC Cost Element Summary

- TWO NON-RECURRING (NR) COST ELEMENTS HAVE BEEN LEVEL FLOWED AND ADDED TO THE OPS COST.
- THE NR COST REPRESENTS NEW FACILITIES, MODIFICATIONS TO EXISTING FACILITIES, GSE, LSE, AND ACTIVATION COST.
- NOT SHOWN FOR CLARITY PURPOSES IS THE PROCESS PLANNING NR COST ELEMENT i.e.: OMI DEVELOPMENT.



KSC Conceptual Cost Total

- THE OPS COST AND NR COST SUMMED UP REPRESENT THE TOTAL KSC COST.

Figure 3.1.2-2. KSC Conceptual Cost.

tures which often are significant cost drivers. For instance, the nozzle placement and booster dimensions of the LRB when employed on the Shuttle can drive the program to require a new launch pad! The insensitivity of a parametric model limits ones ability to employ them in conducting post configuration trade studies. Again these limitations are not often as bad as they seem when tempered with good engineering judgment and the interactive use of the cost model. For instance, the trade study considering Pad replacement could be conducted outside GOCM using the CERs and cost data within GOCM. There may be little or no need for further model development for this one time trade study. But for repetitive trade studies, it is often advantageous to employ a more specialized module or model. This is especially true for very complex trade studies requiring great rigor and/or the use of iteration.

The LRBI Study confirmed the belief that the use of parametric models is greatly dependent on the phase of program study/design. That is, the mix of its cost generation techniques employed on a program varies with program maturity. Initially, during a Phase A conceptual evaluation and study, an all up parametric technique may be employed. Soon to follow, as the program advances in Phase A and/or transitions into Phase B, certain cost drivers and/or cost elements sensitive to design or planning decision will require examination in greater detail and the employment of engineering estimates (analogy). Select cost elements deemed to be very sensitive and significant may transition early and directly to detail estimates. Such elements may be crucial to trade studies or early budgetary planning. These type estimates will have to be conducted outside GOCM. Figure 3.1.2-3 graphically illustrates the typical mix of cost generation techniques employed for each study/design phase. It implies that the use of parametrics and parametric models decreases with program development and must interact with other techniques in varying ways throughout the development and operation phases of the program. This realization is important for two reasons. First, it places real limitations on the completeness and accuracy one should expect from a parametric model. Second, it brings to attention the desirability of having a family of cost generating tools each capable of interfacing with the other and all being interactive with the user.

3.1.3 Study and GOCM Development Approach

The data requirements to run GOCM are small and the data is easily acquired during a Phase A program. The LRBI Study experienced no difficulty in acquiring/developing the GOCM input data. The utility of this parametric model was vividly portrayed when it was applied to the LRB as evidenced by the early Phase A cost estimates made by LSOC.

Output format options and graphics flexibility were missing from the GOCM baseline. The output

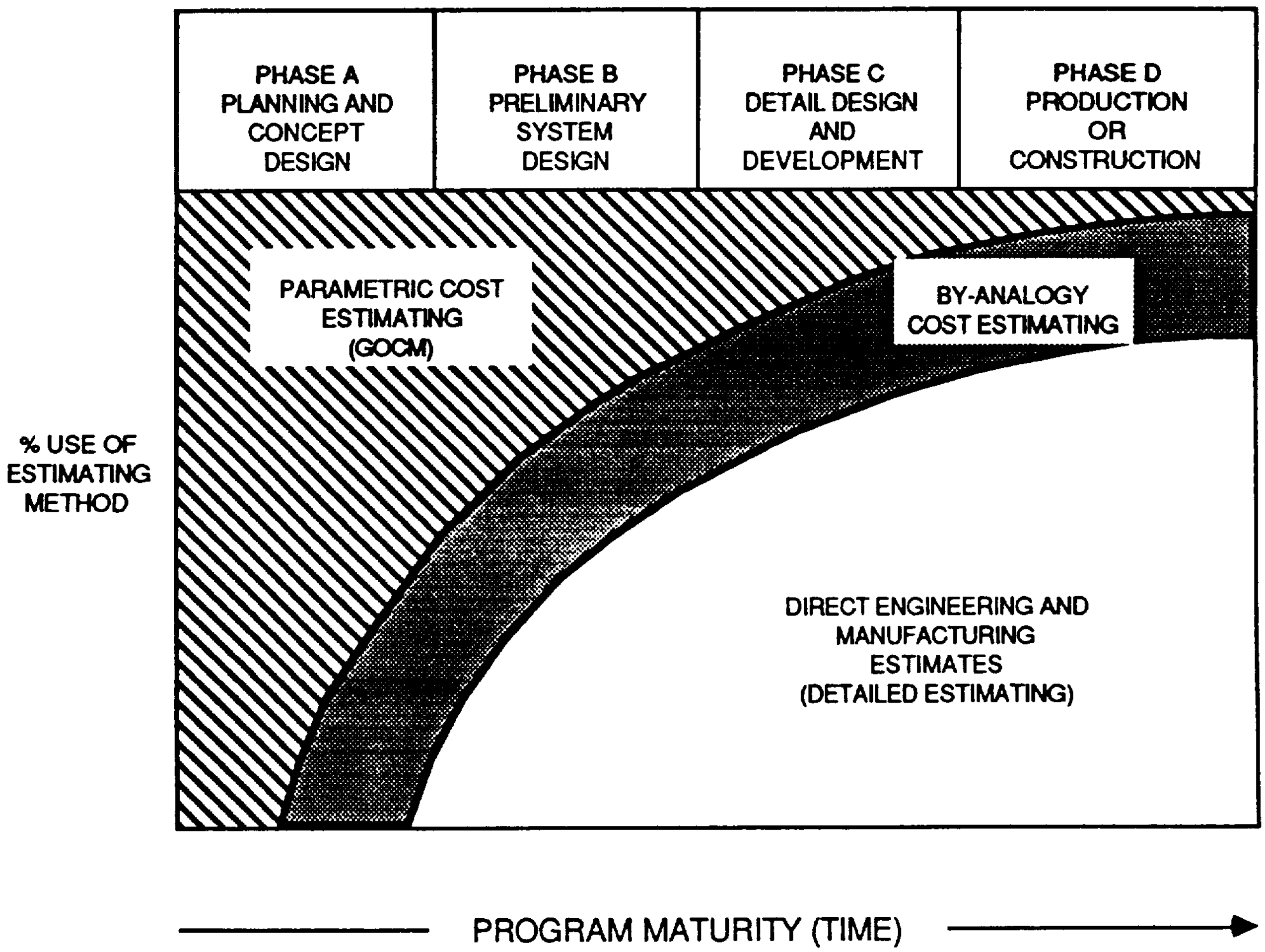


Figure 3.1.2-3. Figure Cost Estimating Methods Versus Program Maturity.

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to some users was confusing and unnecessarily large (nearly 35 pages). It became obvious that no single output report would be universally acceptable. Therefore it became desirable to have some output flexibility.

The value of GOCM and its strengths were quickly recognized by the study team. As a result our efforts transitioned early from evaluation to the enhancements of GOCM. A phased enhancement program was applied to GOCM (see Figure 3.1.3-1).

The baseline GOCM was given to the study group by NASA and from its evaluation two new model configurations have evolved. The first is called the enhanced. It preserves the baseline CERs while streamlining its execution. It is more user friendly and is expansion ready. The degree of user friendliness and expansion potential was limited by the use of the Symphony spreadsheet software which was inherited from the baseline configuration (see Paragraph 3.3). It is believed that GOCM has outgrown Symphony software in size and complexity.

The enhanced modified configuration of GOCM is the third and most recent version of GOCM. It provides the same operations as the enhanced version but no longer preserves the baseline CERs. The expansion feature was exploited in the development of new and/or modified CERs found necessary during the calibration effort, and in use. These are discussed in Paragragh 3.2.

The enhanced baseline evaluation for friendliness was performed using computer illiterates. These subjects were given the GOCM USER'S MANUAL and a functional computer. No preparation nor outside help was provided. Some subjects were observed while others were later interrogated. From this evaluation many lessons were learned and incorporated into the enhanced version. We looked for those user common difficulties which were within the software and hardware capability for rectification. This made GOCM more user friendly for the first time users, thereby expanding the utility of the model to a greater work force (see Paragraph 3.3).

Some of the user enhancements and example screens are found under Paragraph 3.3. It is believed that greater strides in achieving user friendliness could be made simultaneously with achieving greater costing rigor if new software and hardware were implemented in a follow on study.

3.1.4 Utility Evaluation

For nonmixed fleet estimates a reasonable level of merit is obtained for the ground processing costs at KSC for various flight hardware configurations. The enhanced GOCM provides cost projections per fiscal year in both an expeditious and easy manner and requires simple Phase A

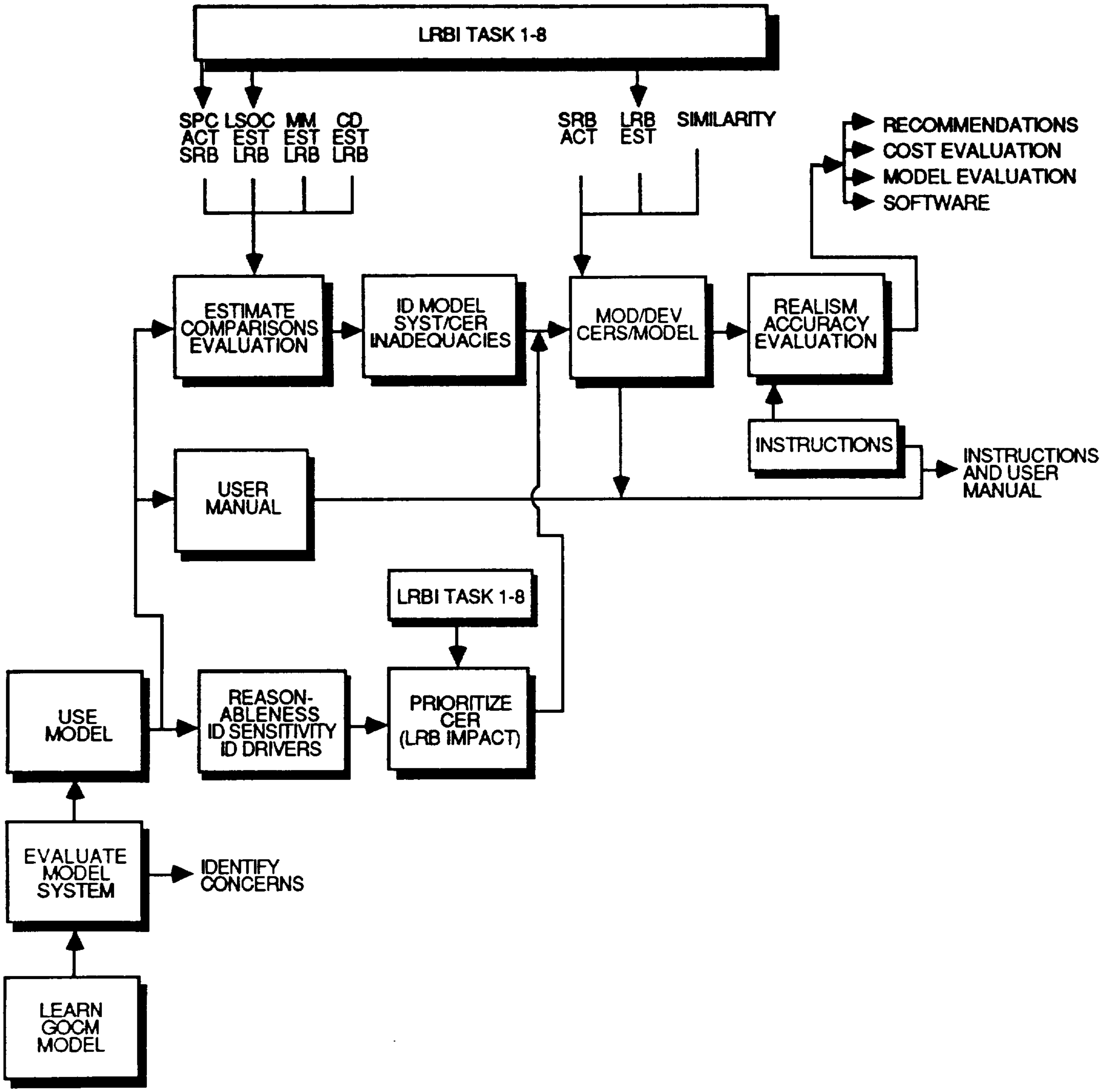


Figure 3.1.3-1. GOCM Study Plan.

conceptual data for input. Paragraph 3.5.2 lists some of the potential applications for the enhanced and/or enhanced modified GOCM.

GOCM projects only current or factored current KSC operations applied against various flight hardware configurations. If a new way of ground processing is envisioned, new or altered facility and ground processing CERs may be required. For instance, the ALS and Shuttle II configurations may require totally different type facilities to accomplish tasks similar to those accomplished elsewhere today. Flight hardware integration may be accomplished at the Pad. Therefore, an expansion ready/modifiable model is necessary. Within limits the enhanced and enhanced modified GOCM are expandable and modifiable. However, if the ALS were run in an unmodified version of GOCM you would be processing a new flight configuration by yesterdays processing, factored to represent tomorrow. This may be good for early comparison, but it would be poor for anything more than a rough estimate of future cost.

As mentioned earlier, GOCM can only perform macro trade studies regarding configuration types. The GOCM generated LRB costs were invariant to the LRB options. GOCM was sensitive only to gross changes in physical dimensions and not to the variations within design. Therefore, Phase-B trade studies concerning KSC ground processing will require engineering type cost modules and/or a logistics support cost model which is more sensitive to design variations.

3.1.5 Potential Modular Growth

A capability such as provided by GOCM is necessary for pre-Phase-A and Phase-A analysis which considers KSC ground operations. It is believed there will be a need in the future to perform these analysis, since all near term alternate and proposed Space Transportation Systems will either be compared against the Shuttle and/or be processed and launched at KSC/Eastern Test Range. Therefore, it is recommended that GOCM be further developed and maintained. Further development entails more than merely expanding the model. A more flexible and responsive approach to cost projection is envisioned. It would be based on a modular model which could evolve and span across the program phases.

The modular approach recognizes that no model, no matter how sophisticated and complex, can answer all questions completely. It is futile to pursue the development of such models. A great majority of the issues to be studied during the upcoming years could be handled in large part by versions (modified perhaps) of developed utilities already resident in GOCM. For instance, the traffic module in GOCM which handles the manifest by year can be employed independently of the CER type and their validity. These utlilities would form the framework for processing future selected modules. Each module would have its own CERs and instructions. For instance, the user might wish to compare the STS Shuttle with either an ALS or Shuttle II. From the GOCM system library a user would call up the most current versions of the STS Shuttle and ALS modules. There might be a dozen modules required to perform this study. The ALS or Shuttle II might require the use of many new type facilities. Previous studies would have been incorporated into the ALS and Shuttle II modules, so that when a comparison was needed in support of some program/management decision (such as the evaluation of a Mars mission utilizing LEO fabrication of a space vehicle), lessons and conclusions previously learned could easily be applied.

The module database and full time resident expertise would eventually be capable of assimilating peculiar modules from existing modules. Nonparametric study data could be selectively applied for specific studies in module form.

The modular approach would maintain configuration control of databases, CERs, methodologies, and utility libraries. More detail recommendations are provided in paragraph 3.5. Paragraph 3.3.2.1 and 3.3.2.2 address in detail some of the long-term and short-term software recommendations resulting from this study.

3.2 CALIBRATION

The study team saw the need to verify GOCM and the baseline GOCM CERs, and if necessary, to modify and add to them. This process was called calibration. Initially it was believed only the SRB portion of ground processing should be addressed. However, it soon became obvious that it was of value to address the entire Shuttle system if only in a cursory manner.

The calibration process was envisioned to primarily consist of collecting "actuals" by WBS, and rolling them up to the station sets and flight element level. This roll up is referred to "as putting the money in the proper bucket". The data collection was performed for the period of December 1985 through January 1986 and provides a data base for the verification of ground processing CERs.

The WBS is an extensive cost, labor and financial event data base. This data on past cost and events is an excellent source of data for the prediction of future costs. Future costs, however, may differ significantly from the costs of similar past activities. Frequently past costs must be adjusted to reflect probable changes resulting from procedure and hardware changes i.e. Post 51-L or LRB.

3.2.1 Scope

One of the difficulties in using the WBS accounting records is that some costs are recorded in a single category, even though they are in fact composed of discretely different costs. These cost categories often differ from those generated in the GOCM. Therefore, an allocation and filtering technique must be employed to regroup and roll up actual costs into GOCM cost categories.

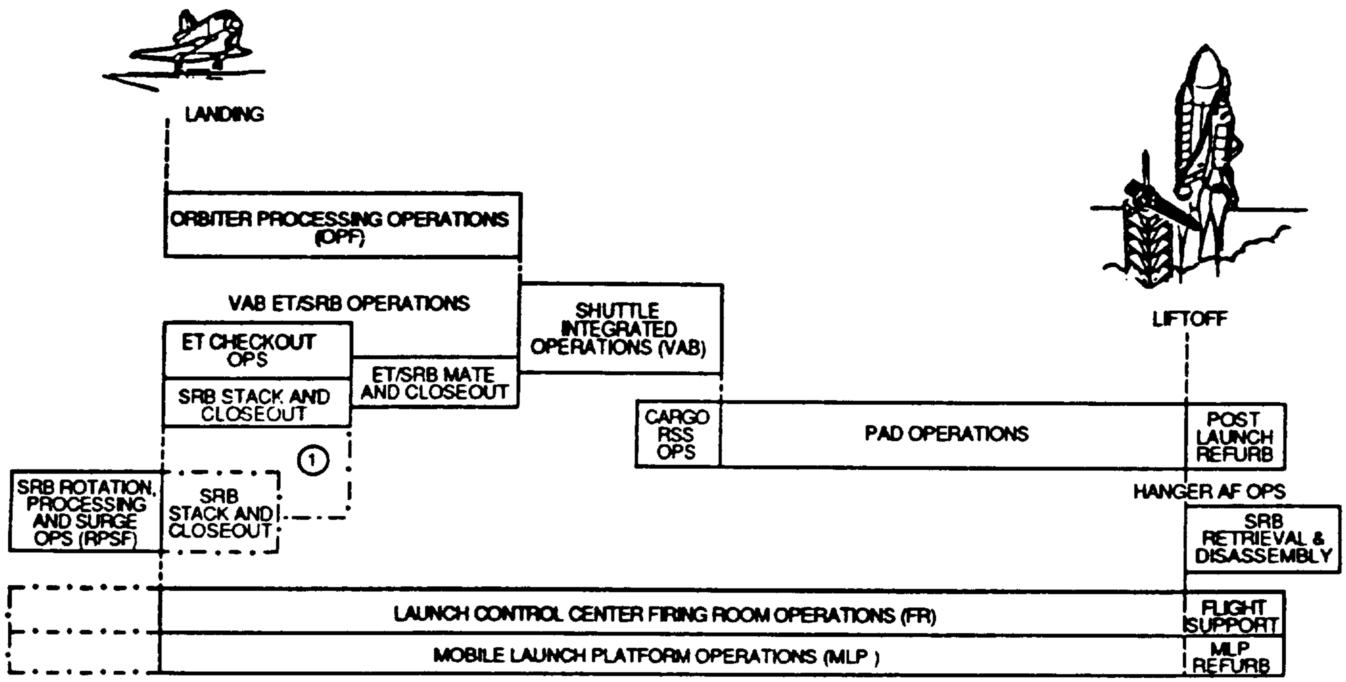
Each category in GOCM is correlated with one or more facilities which (for the Shuttle system) currently exist at KSC. The facilities are manloaded to achieve their design maxium output which is defined by the duration of each task performed within the facility. Each time the given launch rate exceeds a particular facility's capability, a new facility is added and manloaded. Therefore, the current in place STS facilities and their manloading represent a nearly fixed cost which can effect 1-12 launches before additional facilities and personnel are required. Within the nearly fixed cost of processing resides some variability. It is the employment and use of additional first shift personnel and the increased use of second and third shifts. The ground processing cost elements are also subject to three factors. They are technology, learning, and turnaround.

Current programs employ current (baseline) technology. Learning rate is selected by the user, (Paragraph 3.2.7). The baseline version of GOCM uses a cumulative Wright learning curve; which is described in Section 3.2.7. Turnaround is designated as Pre-51-L or Post-51-L ground processing time.

The ground processing portion of GOCM was originally generated based on the 1985 SPC WBS. For example, for the WBS dictionary call out 1.1.1, "Orbiter Operations", the total manhours charged against WBS 1.1.1 was divided by two to account for two OPF high bays. This number was divided by 3 to represent the number of people per bay per shift. The duration (or number of shifts) in a facility for each flow is easily derived from Shuttle Processing "as run data" Summary (NASA Kennedy Space Center SO-MPO).

The difficulty encountered in attempting to calibrate the GOCM CERs occurs when flight elements processing (charged) manhours are accumulated in less discrete categories.

SPC facility loading at Kennedy Space Center can in part be obtained from the 511 report which records cost/manhours by WBS and department code. The 1.1.1 WBS against the Orbiter can be assumed to apply primarily to the OPF. Other flight elements share facilities and professional judgment must be used to allocate their facility utilization. For example, the boosters use the RPSF and the VAB, as does the integration activity of mating the Orbiter, ET and boosters use



(1) SRB STACKING ON MLP AT EXPANDED RPSF - FACILITY

LEGEND:
——— CURRENT OPERATIONS
—•— PLANNED CHANGES

POST-51-L CHANGES TO GROUND PROCESSING	
POSITIVE	**NEGATIVE**
• SECOND PAD (IN PROCESS) • THIRD MLP (IN PROCESS) • IMPROVED SPARES LAY IN • MAJOR MODIFICATIONS COMPLETE TO GSE, LSE, FLIGHT HARDWARE • SRB STACKING ON MLP AT EXPANDED RPSF (FUTURE) • NEW OPF (FUTURE)	• EXPANDED WORK, REQUIREMENTS AND PAPER WORK • PERIODIC INSPECTIONS • AGING GSE

Figure 3.2-1. Present and Future STS/SRB Ground Processing Operations

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the VAB. Most of the ET work is also performed at the VAB (see Figure 3.2-1). The WBS integration category is very broad and stretches from rollout of the Orbiter from the OPF to lift off at the Pad!

Hence, without complete documentation as to how the initial allocation was conducted in the formulation of GOCM, there is no way to replicate or verify the empirically derived CERs used in GOCM for accuracy and realism. It is further realized that the GOCM CERs contain non-SPC cost elements, i.e. NASA, BOC, utilities, etc.... This further complicates the verification process.

To verify anything more than the top gross projections performed by GOCM is an academic exercise at best, since the way we performed ground processing during Pre 51-L is vastly different from the near term Post 51-L, and long range projected Post 51-L ground processing activities. Post 51-L activity has seen a growth in the OMRSD, and an intense conservative approach to ground processing incorporated into the OMIs. Ground processing has become more complex, formal, and a larger activity (see Figure 3.2-2).

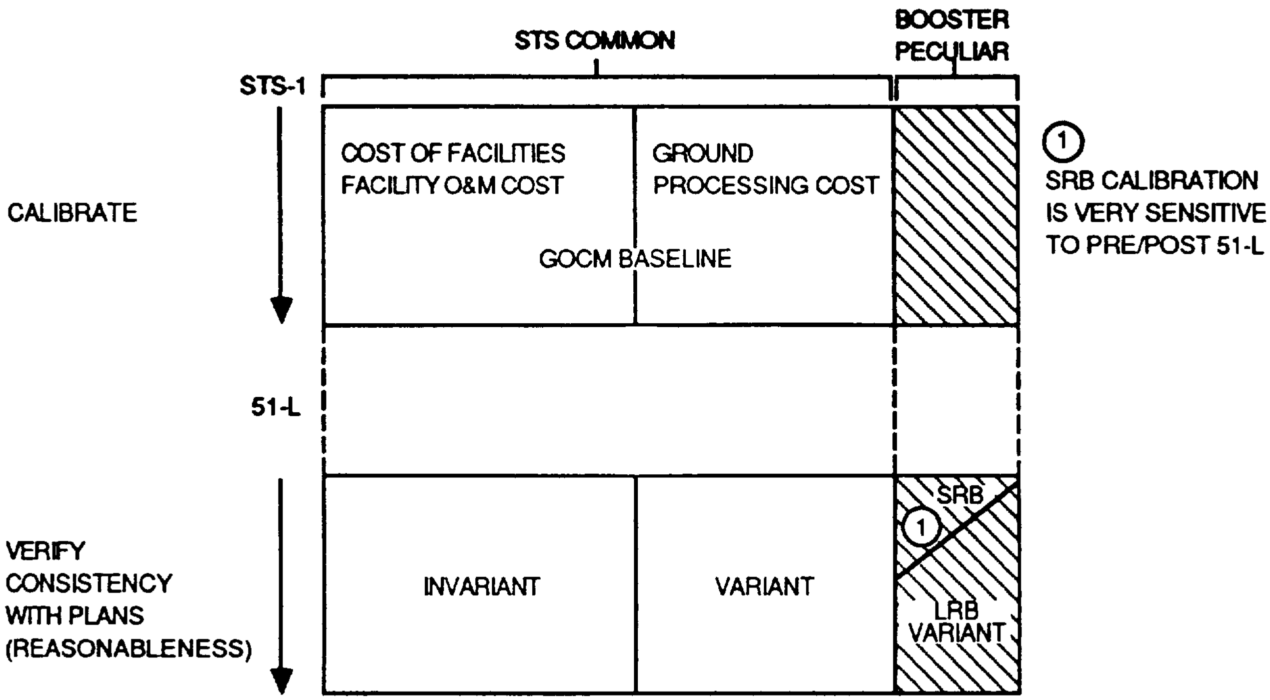
Changes to facilities, which will affect the nature of ground processing are planned (see Figure 3.2.-1). For instance, an added OPF bay and the conversion of the OMRF to become a third OPF bay are planned. The RPSF is planned to have an addition which will be utilized to perform both the SRB stacking, and its mating to the MLP. This will relieve the VAB high bays, implying a greater yearly VAB processing rate. These type changes to ground processing and the ground processing facilities will need incorporation into GOCM. It is for these reasons that only a cursory calibration of the gross numbers was performed on GOCM. Even this was difficult (see Figure 3.2-3).

3.2.2 Realism And Completeness

3.2.2.1 Realism

The concept of realism, as applied herein, describes the quality of a model which accounts for and predicts the behavior of the appropriate cost generation mechanisms found in ground processing such that, when properly calibrated, it can execute realistic cost estimates. This concept recognizes relationships within ground processing which are dependent on the flight program performance that generate cost. A good model will replicate these relationships (mechanisms) in its cost generation activities. The study team has found GOCM to be realistic on the macro level.

GOCM while offering a high degree of realism regarding processing and facilities at KSC, does



ONLY COST OF FACILITIES AND FACILITY O&M COST FOR THE STS COMMON/BOOSTER PECULIAR, CAN BE CALIBRATED. PROCESSING COSTS CAN NOT BE CALIBRATED UNTIL MORE HISTORICAL DATA IS GENERATED. THEREFORE WE CAN ONLY VERIFY CONSISTENCY WITH PLANS AND THE REASONABLENESS OF COST PROJECTIONS.

Figure 3.2-2. Relationship Between Calibration and Verification for Various Cost Elements.

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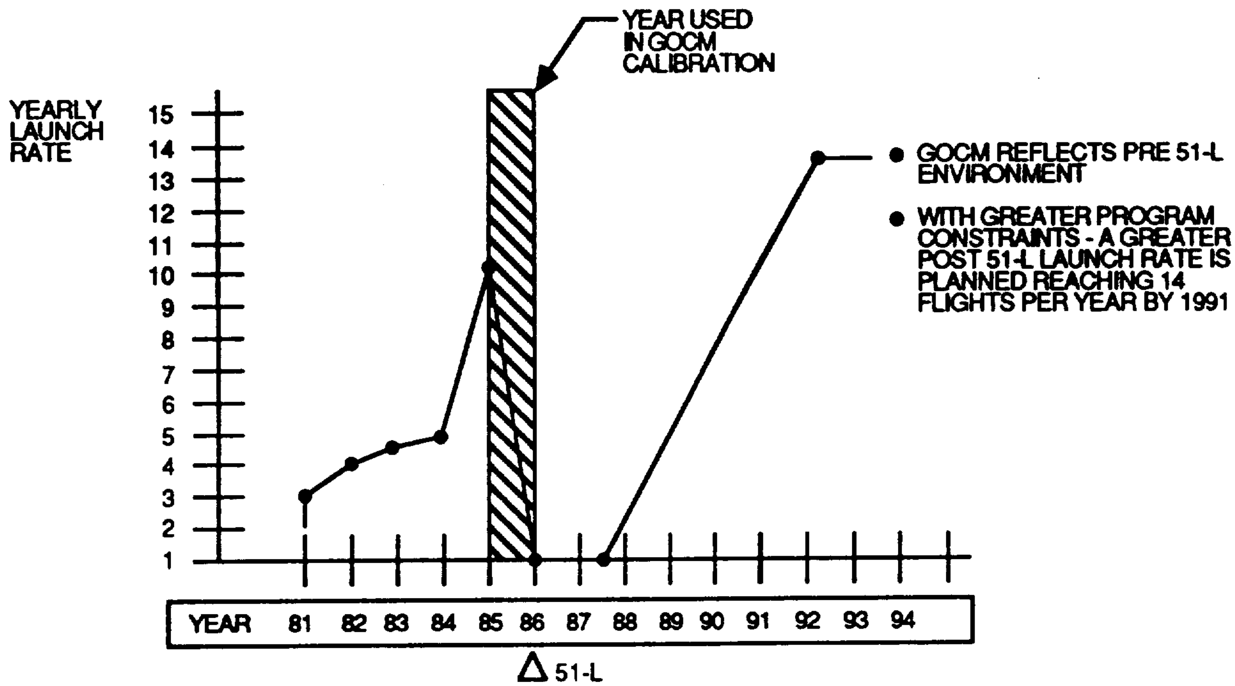


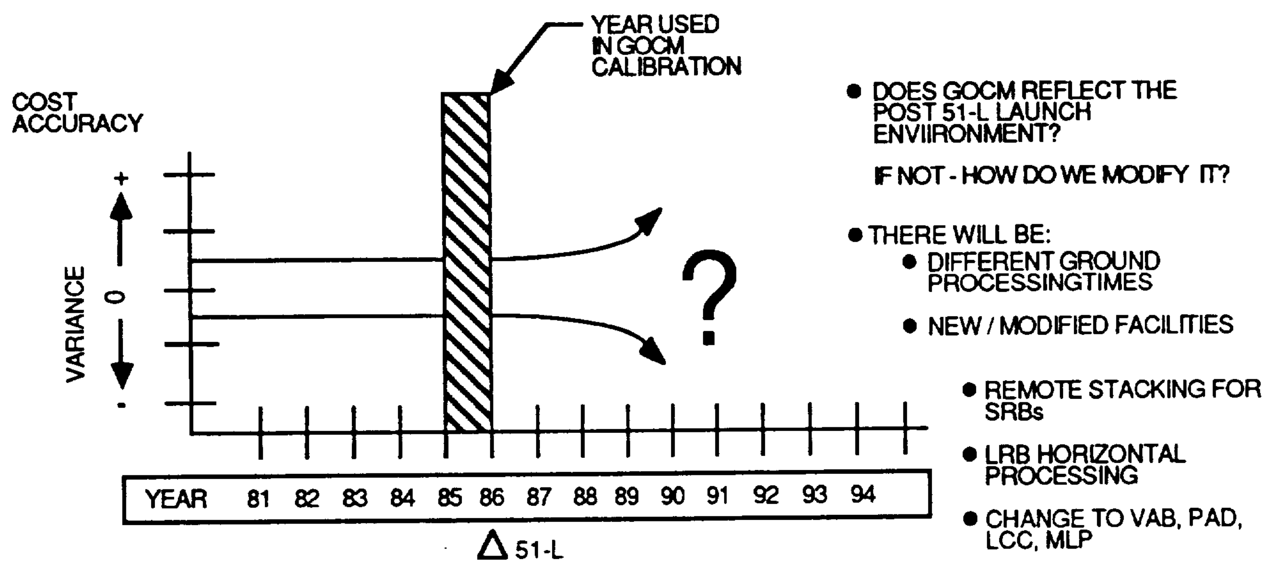


Figure 3.2-3. GOCM Calibration Concerns.

not offer budgeting and start-up realism. All additional facility requirements and cost of facilities instantly appear the year they are needed. These costs should be flowed back to represent design, construction and activation budget requirements during the years leading up to initial facility utilization.

Another important cost element that is present in GOCM, but not visible, is the transition cost. For instance, personnel in training to process the new booster configuration will not be available to process the current booster configuration. Similarly the duplication in booster manufacture on site management/personnel is missing. While these transitional costs may be small in comparison with the overall Life Cycle Cost, they are significant for the transition budget years.

Some cost analyst might think the transitional costs are considered in the learning curve. This is not the case. Transition costs only occur during the start-up through replacement phase of the LRB program. Learning theory applies over a greater period and addresses the recurring tasks. Transition is a peculiar non-recurring task.

3.2.2.2 Completeness

The degree of completeness inherent to a cost model is dependent on the level of observation or sensitivity. GOCM is a macro level model. At the macro level GOCM is considered very complete. GOCM recognizes, but is not limited to, the following:

- Overall system flight hardware configuration
- Launch rate
- Facility needs and new facility cost
- O & M facility costs
- Inflation
- Technology impacts
- Turn around (pre/post 51-L)
- Learning Curves
- Shifts, days, holidays, etc...
- KSC personnel staffing practices

At the next indenture or level of resolution GOCM becomes very incomplete. It does not recognize the following:

- **Flight hardware achieved reliability, maintainability, and supportability (RM&S)**
- **RM&S sensitivity**
- **Sensitivity to hardware costs**
- **Sensitivity to flight and ground subsystem configuration**
- **Management coordination**
- **Paper processing (procedures)**
- Logistics delays, i.e. spares, GSE availability

While GOCM is complete in its representation of KSC ground processing and offers a reasonably complete and moderately accurate cost projection, its usefulness is limited in engineering studies by its insensitivities to design and processing subtlies. GOCM's lack of visibility to design features has already been documented in Paragraph 3.1.2. GOCM's insensitivity to processing delay mechanisms doesn't allow the creation of success criteria and measures of merit for trade studies aimed at streamlining ground processing.

Ground processing delays are more costly than is generally perceived. The most commonly used measure of merit is dollars per pound of payload. MSFC, JSC, and KSC have a fixed manpower loading which can be amortized by the number of launches, which can be related to payload capacity. The greater the launch rate the lower the cost per payload pound. Schedule delays therefore directly translate to fewer flights per year which means greater cost per payload pound. This was thoroughly analyzed and discussed in Volume II, Section 4.
While GOCM empirically accounts for launch schedule realism, it does not provide sensitivity to the causes for launch delay. This level of sensitivity can only be obtained in a Logistic Support Cost (LSC) type model, which considers reliability, maintainability, logistics and other processing influences.

Figure 3.2.2-1 shows a strong correlation between the number of problem reports (PRs) generated per flow and the duration of the flow. PRs are generated in response to the need to accomplish unplanned work, (corrective maintenance, Paragraph 3.2.7.3) which translates into a delay. While PRs are not responsible for delays, the quantity of PRs is an indication of the delay duration. The causes which generate PRs are primarily discovered noncompliances and hardware failures. Noncompliance discrepancies are usually viewed as quality problems and failures are viewed as reliability problems. However, both are greatly affected by the ground processing friendliness of the hardware design and support process. GOCM is insensitive to these considerations and can not provide the necessary sensitivity to evaluate the impact and costs of ground processing friendliness enhancements. See Paragraph 3.2.7 for additional explanation of the role R&M plays in the generation of KSC ground processing cost.

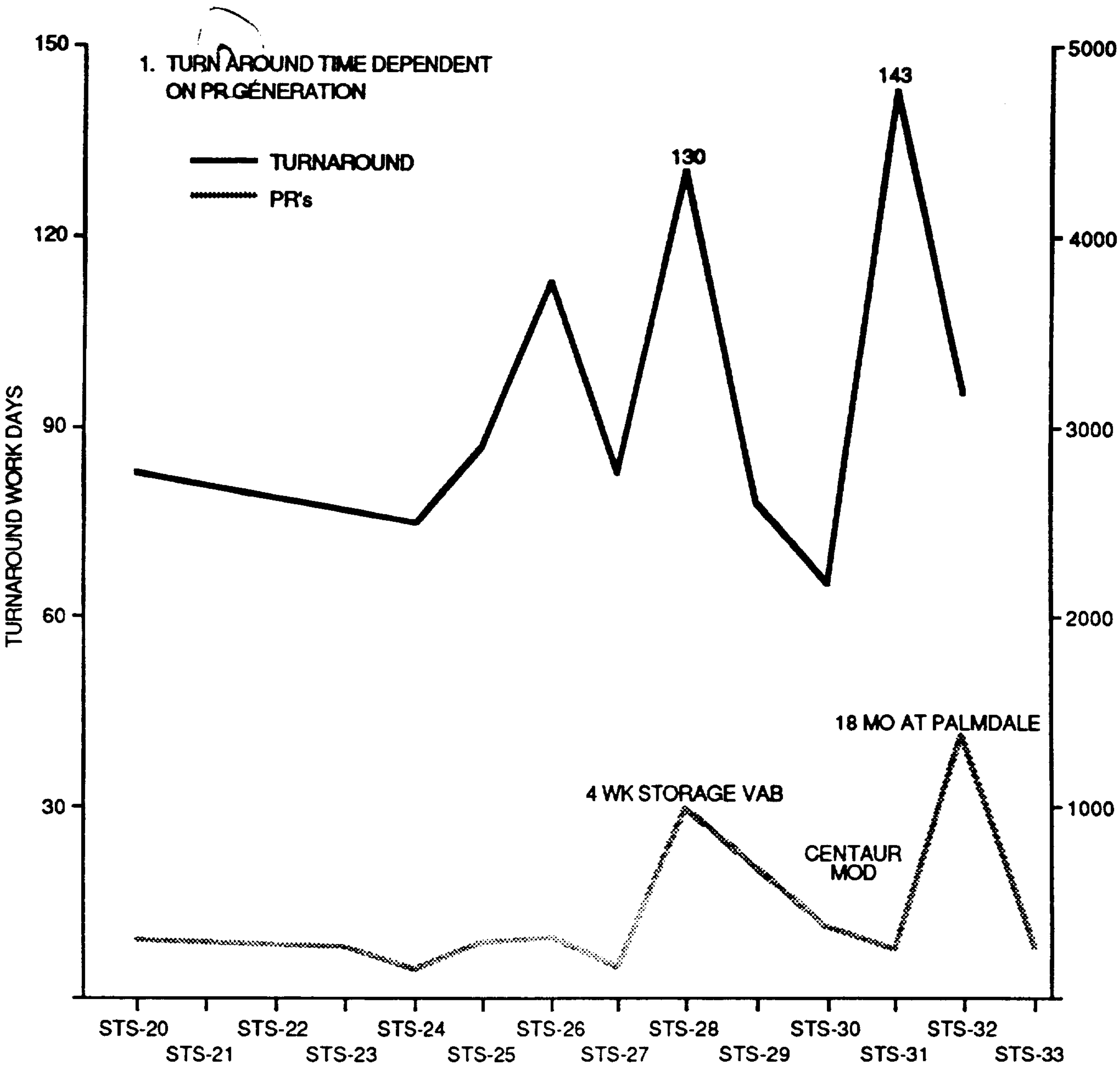


Figure 3.2.2-1. Relationship Between Number Problem Reports and Turnaround Time.

3.2.3 Gross Cost Evaluation

3.2.3.1 1985 Budget (WBS) vs GOCM Comparison

GOCM's estimate of program launch cost incorporates SPC, non SPC, Civil Service, and utility costs. The POP 85 projects these costs and could be used as a yardstick to evaluate the GOCM gross cost estimates. However, this would only determine whether GOCM captured the projected costs for the year its formulation was based on. This would not verify GOCMs accuracy in the extrapolation of future costs and has not addressed actual dollars spent. The LSOC 533 Report capture only the SPC (WBS cost element expenditures) and therefore provides only a portion of the total STS costs at KSC. The use of pre-1985 and post-1985 POPs is not considered valid since the earlier years experienced launch rates too low to verify facility potential processing capabilities and the later years experienced zero launches. Hence, 1985 is the only viable year available to calibrate GOCM (see Figure 3.2.3.1-1).

The gross cost evaluation of GOCM in the year 1985 are presented in Figure 3.2.3.1-2. It appears GOCM was 80% accurate. This is excellent for a preconceptual/conceptual parametric cost

model. Further evaluation and calibration will require the generation of a new historical data base.

3.2.3.2 GOCM Evaluation

The 1985 evaluation did not accomplish the verification of added facilities costs. Nor did it verify the facilities potential processing capability with regard to flows per year. Since future STS applications of GOCM will address the Post 51-L environment, and will probably require the consideration of employing new facilities, the evaluation of GOCM performed above is considered incomplete.

The continued evaluation of GOCM will be addressed in Section 3.2.4, where select CERs and/or results derived from them are compared with other available source data. This should provide a greater degree of calibration, but is considered incomplete.

The important distinction between realism and accuracy must be made, for it precisely applies to the evaluation of GOCM. Based on investigation and use, GOCM realistically portrays the KSC ground processing activity. GOCM identifies macro cost elements and activities and realistically

AUGUST 06, 1988

FLT	DESIGNATION	VEHICLE	LAUNCH	PAD	MLP	LAND	SITE
1	STS-1	OV-102	04-12-81	A	1	04-14-81	EAFB
2	STS-2	OV-102	11-12-81	A	1	11-14-81	EAFB
3	STS-3	OV-102	03-22-82	A	1	03-30-82	WSMR
4	STS-4	OV-102	06-27-82	A	1	07-04-82	EAFB
5	STS-5	OV-102	11-11-82	A	1	11-16-82	EAFB
6	STS-6	OV-099	04-04-83	A	2	04-09-83	EAFB
7	STS-7	OV-099	06-18-83	A	1	06-24-83	EAFB
8	STS-8	OV-099	09-13-83	A	1	09-19-83	EAFB
9	STS-9	OV-102	11-28-83	A	1	12-08-83	EAFB
10	STS-11 / 41-B	OV-099	02-03-84	A	2	02-11-84	KSC
11	STS-13 / 41-C	OV-099	04-06-84	A	1	04-13-84	EAFB
12	STS-14 / 41-D	OV-103	08-30-84	A	2	09-05-84	EAFB
13	STS-17 / 41-G	OV-099	10-05-84	A	1	10-13-84	KSC
14	STS-19 / 51-A	OV-103	11-08-84	A	2	11-16-84	KSC
15	STS-20 / 51-C	OV-103	01-24-85	A	1	01-27-85	KSC
16	STS-23 / 51-D	OV-103	04-12-85	A	1	04-19-85	KSC
17	STS-24/ 51-B	OV-099	04-29-85	A	2	05-06-85	EAFB
18	STS-25 / 51-G	OV-103	06-17-85	A	1	06-24-85	EAFB
19	STS-26 / 51-F	OV-099	07-29-85	A	2	08-06-85	EAFB
20	STS-27 / 51-I	OV-103	08-27-85	A	1	09-03-85	EAFB
21	STS-28 / 51-J	OV-104	10-03-85	A	2	10-07-85	EAFB
22	STS-30 / 61-A	OV-099	10-30-85	A	1	11-06-85	EAFB
23	STS-31 / 61-B	OV-104	11-26-85	A	2	12-03-85	EAFB
24	STS-32 / 61-C	OV-102	01-12-86	A	1	01-18-86	EAFB
25	STS-33 / 51-L	OV-099	01-28-86	A	2		

FY85 8 FLTS (flights 13–20)

FY86 5 FLTS (flights 21–25)

CY85 9 FLTS (flights 15–23)

Figure 3.2.3.1-1. LRBI STS Flight History

FIXED PROGRAM COST INPUT

PROGRAM FIXED INPUT COSTS: ①

BOC	=	652 PEOPLE
CIVIL SERVICE	=	754 PEOPLE
PAYLOAD OPERATIONS	=	476 PEOPLE
PROPELLANTS	=	11.5M ($)

100% LEARNING APPLIED IN GOCM ESTIMATES

THE RESULTS OF GROUND PROCESSING LEARNING WERE NOT REALIZED IN MANPOWER REDUCTIONS. RATHER, THE RESOURCE SAVINGS WERE APPLIED ELSEWHERE. FOR INSTANCE: PAD AND OTHER FACILITY NON-RECURRING ACTIVATION. THE EFFECTS OF LEARNING DID MANIFEST THEMSELVES IN ACHIEVING A SHORTER TURNAROUND WHICH EQUATES TO A GREATER LAUNCH RATE CAPABILITY.

SINCE GOCM CAN ONLY APPLY LEARNING TO BOTH TURNAROUND AND MANPOWER, OR ONLY MANPOWER, WE ELECTED TO APPLY NO LEARNING TO THE CALIBRATION PROCESS.

COST SUMMARY

GOCM	KSC
$ 442M	$ 549M ②
	GOCM - 19% VARIANCE

① ② ACTUAL COST IS PROVIDED IN "CONGRESSIONAL EXERCISE ON SHUTTLE OPERATIONS COST TRENDS" AC - REQ, NOV. 15, 1985.

Figure 3.2.3.1-2. GOCM Estimate versus Actual Cost Comparison for FY85.

relates them to launch operations. GOCM is realistic. GOCM appears to be accurate. It is possible for a model to be realistic and inaccurate! The beauty of GOCM is it could be made to realistically process a host of next generation CERs. This is GOCMs strength.

3.2.4 Ground Processing STS LRB/SRB CER Verification

It is important to the LRBI study to compare the POST 51-L GOCM CERs with the Shuttle Operations Mission Planning Office processing projections and with the LRBI projections. Comparison of processing shifts is provided in Figure 3.2.4-1 for the Post 51-L environment. While there seems to be points of great variance, the overall costs sensitivity to the processing variance is modest. For instance, the VAB variance between GOCM and LRBI represents approximately $600,000 dollars for 14 launches per year. This represents approximately .12% of the total program yearly cost at KSC.

3.2.5 Facility Cost Driver Verification

The facility costs are invariant to turnaround, and technology. The original facility cost model has more documentation than the original processing model. However, the opportunity to verify the CERs is not available, since much of the source data is no longer available.

Facilities are a very significant cost and schedule driver, and verifying the accuracy of the GOCM CERs for select facilities is important. A comparison of facility cost generated by GOCM with cost independently developed in the LRBI was possible only for the MLP (the only new LRBI facility in the GOCM repitoire). The two costs were within a few percent of each other.

3.2.6 Transition

There has never been a transition of the type and magnitude envisioned to occur with the LRB introduction in NASA history. There is little experience applicable to transition planning, development of transition cost and transition management. We can only approximate the cost by factoring past experience (i.e. change from Saturn V to Shuttle at KSC) and using professional judgement.

GOCM treats startup (Facility & Ground Processing) expenditure growths by averaging and smoothing the changes over a two year period. This in effect generates an extra buffer for transistioning on the growth side. GOCM smoothes transient expenditures.

	ELEMENT/FACILITY	EFFECTIVITY	SECOND OPERATIONAL YEAR		WORKING SHIFT
KSC PLANNED	ORBITER SRB	OPF	112 POWER ON 56 POWER OFF 168 POWER	(56)	7/3
		VAB	18	(6)	7/3
		PAD	3	(21)	6/3
GOCM ①	ORBITER SRB	OPF	120	(40)	7/3
		VAB	36	(12) ②	7/3
		PAD	42	(14)	6/3
	ORBITER LRB	OPF	120	(40)	7/3
		VAB	21	(7)	7/3
		PAD	42	(14)	6/3
LRBI	ORBITER LRB	OPF			7/3
		VAB		(20)	7/3
		PAD		(20)	6/3

THE VARIANCE BETWEEN THE CURRENT PLANNING FACTORS FOR POST 51-L, AND THE GOCM POST 51-L PROJECTED FACTORS FOR THE STS/SRB ARE SIGNIFICANT. THE GOCM LRB IS MORE CLOSELY ALIGNED WITH THE PLANNED SRB.

① GOCM BASELINE CONFIGURATION, UTILIZING POST 51-L TURNAROUND, BASELINE TECHNOLOGY AND NO LEARNING/GROUND PROCESSING CURVES.

② STACKING ACCOMPLISHED IN PARALLEL (24 SHIFTS).

Figure 3.2.4-1. Ground Processing Shift Comparison.

The LRB growth should accumulate a substantial cushion in GOCM during the transition. Figure 3.2.6-1 conceptually illustrates these effects. It is felt the GOCM transition costs are high. However, a smooth efficient transition is not expected. The transition period is subject to great cost, schedule and technical risk. It is therefore considered prudent to cover these risks with a conservative (high) estimate. The GOCM approach (bow wave modeling) is as good as any. It applies 1/2 the years additional expenditure to the prior year. Decreases in expenditures, however occurs in real time. Therefore, SRB phase-out should see a real time decrease in personnel costs while LRB phase-in will see a one-half plus delta buildup one year before the needed growth. This is transition. Either one-half of the equivalent additonal personnel are in training or they are performing duplicate duties on an alternate basis.

3.2.7 Cost Reduction Curves

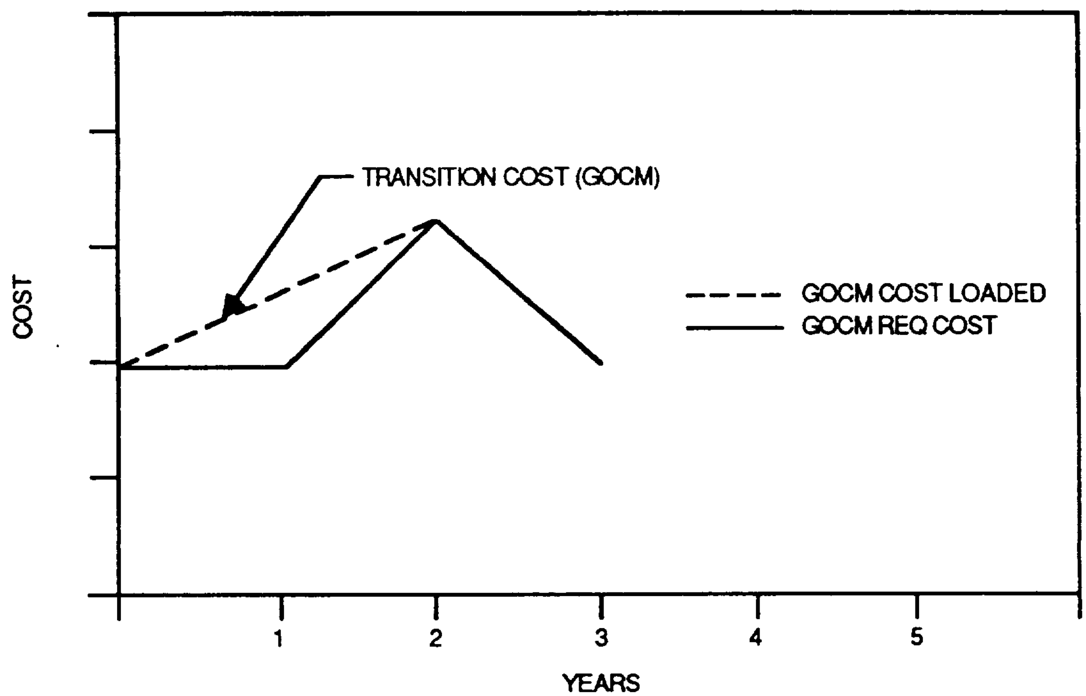
The baseline configuration of GOCM employs a typical manufacturing learning curve feature. Learning curves and growth curves are addressed under the concept of cost reduction curves, since they both vary cost as a function of cumulative launches. Learning curves and growth curves are treated separately for discussion purposes, but are applied within a composite curve which also contains modification work and other activities. The composite curve is called the ground processing curve.

3.2.7.1 Reliability and Maintainability Growth Curves

It is common for new products to be less reliable during early development and production than later in the program when improvements have been incorporated into the program as a result of failures observed. This was first analyzed by J. T. Duane. He observed that the cumulative mean time between failure (MTBF) plotted against total time on log-log paper gave a straight line. The slope gave an indication of reliability growth.

The Duane method can be employed to assess the amount of time required to attain a target MTBF (contractual requirement) during the test phase. This assessment is typically presented as a reliability growth curve.

Achieved reliability is important to ground processing planning. The Orbiter, for instance, experiences many failures during ground processing. Systems are routinely powered up to support modification check-outs, system integrity checks, and to support ground operations. Failures occurring on the ground will result in unplanned corrective maintenance events, which will burden the ground processing activity, and frequently cause delays. Additional ground failure may be



GOCM LOADS A REQUIRED INCREASE EXPENDITURE BY TAKING ONE-HALF THE CHANGE (DELTA) AND APPLYING IT ONE YEAR EARLIER.

IT IS BELIEVED THIS COVERS TRANSITION.

Figure 3.2.6-1. Simplification of GOCM Averaging and Smoothing Applied to Transition Costs.

induced by scheduled ground processing activities. It is for these reasons the ground processing activity is concerned with the degree of achieved reliability and maintainability (R&M) prior to the first manned launch and the resulting degree of subsequent growth there after.

For the LRB program, the degree of achieved R&M growth is dependent on the magnitude of R&M incorporated into the initial design and the duration and intensity of the follow through during initial operations test and evaluation (IOT&E). Follow through of initially realized R&M performance is only achieved through contractual implementation and institutionalization (during IOT&E). This requires rigorous quantitative contractual R&M requirements to be imposed on the prime developing and support contractor as a function of cumulative launches. In other words, R&M performance is contractually defined by use of a growth curve.

The important concept underlying the use of growth curves in projecting great cost enhancements over time is to realistically ascertain whether the contracted and institutional mechanisms are in place or will be employed for the realization of R&M growth.

3.2.7.2 Learning Curves

The learning curve is a graphical or analytical representation of the anticipated reduction in required input resources as the production process is repeated. Empirical evidence supporting the existence of this learning phenomena has been extensively documented.

The most widely used technique to generate learning curves is the one developed by Dr. Wright for use in the aircraft production industry. This technique has found broad use in the aircraft industry and in the governmental agencies responsible for military procurements. However, while the existence of learning curves is observed in many other repetitive processes, the technique for the generation of learning curves and their application is the subject of much debate.

The model Wright formulated was:

$$y_i = a(i)^{-b}$$

where i is the production count beginning with the first unit

a - is the labor hours required for the first unit

b - is the measure of the rate of reduction

y - is the i th unit labor hours

Typically this is translated into the following form:

$\ln y = \ln A - b \ln i$

Where b is derived from early experience with:

$$b = \frac{\ln A - \ln y}{\ln i}$$

3.2.7.3 Cost Reduction Curves for Ground Processing

Great difficulty is encountered in the application of the learning theory and the growth theory to the STS ground processing. Both theories are based on task impact reduction for repetitive activities, and do not consider non-repetitive (unique) tasks or delays. A significant portion of the ground processing activity is the modification of flight hardware, which is a non-repetitive task. The modification activity introduces schedule delay due to the planned extra work and schedule delay due to the unscheduled corrective maintenance resulting from the planned extra work (induced, and processing operating failure). The frequent Shuttle modifications and their associated unscheduled maintenance introduces significant delays to ground processing which is not normally addressed by the learning and growth curve theory.

These processing delays have many contributing elements. A few are listed below:

- Logistics delays due to budget short falls
- Management problems
- Modification requirements
- Quality procedures
- Other, payload, etc...

There is an underlying belief by many people that there are cost curve mechanisms in effect related to user experience or accumulative launches. In projecting future KSC costs, some estimators have employed the aircraft industry manufacturing growth rate of 85%, which greatly affects the overall life cycle ground processing costs. Investigation of the KSC ground processing activity reveals that the 85% learning curve does not apply to ground processing! However, further investigation does show an empirical trend regarding Shuttle turnaround, which can be handled in a Wright fashion. We call this a ground processing curve.

3.2.7.4 Ground Processing Curve Assimilation

The best data available for developing ground processing curves appears to be the processing times for various missions (see Figure 3.2.7.4-1). Even they are not pure and require careful evaluation, and only represent 24 ground processing flows. However, some interesting curves emerge upon careful investigation.

There is a trend regarding each successive Orbiter delivery to KSC and the delay experienced in their first flight processing. It quickly decreases (see Figures 3.2.7.4-2 and 3.2.7.4-3). It appears lessons learned in early processing delays have been incorporated in follow-on production. The early Orbiters have experience after delivery manufacturing which was performed at KSC. This appears to be quickly diminishing with each successive Orbiter delivery.

The cost reduction curves for the LRB should differ from the Shuttle derived curves. The LRB is not reusable. However, it could experience growth and early field modifications at KSC and this would burden the initial ground operations process. If a rigorous contractual R&M requirement is levied up front during development, and follow-on development is institutionalized within ground processing, then a more gradual curve would be expected.

The overall empirical STS ground processing curve is presented in Figure 3.2.7.4-4. Applying learning curve methodology (Wright) graphically, and varying the rate of reduction (learning), an excellent fit was obtained on the computer. The rate of reduction was 59% (b = .755). This is in close agreement with another curve developed earlier and independently by SPC subcontractor, PAN-AM. They derived a 60% (b = .725) curve.

The STS learning should be small since the OMIs for ground processing should be extensively preplanned and frozen before initial operations. R&M growth and learning should also be small if the program strives to achieve high up front R&M performance requirements and if the hardware design and support process is made processing friendly. Hence, it is believed (if the above is true) that the STS should experience a 90% cost reduction curve.

Upon reevaluation of the historical ground processing data, a different set of curves can be derived which bears out the above belief in a small rate curve (90%). Figure 3.2.7.4-4 is believed to exhibit two distinct mechanisms. There are new Orbiter introductions into the fleet which perturb ground processing and the recurring ground operations curve. If the four perturbations are curve fitted (alone) a 70% curve is derived. This curve is called the transitory Orbiter introduction curve. The remaining is the ground processing performance curve. If the highest and lowest

SEQ. NO.	STS NO.	MISSION NO.	ORB FLT NO.	LAUNCH DATE	LANDING DATE	WORKDAYS IN:			
						OPF	VAB	PAD	TOTAL
1	1		102-1	04-12-81	04-14-81	532	33	104	668
2	2		102-2	11-12-81	11-14-81	99	18	70	187
3	3		102-3	03-22-82	03-30-82	55	12	30	97
4	4		102-4	06-27-82	07-04-82	41	07	29	77
5	5	31-A	102-5	11-11-82	11-16-82	48	09	45	102
6	6	31-B	099-1	04-04-83	04-09-83	123	06	115	244
7	7	31-C	099-2	06-18-83	06-24-83	34	05	21	60
8	8	31-D	099-3	08-30-83	09-05-83	26	04	25	55
9	9	41-A	102-6	11-28-83	12-08-83	822	123	342	128
10	11	41-B	099-4	02-03-84	02-11-84	52	06	22	80
11	13	41-C	099-5	04-06-84	04-13-84	31	04	18	53
12	14	41-D	103-1	08-30-84	09-05-84	1232	153	722	210
13	17	41-G(F)	099-6	10-05-84	10-13-84	53	05	22	80
14	19	51-A	103-2	11-08-84	11-16-84	34	05	17	56
15	20	51-C	103-3	01-24-85	01-27-85	31	05	20	56
C/3-1	(22)	(51-E)	099	(03-07-85)		57	05	14(6)	(82)
16	23	51-D(D')	103-4	04-12-85	04-19-85	53'	05	15	73
17	24	51-B	099-7	04-29-85	05-06-85	31	04	15	50
18	25	51-G	103-5	06-17-85	06-24-85	37	07	14	58
19	26	51-F	099-8	07-29-85	08-06-85	39	05	31	75
20	27	51-I	103-6	08-27-85	09-03-85	27	07	22	56
21	28	51-J	104-1	10-03-85	10-07-85	84	14	34	132
22	30	61-A	099-9	10-30-85	11-06-85	35	04	14	53
23	31	61-B	104-2	11-26-85	12-03-85	27	04	15	46
				COMPOSITE EXPERIENCE MINIMUM MODIFICATIONS		26	04	14	44

Figure 3.2.7.4-1. Turnaround Experience.

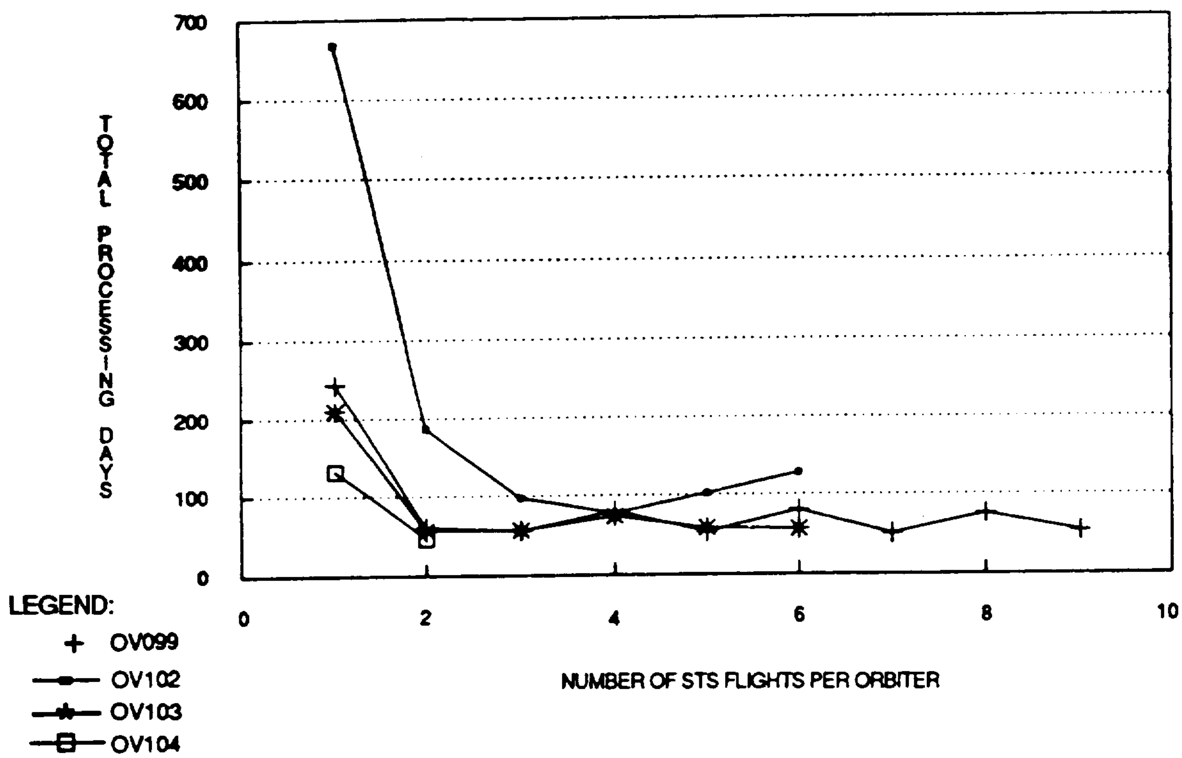


Figure 3.2.7.4-2. Processing Times by Orbiter by Flight.

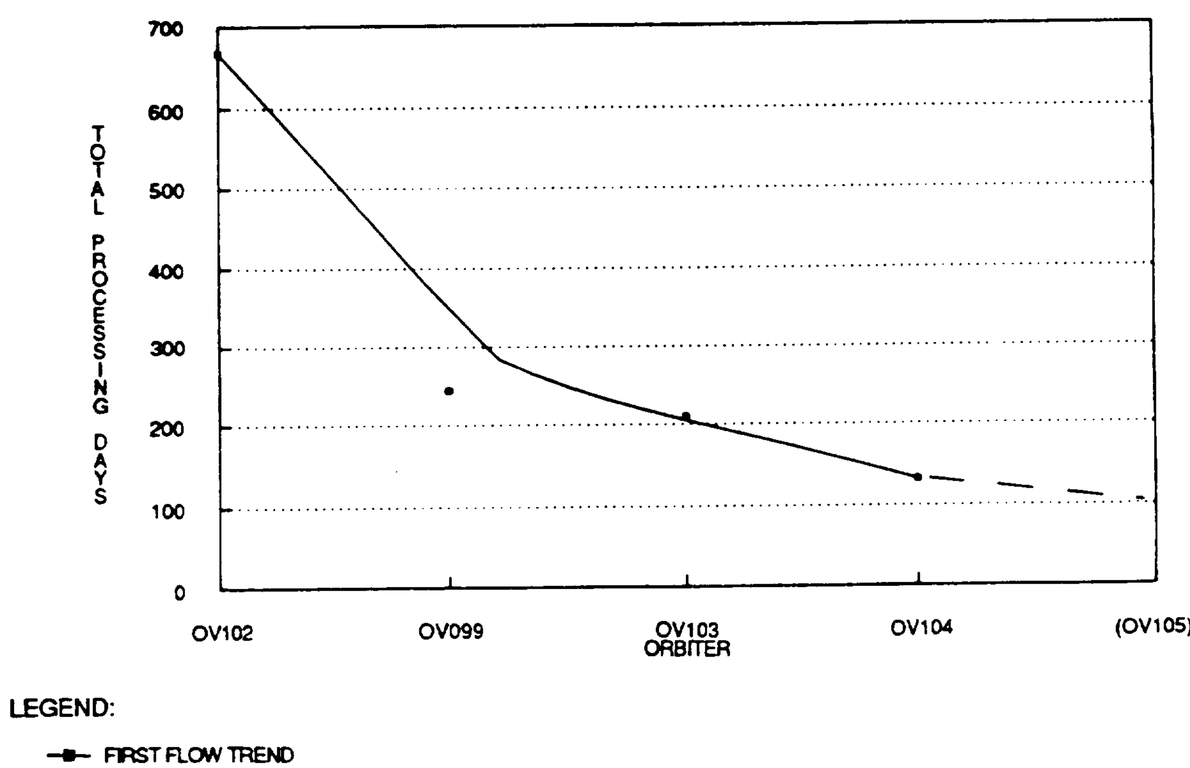


Figure 3.2.7.4-3. Process Trends for Orbiter Introductions.

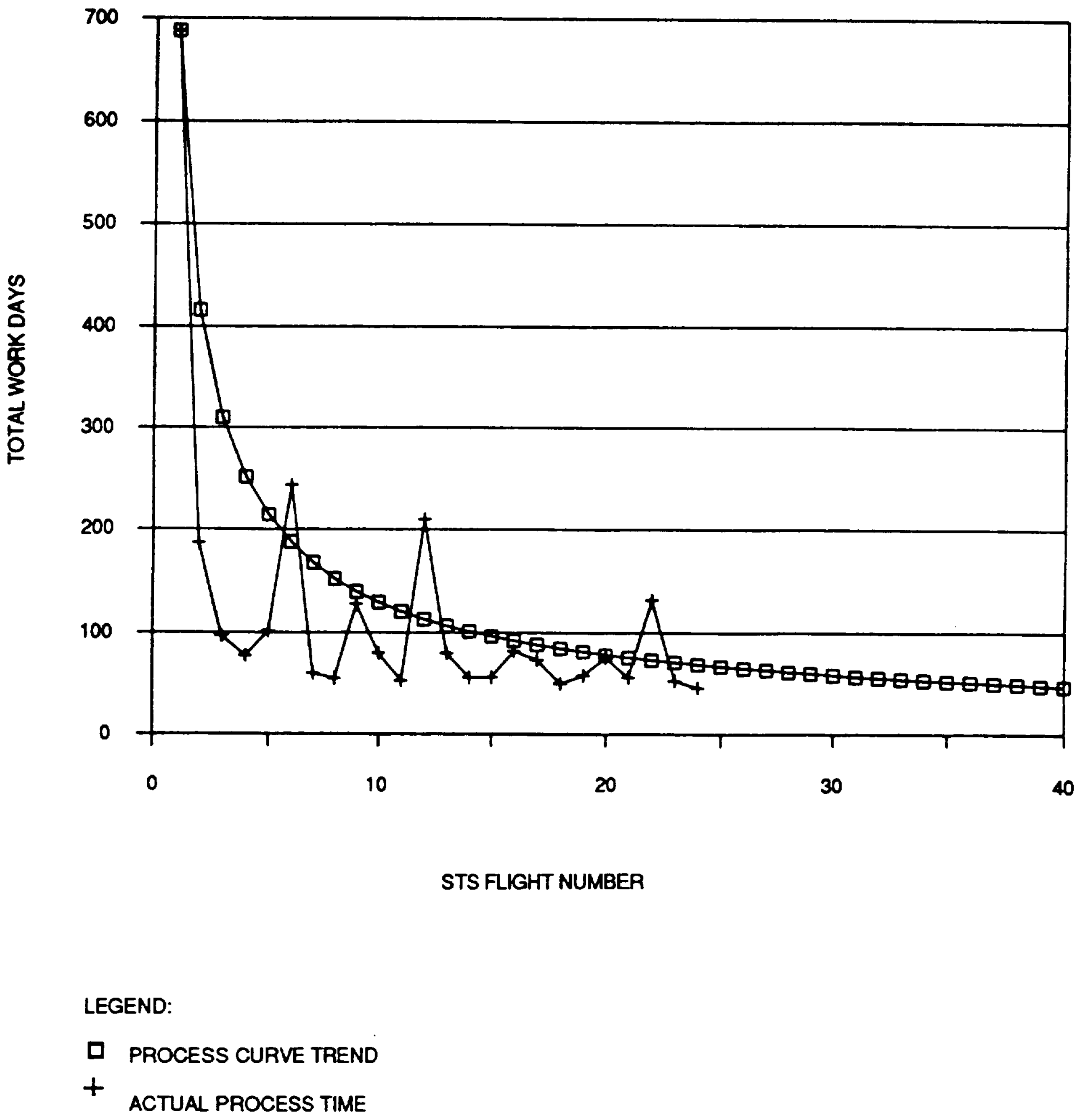


Figure 3.2.7.4-4. Overall STS Ground Processing Curve.

points are independently connected they form two curves which are interpreted to be the upper and lower performance limits. Figure 3.2.7.4-5 shows these curves with a mid-point (average) curve. This ground processing curve is recommended for use in all studies of ground processing at KSC in the near term. Long-term applications may require a new curve if different processing reduction mechanisms are contractually and/or institutionally employed.

There is difficulty in applying a peculiar curve to the booster in GOCM without applying it to the overall Shuttle system. This is because GOCM in its present configuration won't segregate the flight element costs. This may not be a problem for GOCM operations. Booster processing represents a small portion of the overall flow, with the LRB processing costs being equal or slightly larger in magnitude to the SRB processing costs.

Cost reduction curves rates are dependent on either an intense effort spent early to quickly realize lower potential cost (high rate) or an intensive follow up improvement program concurrent with operations or test (low rate), i.e. engineering change requests. If no new effort for improvement is spent (a high rate), then little improvement is realized. Hence, a high rate learning curve only provides little improvement to either poor cost performance or good cost performance. The ground processing curve rate is the most sensitive early life cycle GOCM ground processing parameter. Figure 3.2.7.4-6 illustrates the effect a 90%, 80%, 70% and 60% ground processing curve has with regard to the overall ground processing time.

3.2.8 <u>Success Oriented vs Post 51-L</u>

As illustrated in Paragraph 3.2-7, the ground processing curves represent the most significant and sensitive initial ground processing cost drivers. Since pre-51-L turnaround CER values are not applicable, and Post-51-L actual values are already becoming available, the primary issue concerning GOCMs accuracy is in the application of the ground processing curve. It is assumed that the GOCM CERs will soon be updated. It is further assumed that users will not wait for additional launches to derive a new processing curve. Therefore the issue of success oriented versus accuracy is reduced to the soundness of applying the ground processing curve.

GOCM can handle any curve the user wishes to incorporate into the cost analysis. The difficulty is choosing the correct curve. The choice of curve is dependent on the potential for improvement and the presence of in-place incentives and mechanisms to realize the programs potential (performance). Paragraph 3.2.7 derived a ground processing curve based on the assumption that the growth/learning in place at KSC will be present in the near future to effect the STS and similar programs.

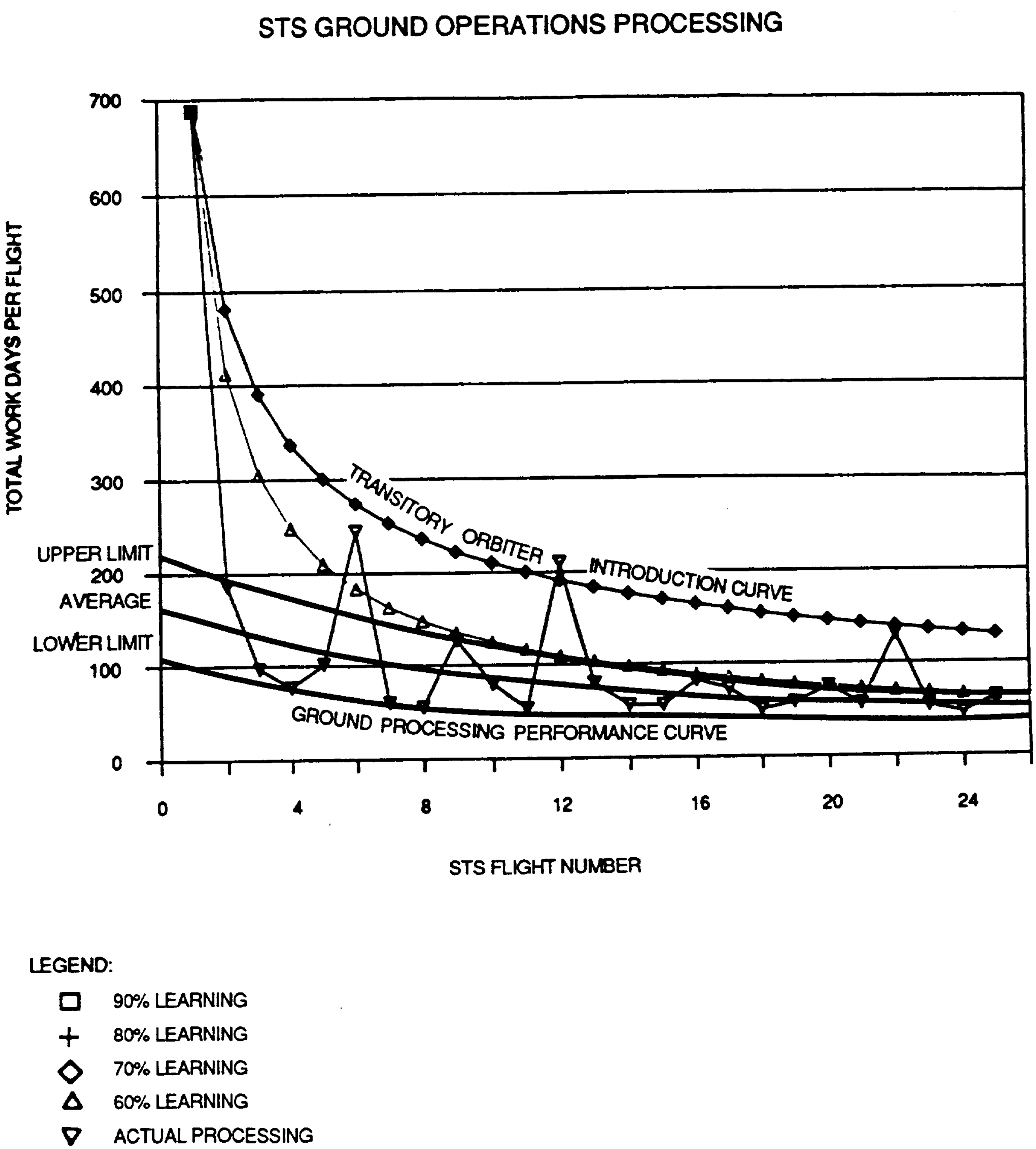


Figure 3.2.7.4-5.. Ground Processing Curve

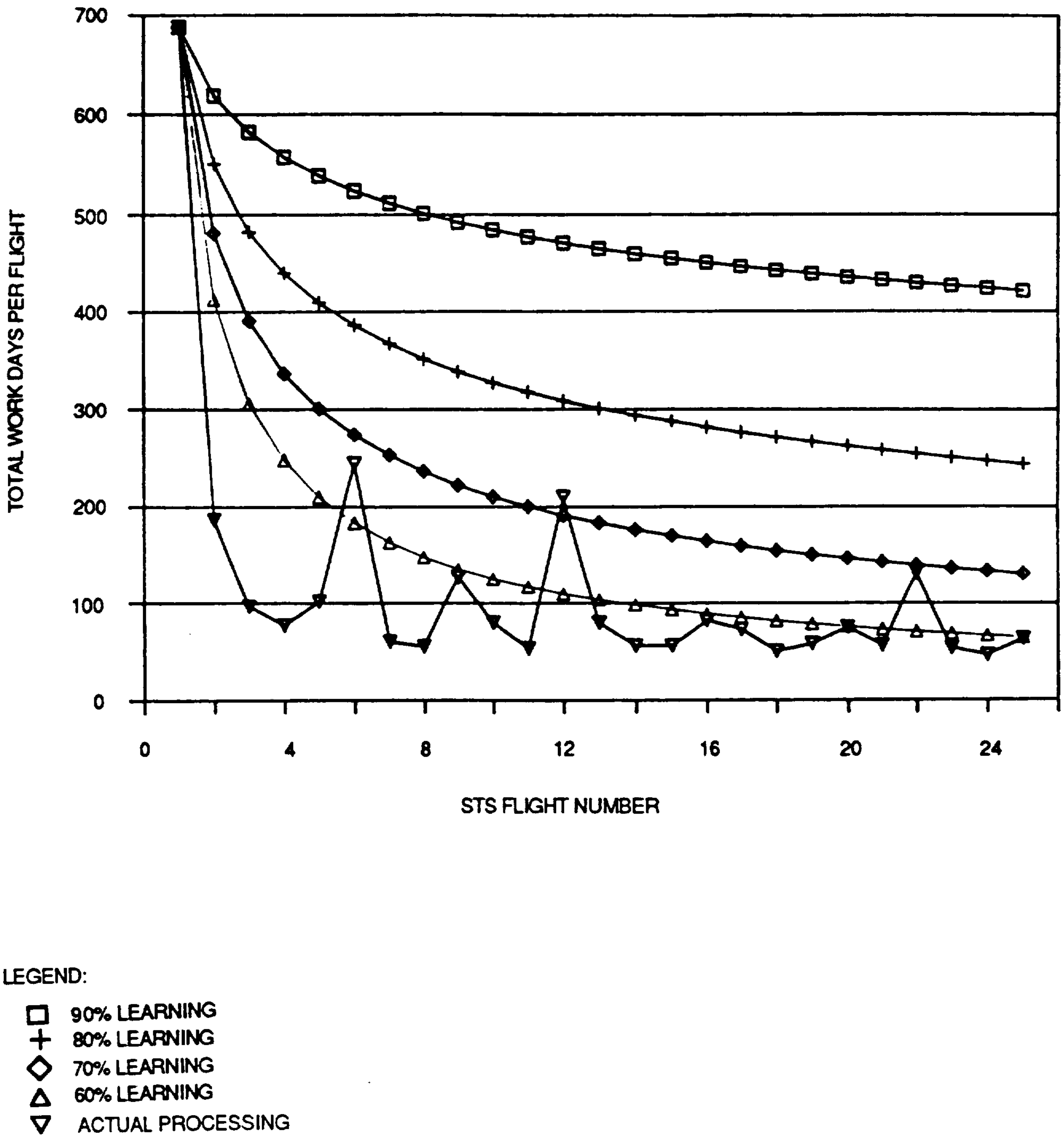


Figure 3.2.7.4-6. Ground Processing Sensitivity to Ground Processing Curves

The Post-51-L ground processing performance will be a partial "fresh start". The ground processing system and flight hardware have experienced significant changes since Flight 51-L. While past user experience has not been forgotten, new changes independent of it have been implemented. As a result, some people think KSC is embarking on a new program, subject to starting all over again on the processing curve. This contention does not ignore the benefits of past experiences which prevails on the program today. The debate on where to resume on the curve is not very important to LCC, however, since it is relatively flat after 30 launches (assuming mature program reductions in cost are realized).

The magnitude of change to the ground processing duration resulting from 51-L is so great that it inferes a great potential for improvement. This supports the contention that ground processing should commence at the beginning of the curve. The real question is whether the pre-51-L potential and improvement mechanisms still prevail at KSC. It is our contention that they do as evidenced by the manifest and NASA's recent investigations into Ground Processing efficiencies, i.e. VITRO, Boeing.

Therefore, it is believed the early portion of the curve should be applied at the STS 26R launch for extrapolation into the future. It is concluded the ground processing curve derived in Section 3.2.7 is the preferred curve and that no perturbations should be added until the introduction of the fifth Orbiter in 1992-1993. The baseline GOCM utilizes the preferred processing curve and does not address new Orbiter introduction for STS applications.

3.2.8.1 Applying The Ground Processing Curve

The ground processing curve is applied to STS 26R and up (Paragraph 3.4.2). The interesting conclusions are:

- Through 1994 the planned STS launch rate is not likely to be achieved.

- The degree of follow-on STS ground processing improvement from 1994 and on, is small, and for a first order approximation can be ignored from this point on to simplify the LRB analysis.

3.3 MODEL ENHANCEMENTS

3.3.1 Configuration

The original Ground Operations Cost Model is based on a IBM PC-compatible microcomputer with a hard disk, 640K of RAM memory and Symphony 1.2 software. The operation and automation of the model was based on Symphony macro instructions. The original model was highly innovative in its approach. It provided a high degree of analysis with a moderate degree of user experience and with minimum user input. It made effective use of the familiarity with Lotus spreadsheet products as used on IBM PC-compatible hardware. Symphony itself is classified as an integrated software product. It provides, in one software package, spreadsheet, word processing, graphics, database and communication capabilities. Symphony is "RAM resident", which means that the entire Symphony program and Symphony spreadsheet must completely co-reside in the computer's memory. As a result, the size of the spreadsheet is restrained by the size of computer's memory. Since Symphony is designed to work with the PC DOS operating system, the user is limited to 640K of RAM memory without the use of "expanded memory" (which requires a special expansion board and software). Many IBM PC-compatible computers at the Kennedy Space Center are simply not equipped with this expensive option.

The original Ground Operations Cost Model evolved over several years. As a result, a new area added to the model would reference a value in the area above it. This second value would in turn reference another value higher in the spreadsheet, and so on. This led to a string of references that provided accurate information but was extraordinarily difficult to "unravel".

Spreadsheet software provides exceptional visibility to calculations and is easy to use. The name of the original microcomputer electronic spreadsheet, VisiCalc, was a contraction of visible calculator. This visibility makes the use of electronic spreadsheets much less intimidating for inexperienced microcomputer users. In addition, Lotus Symphony provides its spreadsheet with an internal application language. This language is formally called the Symphony Command Language, but is informally referred to as "macros." The use of macros allows quick development of sophisticated, menu-driven spreadsheet automation within a limited range of functions. Unfortunately, macros are also highly unstructured and difficult to document. As application languages go, macros, when used outside a limited range, can be very awkward for the programmer. Ease of use is offset by lack of power.

3.3.1.1 Baseline

The original Ground Operations Cost Model consisted of one large spreadsheet (Opsmod.WR1) and 2 much smaller, supplementary spreadsheets (Procmod.WR1 and Facmod.WR1, (see Figure 3.1.2-1). Opsmod.WR1 was so large that only 11K of user memory was available for expansion or enhancements. With the original model configuration, this constraint was a fatal limitation.

The original model provided up to 35 pages of output. This included facility utilization, vehicle characteristics, technology influences, record of facilities shared with the SRB, a traffic model, new facility requirements, a Wright Learning Curve, a summary of intermediary results, and a final analysis output.

The user was guided through all these areas with macros and macro menus that were all contained in the Opsmod.WR1 spreadsheet. These macros were located across a large portion of the spreadsheet, and determining their logical flow was difficult. As this model was originally intended for the personal use of experienced employees, the users manual was austere. In addition, some places were found to be incomplete.

3.3.1.2 Enhanced/Modified

Introduction

In order to initiate any enhancements or modifications, we first had to make better use of the available RAM. This was a problem that did not confront the original model, as it did not exceed the 640K limit. However, to make the model more comprehensive and "user friendly" required making the model larger. In the original configuration, there was simply no room to do this. We were able to achieve a reduction in the memory requirements of the main model by modularizing all supplementary data areas. This approach had the added benefit of allowing experienced users to build a library of output data files. For example, a variety of facility "portfolios" could be created and saved to disk. At a later time, a less experienced user would be able to access the different output files, and import them into the main Operations model at will. Since each module saves output files with a unique file extension, only the appropriate output file library is displayed to the user.

This task was begun in the original model, which had a processing and facility submodules. Variable and traffic data areas were extracted from the original model and established as separate modules. The original Processing and Facility submodules were enhanced with a more comprehensive user interface.

We assume that the model was first programmed in Lotus 1-2-3 and then ported into Symphony. We have based this assumption on a variety of powerful Symphony functions and enhancements, not available in Lotus 1-2-3 that were not incorporated in the original model. For example, Symphony database functions, multiple windowing capabilities and a variety of Symphony environments were not addressed in the original model. We aimed at using the full power of the Symphony spreadsheet and Command Language to 1) enhance the power of the model where possible, and 2) refine the user interface for those with limited PC experience.

We first addressed the user interface. Our guiding philosophy was to keep the format and information on the monitor screen as stationary as possible. We would then let the macros and macro menus move data in and out of the screen. Where appropriate, different windows would overlay the screen without disrupting the original information when the window was removed. This leads to a more stable screen environment that inexperienced users find less confusing.

Processing Module

The original Processing module presented the user with different choices for vehicle configuration. The user chose the configuration, technology status and turnaround rate. Based on this information, the module generated the appropriate number of shifts and manpower and assigned them to the appropriate Shuttle systems. This information was exported to the main Operations model as an extracted file.

Based on the original CERs and logic, we reprogrammed the Processing module with a number of enhancements. The macro automation was made more robust, the required user input was unified into one stationary screen, and the elements and processing systems were standardized. In addition, the enhanced module allowed a wider choice of configurations, including mixed booster fleet vehicle configurations.

We attempted to achieve a level of comprehensiveness that would allow the model, as new information was generated, to accurately evaluate the widest possible number of future configurations without structural modification to the model. We view this improvement as making the model "expansion ready." The structure for future enhancements are in place. The incorporation of additional formulas and CERs can be made as they become available.

As an example, the use of the Symphony @CHOOSE function in the selection of technology and turnaround levels allows the addition of new levels to be quick, easy, and virtually self-documenting.

The main screen for the Processing module is shown below:

Processing Factors

Vehicle================> STS
Technology=============> BASELINE
Turnaround=============> REVISED

Vehicle Configuration

Module	Number	Element	Location	Fuel	Recovery
SRB	2	4	SIDE	SOLID	WATER PARACHUTE
LRB	0	N/A	N/A	N/A	N/A
CORE	1	0	SIDE	LH2	EXPENDABLE
LEO	1	3	SIDE	LH2	MANNED GLIDEBACK
PAYLOAD	2		INTERNAL		

Facility Module

The original Facility Module provided CERs which are based on facility dimensions, Cost of Facilities, Equipment Costs and Support Facility Costs. With this solid foundation as our base, we aimed at 2 enhancements. First, we would improve the user interface. Second, we would use this interface to allow the user to simultaneously evaluate a wider range of facilities. For instance, the original model did not allow the user to send both LRB and SRB facility information to the main Operations model. You had to choose one or the other. Using Symphony's database functions, the Form environment, and window overlays for on-screen instruction, the user can now choose multiple booster facilities. Financial information on all these facilities can now be simultaneously sent to the main Operations model.

The enhanced module provides two levels of user involvement. At the "INPUT" level (shown below), the user is presented a database edit form and is able to view all facilities in the model. This allows inexperienced users to send a variety of facility combinations to the main Operations Model.

```
+-----------------------------------------+
|GENERIC NAME LEOPF_____                  |
|CER 4_                                   |
|NUMBER OF FACILITIES: 3_                 |
|SHARED FACILITIES: Y     (Y or N)        |
|ELEMENT LENGTH: 122______(ft)            |
|ELEMENT WIDTH: 78______  (ft)            |
|ELEMENT HEIGHT: 57______ (ft)            |
|FACILITY LENGTH 197.0____(ft)            |
|FACILITY WIDTH 150.0____ (ft)            |
|FACILITY HEIGHT 95.0_____(ft)            |
|COF $28.2_______($M)                     |
|EQUIP $173.9____($M)                     |
|SUPT $5.2_______($M)                     |
+---------------------------------INPUT--+
```

More experienced users may wish to modify the original CERs, change facility dimensions, or alter the costs.

Variable Module

The original model did not have a Variable module. A variety of variables were assigned throughout the spreadsheet. These variables were the basis of much of the original model's flexibility, and were inherent to meaningful output. However, they were dispersed throughout the spreadsheet, and were often difficult to locate. In addition, there was no guidance for inexperienced users as to standard rates and factors. We unified the majority of these variables into the Variable module. Changes are made via macro menus, and on-screen standard rates and factors also guide the inexperienced user. The escalation and discount factors were combined into one variable. This allows the user to more easily select an index year, and express any time period in index year dollars. For example, this module permits the user to create factors that allows the period 1988 to 2006 to be expressed in 1995 dollars. Facility Utilization, Manpower Rate, Scheduled Days per Week, Scheduled Shifts per Day, Surge Factor, Index Year, and the Location of Launch Site are all user modifiable, as shown by the following:

```
=======================================================================
Variable Rates and Factors
=======================================================================
Location of Launch Site==>    ETR     Standard is: ETR
Manpower Rate============>   $186     Standard is: 186 (1987$)
Index Year===============>   1987     Standard is: 1987
Schedule Days/Week=======>      6     Standard is: 6
         Shifts/Day======>      3     Standard is: 3
         Holidays/Year===>     19     Standard is: 19
Factors  Escalation Rate=>   0.0%     Standard is: 4.5 (NASA)
         Facility Utiliz=>  85.0%     Standard is: 85
         Surge Factor====>   0.0%     Standard is: 0.0 (NASA)

-----------------------------------------------------------------------
Start Year===========>       1996 (From Traffic Model)
Rate Factor==========>          1 (From escalation)
Nth Factor===========>          8 (Start_year less
                                      Index_year)
-----------------------------------------------------------------------
YEARS                  1996     1997     1998     1999     2000
-----------------------------------------------------------------------
INDEX FACTOR           1.000    1.000    1.000    1.000    1.000
ESCALATION FACTOR      1.000    1.000    1.000    1.000    1.000
ESCALATION RATE        1.000    1.000    1.000    1.000    1.000
-----------------------------------------------------------------------
=======================================================================
```

<u>Traffic Module</u>

The Traffic module was extracted from the original Operations model and expanded to include either a SRB, LRB (or both) flight schedule. It permits the user to select a starting year, the maximum weight each vehicle can carry into space, the payload utilization factor, and a variety of different predetermined flight schedules. The user can call up a schedule by name, or create a customized schedule for, among other things, special sensitivity analyses, as shown below:

Traffic Rates and Factors

START YEAR=========>	1996		
SRB VEHICLE========>	CUSTOM	LRB VEHICLE========>	LRB STUDY
MAX WEIGHT=========>	65 K-LBS	MAX WEIGHT=========>	75 K-LBS
PAYLOAD UTILIZE===>	100%	PAYLOAD UTILIZE===>	100%

FLIGHTS: CUSTOM	11	8	5	2	0
FLIGHTS: LRB STUDY	3	6	9	12	14
WEIGHT (CUM) K-LBS	195	390	585	780	

SCHEDULE	1996	1997	1998	1999	2000
POP 85	20	20	20	20	20
POP 87	14	14	14	14	14
POP 88	1	7	10	10	12
MAIFEST	1	5	10	10	11
LRB STUDY	3	6	9	12	14
GENERIC	1	3	4	4	10
CUSTOM	1	1	1	1	1

3.3.2 Future Potential Enhancements

3.3.2.1 Short Range

Short range potential enhancements are constrained by the current use of Symphony software, the IBM PC, and the DOS operating system. The enhancements we have made to the Ground Operations Cost Model have, as mentioned earlier, made the model "expansion ready." As a result, the model has been restructured with the idea of additional CERs in mind. As our knowledge and database increases, more and more CERs, and more refined CERs, can be inserted into the model. The constraint here is not the model's ability to compute, but human inability to provide the model with perfect information. Despite the hardware and software limitations discussed above, this model provides an exceptional opportunity to refine our thinking and explore more sophisticated areas of financial analysis that apply to ground processing. The Operation Model is also in good posture to be modified to accept mixed vehicle fleet in addition to mixed booster fleet configurations.

3.3.2.2 Long Range

Long range enhancements will have to acknowledge the imminent advances in computer hardware, application software, and operating systems. OS2, when available and supported, will remove the current IBM PC memory restraints. A new generation of application software will open doors to data and analysis that are presently closed and locked. The CERs developed now, along with improved technology, will be an invaluable foundation for any future effort. The power provided by advances in hardware and software are the raw means of calculation. Nevertheless, the wisdom behind these calculations will determine their viability.

We believe, however, that for the model to continue to grow in power and sophistication, we will have to abandon the use of spreadsheet software. More advanced graphics, more sophisticated database management, access to elements of artificial intelligence, use of virtual memory and commercially available subroutines all point to the use of a more powerful application language such as dBASE IV or PASCAL. Symphony is exceptionally versatile in a limited area. Nevertheless, to expand one step beyond this area requires a totally new software environment.

3.4 GOCM APPLICATION TO LRBI STUDY

3.4.1 Cost Estimates

The LRB single fleet and LRB/SRB mixed fleet costs are provided in Figure 3.4.1-1.

3.4.2 Cost Comparison

GOCM cost projections are compared with LRBI, General Dynamics, and Martin Marietta projections in Figure 3.4.2-1.

3.4.2.1 LRBI Study Comparison

The LRBI Study "bottoms-up" approach to the generation of cost is an engineering detail estimate, providing greater resolution in costs. Its accuracy and realism are undetermined, but its cost generation is more rigorous than GOCMs. The LRBI analysis is a Phase-B and C estimating technique and, as such, was probably too ambitious too soon to be both complete and accurate.

Follow-on LRB study will have to apply the "bottoms-up" approach to more use, on a select basis, and be supplemented with parametric CERs. It is also possible to supply the cost element values to a derivative of GOCM in order to generate cost reports. These cost reports would provide the effects of learning, inflation, discount, flight schedule, work days, work shifts, etc... to the Life Cycle Cost. See Figure 3.4.2-1 for the LRBI cost estimate.

3.4.2.2 General Dynamics

SCENARIO	NON-RECURRING COST	RECURRING COST	TOTAL COST
MIXED FLEET	389 (716) ①	5,109	5498 (5825)
SRB FLEET	373 ②	5,236	5609
DELTA	16.0M	127.0M	111M (219)
LRB (Alone) ③	716	700	1416
SRB (Alone) ③	373	472	845

NOTE: NO LEARNING HAS BEEN APPLIED ALL COSTS FY 87 DOLLARS.

① ONE NEW MLP, HORIZONTAL PROCESS FACILITY, 1 VAB HIGH BAY = 389M, PLUS 1 EXTRA MLP AND MODS TO PAD 327M (GOCM DATA APPLIED TO MEET LRB / KSC CONSTRAINTS)

② FOR SRB TO ACHIEVE 14 LAUNCHES PER YEAR REQUIRES 1 NEW MLP OR EQUIVALENT, 1 VAB HIGH BAY ACCORDING TO GOCM.

③ BOOSTERS ALONE DO NOT EXPERIENCE THE ECONOMIES OF SCALE AS THEY DO IN THE STS PROGRAM.

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Figure 3.4.1-1. GOCM KSC STS Life Cycle Cost

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COST EST (FY 87 B $)		NON-RECURRING	RECURRING	SUB - TOTAL	ADJUSTMENT (1)	TOTAL
1 KSC INITIAL CONCEPTUAL ESTIMATE		.476	.501	.977	40%	1.368
2 INITIAL GOCM		NA SINGLE FLEET LRB SRB	NA	NA	NA	NA
3A GENERAL DYNAMICS		.337	.488	.825	40%	1.155
3B MARTIN MARIETTA		.324	.501	.825	40%	1.155
4 KSC BOTTOMS-UP ESTIMATE	(3)	.705	.974	1.70	N/A (2)	1.70
	(4)	.826	.974	1.80 (1)	N/A (2)	1.80
5 FINAL GOCM ESTIMATE	LRB	.716	.700	1.42	25% (5)	1.78
	SRB	.373	.472	.845	25% (5)	1.06
6 FINAL LRB COST ESTIMATE	(6)	.700	1.00	1.70	N/A (2)	1.70
	(7)	1.00	1.00	2.00	N/A (2)	2.00

(1) NASA FACTOR @ 40% (FEE @ 10%, GOV'T SUPPORT @ 5% AND CONTINGENCY @ 25%)

(2) INCLUDES 40% IN SOURCE DATA

(3) RP-1/LOX

(4) LH2/LOX

(5) INCLUDES FEE & GOV'T SUPPORT, MUST APPLY CONTINGENCY

(6) MIN VALUE

(7) MAX VALUE

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Figure 3.4.2-1. KSC LRB Life Cycle Cost Matrix.

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The General Dynamics KSC LCC for LRB ground processing was provided to LSOC in their final study report. Little insight into the cost generation was provided. The GOCM was used in part in their cost estimate.

3.4.2.3 Martin Marietta

The Martin Marietta Company used the initial LSOC conceptual cost estimate (dollar value) in their total Life Cycle Cost estimate. Subsequent cost generation analysis is unknown.

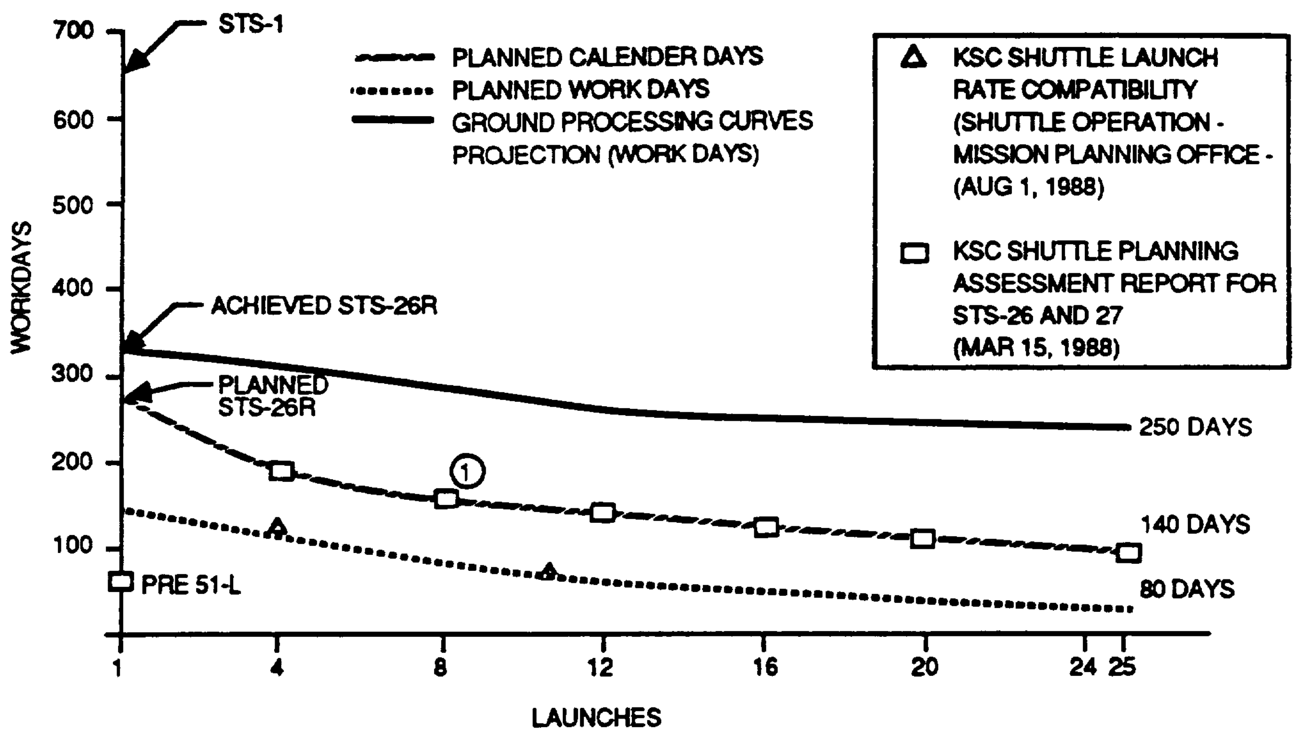
3.4.2.4 NASA Planning

The comparisons between the GOCM ground processing projections and Shuttle Operations Mission Planning Office Plans differ greatly. The LRB Study Planning factors and the SRB manifest are at variance with the GOCM projected launch rate based on the existing facilities capability, in the post 51-L environment for the SRB. This is shown in Figure 3.4.2.4-1. The implication is that KSC has to do something different in order to achieve the planned launch rate, or more facilities and associated personnel (and flight hardware) will be needed. Since facility costs are very significant, in that there is the non-recurring cost of facilities and there is the large recurring O&M costs, the overall KSC cost impact could be very large. Figure 3.4.2.4-1 indicates roughly doubling the facilities and O&M costs may be required, more than 3 billion dollars!

The importance of the above implication is either greater cost in facility/personnel will be experienced, or new planning and processing will be implemented which isn't visible to GOCM, or the launch rate must be reduced. The last implication infers the cost per launch will grow (do less for the same cost). Since many of the LRB trade studies performed by the prime contractors and NASA centers are based on 128 launches over 15 years for STS, their conclusions may be in question.

3.4.3 Role in LRBI

GOCM has generated two types of cost estimates. They are single booster fleet and mixed booster fleet. The single fleet estimates were generated early in the study using the baseline version of GOCM. All GOCM estimates were insensitive to LRB configuration. The single fleet analysis was performed to support cost element comparisons with cost developed independently in the LRBI, i.e. MLP costs, etc...



THERE IS A LARGE VARIANCE BETWEEN THE GROUND PROCESSING CURVE PROJECTED WORKDAYS PER FLOW AND THE PLANNED WORK DAYS PER FLOW FOR THE NEAR TERM POST 51-L LAUNCH ENVIRONMENT. THIS INDICATES A NEED FOR INNOVATIVE PLANNING, PROCESSING AND MANAGEMENT IN ORDER TO ACHIEVE A BETTER (LOW RATE) GROUND PROCESSING CURVE, IF THE PLANNED LAUNCH RATE IS TO BE ATTAINED. THESE INNOVATIONS ARE NOT CURRENTLY VISIBLE TO GOCM.

IT IS BELIEVED THESE INNOVATIONS WILL NEED TO COMPRISE MORE THAN IMPROVEMENTS IN TECHNICIAN EFFICIENCY, ADDITION OF MORE FACILITIES, AND A REDUCTION IN PROCESSING REQUIREMENTS.

(1) EXTRAPOLATED BASED ON GROUND PROCESSING FOR PLANNED STS-27.

Figure 3.4.2.4-1. Ground Processing Work.

The mixed booster fleet cost estimates were performed late in the study after the mixed fleet capability was incorporated into the Enhanced Modified version of GOCM. Independent of the concern over CER accuracy, GOCM was capable of performing a much more sophisticated cost estimate than was accomplished elsewhere in the study. GOCM addressed:

- Transition
- Learning (Ground Processing Curve)
- Activation (Facility)
- Escalation/Discount
- Yearly cost/customer cost
- Cost categories, variable, fixed O&M

GOCM estimates throughout the study proved to be an excellent cost reference and at the end, with lessons learned, it became a good budgetary aid for planning. GOCM has been unable to provide an adequate level of completeness at the lower levels of resolution to conduct trade studies and, therefore, has not been employed in this manner. Lessons learned in the LRBI were not in sufficient detail for incorporation into GOCM for trade study use.

3.4.4 Trade Studies

No trade studies with cost sensitivity were performed in the LRBI study.

3.4.5 Overview/Conclusions of GOCM Utility to LRBI

GOCM while limited in applicability to Phase-A trade studies, has performed some very important functions:

- Identified Processing Sensitivities And Shortfalls
- Provided Cost Reference
- Budget (Macro) Planning
- Initial Cost Estimates
- Indentified Major Cost Drivers

GOCM is an excellent macro decision tool, for Phase A and Pre-Phase A studies. GOCM also provides an effective framework for processing more discrete CERs which would span over to the micro level and be useful in Phase A, and Phase B trade studies.

GOCM has identified launch rate as an area of cost risk, as it involves facility capability and the ground processing curves. However, besides the cost (non-recurring) to build facilities, facility O&M costs have been identified to be a KSC cost driver.

3.5 FUTURE DIRECTION

3.5.1 GOCM Recommendations

Expanding GOCM to provide more options expands its applicability. Changes to software employed and to hardware enables the expansion to be conducted. Establishing a full time custodial and development organization assures future viability in cost generation.

The capability viewed below is more than the ability to respond to outside requests, RFPs, and challenges from competing concepts. A capability as described below could evaluate major KSC ESRs, conduct internal trade studies, and be used to plan and implement efficiencies into the KSC operation. It could perform budgetary estimates at many indenture levels. GOCM could be used to assess and evaluate future proposals involving KSC, and participate in NASA center cost working groups. For the above reasons the following preliminary recommendation is offered:

- Establish a cost projection organization (CPO) to serve KSC composed of:
  - CPO would include an R&M team for generation of logistics support cost elements and to participate in operational capability assessments
  - CPO would include estimators
  - Technical experts in flight hardware and ground processing
  - Business/computer programming experts
  - Clerical, graphic, typing

3.5.1.2 Recommended Statement Of Work For Follow-on GOCM Development

Purpose

Design and implement a ground processing cost and assessment system which will serve KSCs future program planning.

Requirements

The ability to tailor a GOCM type modeling system to the application and its phase of study requires the concept of modularity to be employed. Many in place GOCM features today would just as easily handle parameters developed elsewhere from accounting techniques, engineering judgement and logistics support cost models, as well as those currently developed parametrically. Therefore, with further refinement GOCM (as a redesign it would become GOCM II) could span the vast needs for costing over a wide range of study phases. There would be the quick broad response obtained from parametrics to the focused, detailed accounting cost techniques, available in various mixes for each application (see Figure 3.5.1.2-1).

Approach

- Expand GOCM to provide more option and expand its applicability

- Develop the requirements for the establishment of a full time custodial, development and user organization, referred to hereafter as the Cost Projection Organization (CPO).

- Establish a CPO plan and budget request

- Participate or at least review all studies conducted relating to launch/ground processing activities, to:
- Expand the CPO Database
  - Perform Cost Evaluation
  - Establish cost and effectiveness projection for NASA, and its customers
  - Develop costing and measure of merit capability

- Participate in NASA/industry working groups
  - Cost
  - R & M
  - Technology
  - Other

- Other

- Assist budget generation, review etc...

- Develop a supplementary data collection system which would supply the necessary feedback data to maintain the GOCM CERs currency and relevancy. This data system would also be used to create and maintain CERs of greater resolution for phase A-D Studies (budgets and trade studies). Typical SPC data elements would be:
  - By station/facility
    - Shifts, manpower, elapse time per flow

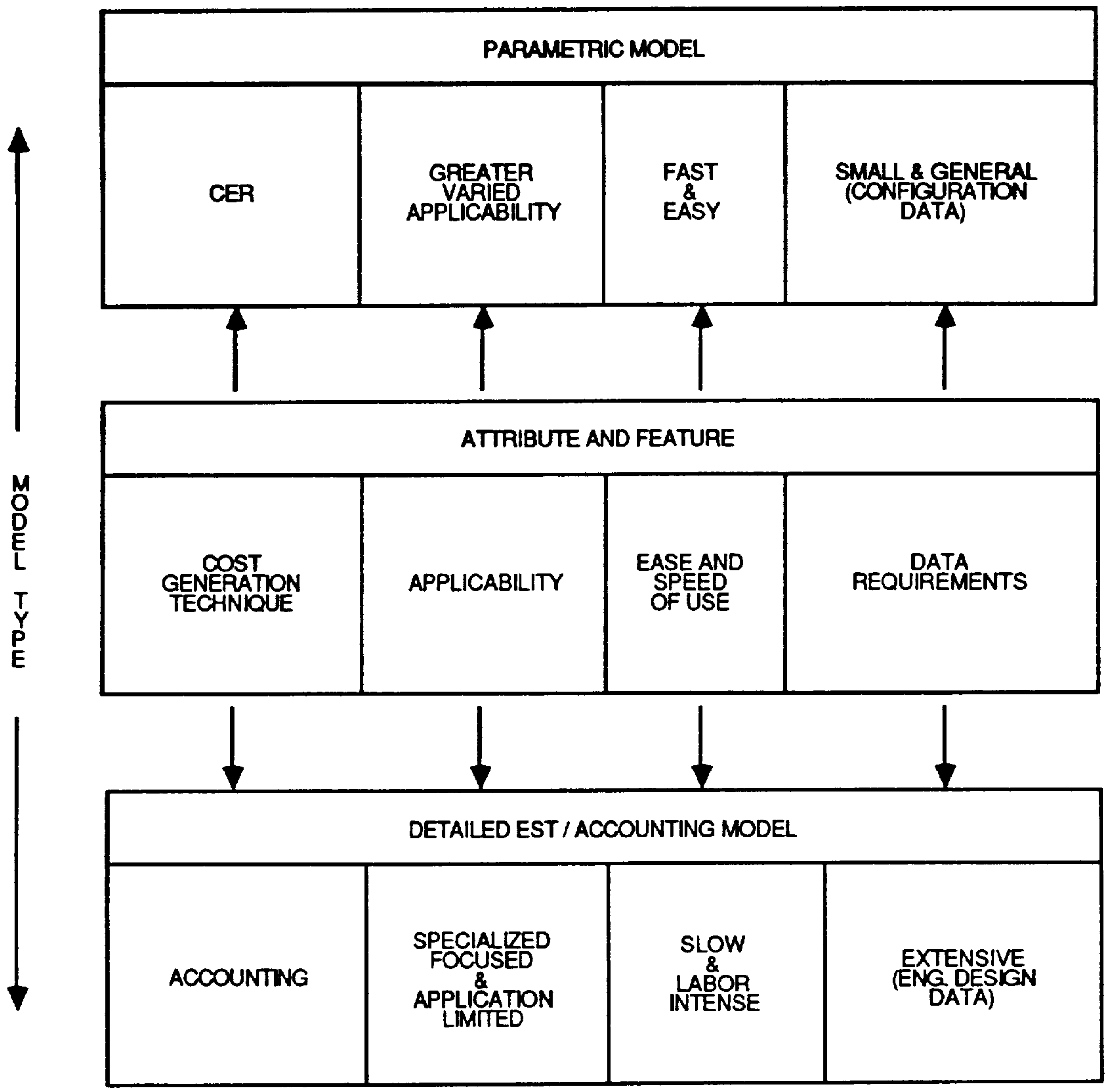


Figure 3.5.1.2-1. Features & Attributes of Various Cost Model Types.

- Associated flight/ground hardware R & M
- Logistics data
  - Spares
    - Other Cost Elements
  - Indirect Support
  - BOC
  - Civil Service

- Study alternate computer hardware and software programs that are currently on the market, to further enhance the utility of the GOCM. Enhancements can include standalone capability, enlarged database memory, user friendly menus and pop-up help screens.

- Integrate an enhanced mixed fleet capability into GOCM which could evaluate combined concurrent Shuttle II, Shuttle C, ALS and other possible vehicle operations.

- Consider expanding model to include mixed site capability to include concurrent launches from the Eastern Test Range (KSC and CCAFS) and Western Test Range.

- Consider optimization capability to include both mixed fleet and mixed site launch operations. This option would allow the user to optimize costs of putting various types of payloads into orbit based on space, weight or configuration constraints.

- Consider combining a schedule module to GOCM that would allow automatic mission model schedules to be produced. A trade study should be made to determine if GOCM could be integrated with the LSOC mission model that uses Artemis software or find an alternate program that would integrate both costs and schedules.

- Evaluate the utilization of a Database Management System incorporating Global commands.

<u>Products</u>

1. MODEL/DATA SYSTEM CONFIGURATION CONTROL
   - SOFTWARE
   - DATABASE
   - DOCUMENTATION
   - USER'S MANUAL

2. MODEL/DATASYSTEM ASSESSMENT REPORT
   - COMPLETENESS
   - ACCURACY
   - UTILITY

3. SUBJECT APPLICATION

3.5.2 Future Applications

Aside from the functions described above a GOCM type system (enhanced Modified GOCM or GOCM II) has many potential program applications. Some are listed and explained below:

1. Shuttle Booster Assessment for ASRM, LRB, RSRB and other. Booster replacements and modifications are being considered due to shortfalls in reliability, and Payload capability. Considerable interest has been shown regarding KSC impacts and the effect on schedule. Some alternative designs are technology transfer candidate for future systems i.e. LRB engineering for ALS.

2. More Shuttle and Shuttle derivatives. With the constrained post 51-L launch capability, achieving ambitious launch rates to serve the backlog, DOD launch growth, to lift space station, future moon and mars missions, will require alternate systems, and/or derivatives like Shuttle C and/or more Shuttles. Each option will likely involve KSC and need to evaluate ground processing costs and the capabilities of existing and new facilities and practices.

3. International cooperative space ventures -- KSC will likely be involved.

4. Transition launch vehicles and their derivatives. New systems are likely to be more reliable and have a large up-front cost. Economic viability of a new system is dependent on launch rate. This would require GOCM application to the ground processing system in order to quantify the cost and merit of considered derivative system.

5. Advanced Launch System. Office of Technology Assessment of the United States Congress (ISC-391 July 88) states "current launch systems are neither sufficiently economical to support SDI deployment nor reliable enough to support a dramatically increased military space program". KSC's role would be ground processing. Launch rate development and ground processing costs estimates would need a model like GOCM II.

VOLUME II

SECTION 4

COST ASSESSMENT

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VOLUME II

SECTION 4

COSTS

The STS/LRB recurring KSC costs are not very sensitive to the LRB options, and are slightly larger than current SRB recurring costs. The LRB non-recurring KSC cost range from 5-12 percent of the projected LRB LCC, and are sensitive to LRB option. The principle potential non-recurring cost driver is the potential need to build a new Pad for large diameter boosters.

The comparison of KSC booster processing costs with the STS program LCC reveal the booster to be less than 1% of the total, indicating the KSC booster costs are insignificant. However, this is very misleading. STS LCC is very sensitive to KSC ground processing delays and in this manner the booster (and other flight elements) is an important cost driver.

This report demonstrates the extreme importance of achieving ground processing efficiency and to minimizing facility requirements.

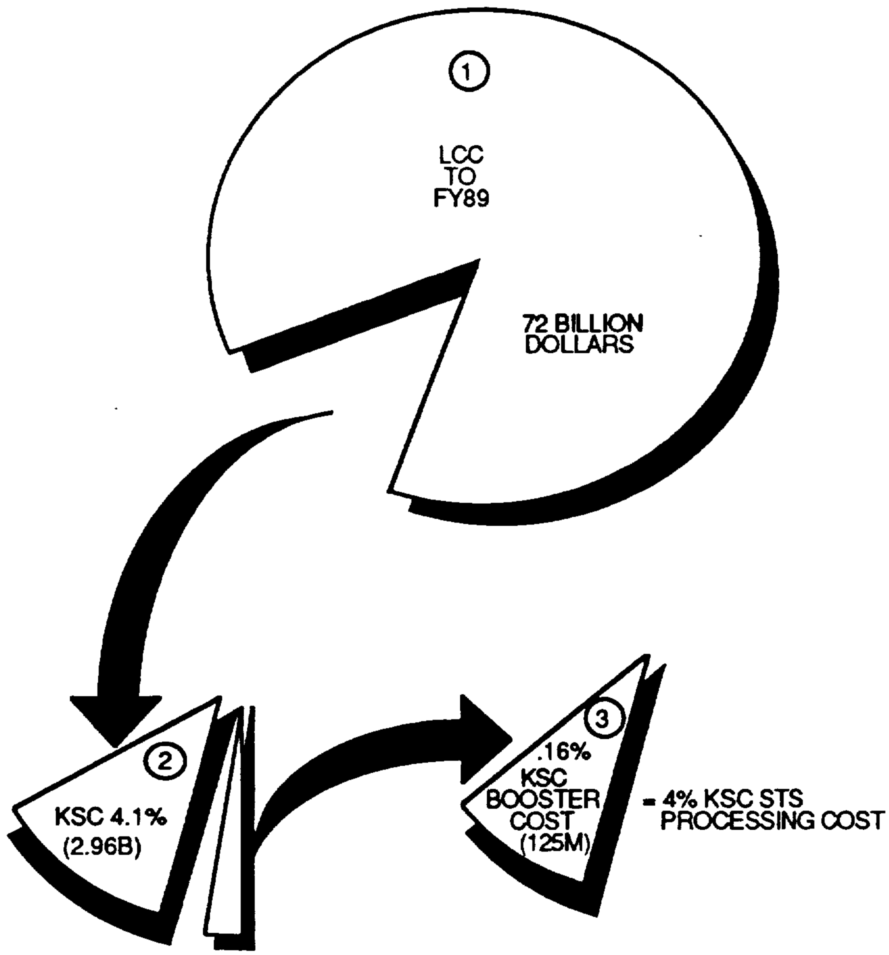
4.1 RECURRING COST ANALYSIS

It is necessary to understand the STS cost sensitivity to booster ground processing in order to assess the overall potential LRB cost impact to the STS program. This encompasses the KSC ground processing cost, and ground processing schedule impact which can be related to cost performance.

4.1.1 Program Cost Significance

It is estimated (using NASA STS congressional data as collected and reported by JSC/LEMSCO) that the KSC budget for 1983-1988 represents less than 5% of the total to date STS budget (Life Cycle Cost) See Figure 4.1.1-1. Approximately 4% of the total KSC STS operating budget during the period has been spent processing SRBs. This equates to .14% of the total STS life cycle cost! From this it can be concluded, that if the LRB recurring KSC ground processing costs are similar in magnitude to the SRB, then the LRB KSC ground processing costs will be less than 2% of the overall STS LCC. Therefore, the LRB is not a significant program recurring cost driver.

An approximate breakdown of KSC yearly costs is provided in Figure 4.1.1-2. From this figure it



(1) STS/LRB COST MODEL BRIEFING, JUNE 24, 1988 ADVANCE PROGRAM OFFICE, JSC, BLUMENTRITT/LEMSCO.

(2) KSC COST FY83-88, AC-REQ NOV. 15, 1985. SUBJECT: "CONGRESSIONAL EXCERCISE ON SHUTTLE OPERATIONS COST TREND" (2.96B).

(3) ESTIMATE BASED ON REF (1) AND (2).

Figure 4.1.1-1. Estimate of Processing Portion of KSC Cost, and Program Life Cycle Cost.

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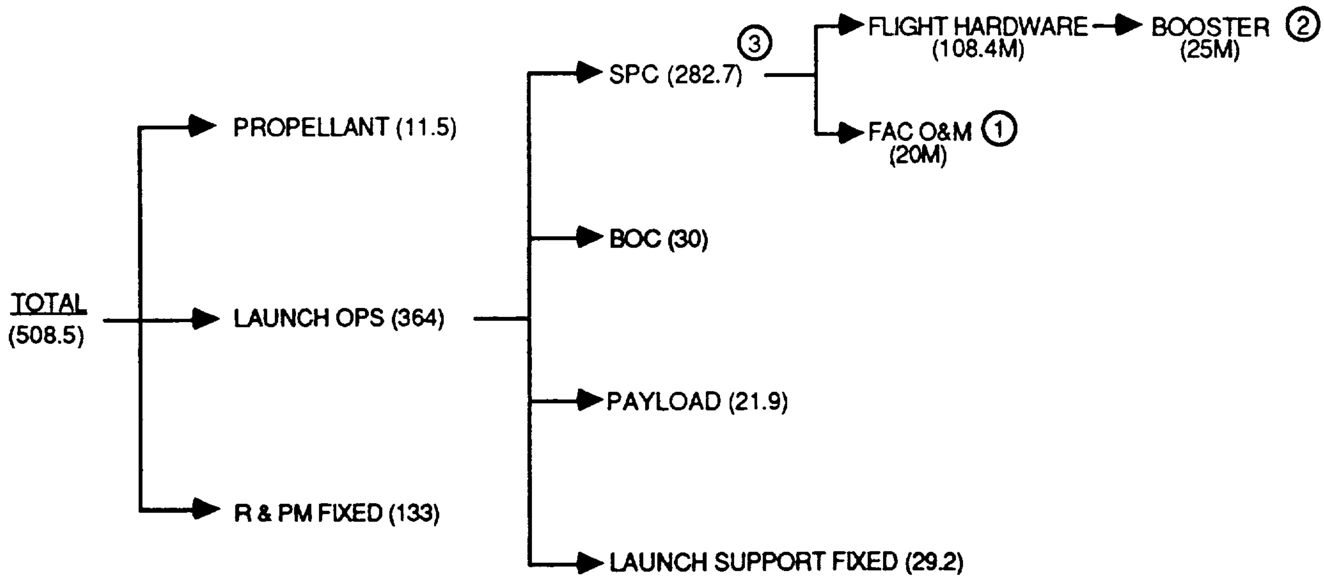


NOTE 1: COST FY85 IN (MILLION DOLLARS)

NOTE 2: SOURCE DATA:
AC-REQ/COMPTROLLER, "CONGRESSIONAL EXCERCISE ON SHUTTLE OPERATIONS COST TRENDS", LAUNCH OPERATIONS COST (FY85) ENCLOSURE 2, NOV. 15, 1985

① WBS1.3 = 20M

② BOOSTER EST USING WBS (1985)

③ COST FY85 vs CALENDAR YEAR 85 RESPECTIVELY IS 282.7M vs 307M

Figure 4.1.1-2. Typical KSC Cost Breakout.

can be seen again that the SRB processing costs still represents 4% of the KSC STS budget. Included in the SRB processing costs are the indirect (amortized) facility O&M costs, utilities, and the other SPC costs (see Figure 4.1.1-3). Absent from them is NASA and other subcontractor costs.

4.1.2 Cost Sensitivity

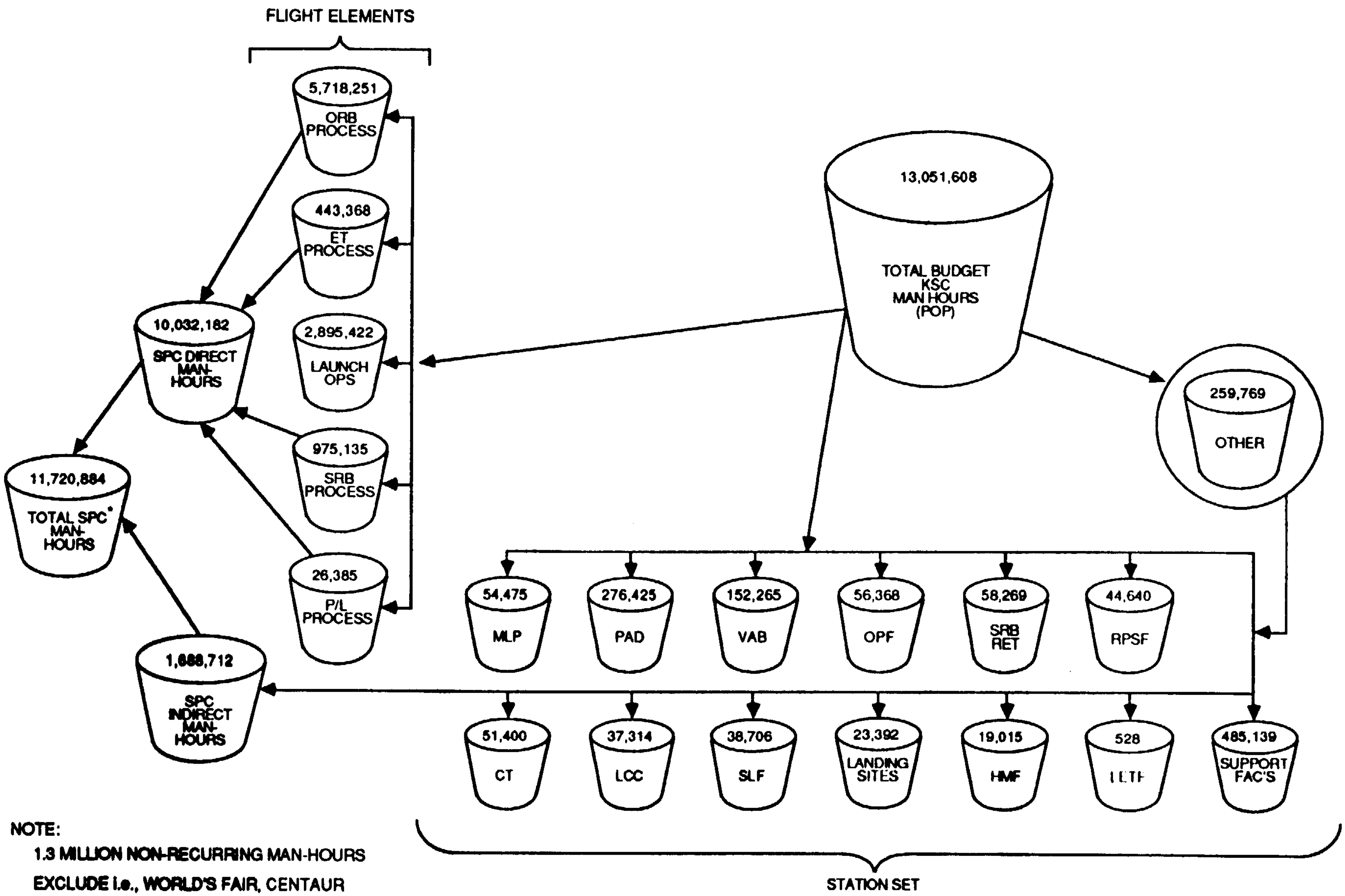
An approximate STS/SRB life cycle cost estimate out to the year 2006 is presented in Figure 4.1.2-1. This estimate includes the time period of LRB deployment. It assumes the current STS yearly budget of approximately 5 billion dollars per year and accumulate it through out the life cycle (2006) and arrives at a cost (FY 87 dollars) of $162 billion dollars for 212 (SRB) flights. Similarly for the STS/LRB the LCC is projected to be $182 billion dollars. These results are utilized below.

There are three potential STS cost mechanisms. The first holds the period of operational life constant. The more flights achieved during this period, the cheaper the cost per flight and, therefore, the cost per payload pound. The second mechanism holds the planned number of flights constant. The larger the launch rate, the shorter the period of operation. This lowers cost. The implication is those years after the required number of launches has occurred; do not contribute cost to the STS program. The third increases resources to meet launch schedule and to meet the programs life constraint.

The first cost mechanism is not considered viable. A programs life is not held constant with respect to calendar time. Program life is usually determined by the persistence of mission need and/or by the life of the flight hardware. The life of a program is usually determined by the required calendar time needed to reach the end of the hardware life. Hardware life is usually expressed in number of operating hours or the designed number of launches. Currently the STS program is defined to achieve 212 launches. Therefore the second cost mechanism is considered to be viable.

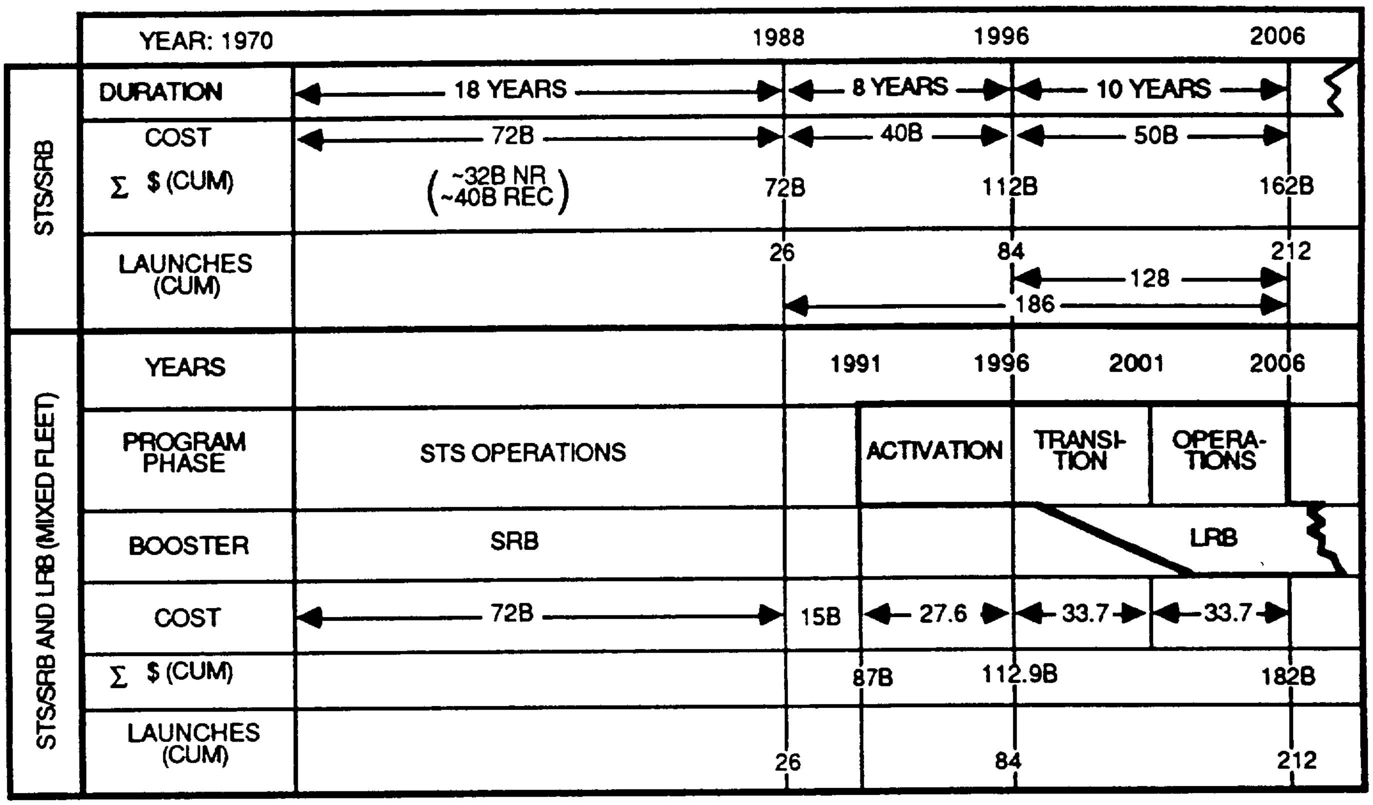
The third cost mechanism implies launch rate to be a priority, with little regard to LCC. Facilities and flight hardware quantities would be increased to meet launch rate, i.e. additional Pads, LCC, OPF and Orbiters. This cost mechanism has been ground ruled out since a launch rate priority has not been identified.

Applying the second cost mechanism to the one-hundred-twenty-eight (128) launches tentatively planned for the last ten (10) years of LRB operations, we can derive the delta LCC and delta program duration (years) for various launch rates,(see Figure 4.1.2-2). This allows schedule slip-



NOTE:
1.3 MILLION NON-RECURRING MAN-HOURS
EXCLUDE i.e., WORLD'S FAIR, CENTAUR
MODS, ETC. (65 PEOPLE).

Figure 4.1.1-3. Calendar Year 1985 SPC Manhours by Flight Element and Station Set.



NOTES:

- STS/LRB ESTIMATES NON-KSC LCC BASED ON GDSS
- KSC COSTS ARE FINAL LRB COST ESTIMATES

Figure 4.1.2-1. STS LCC Estimate.

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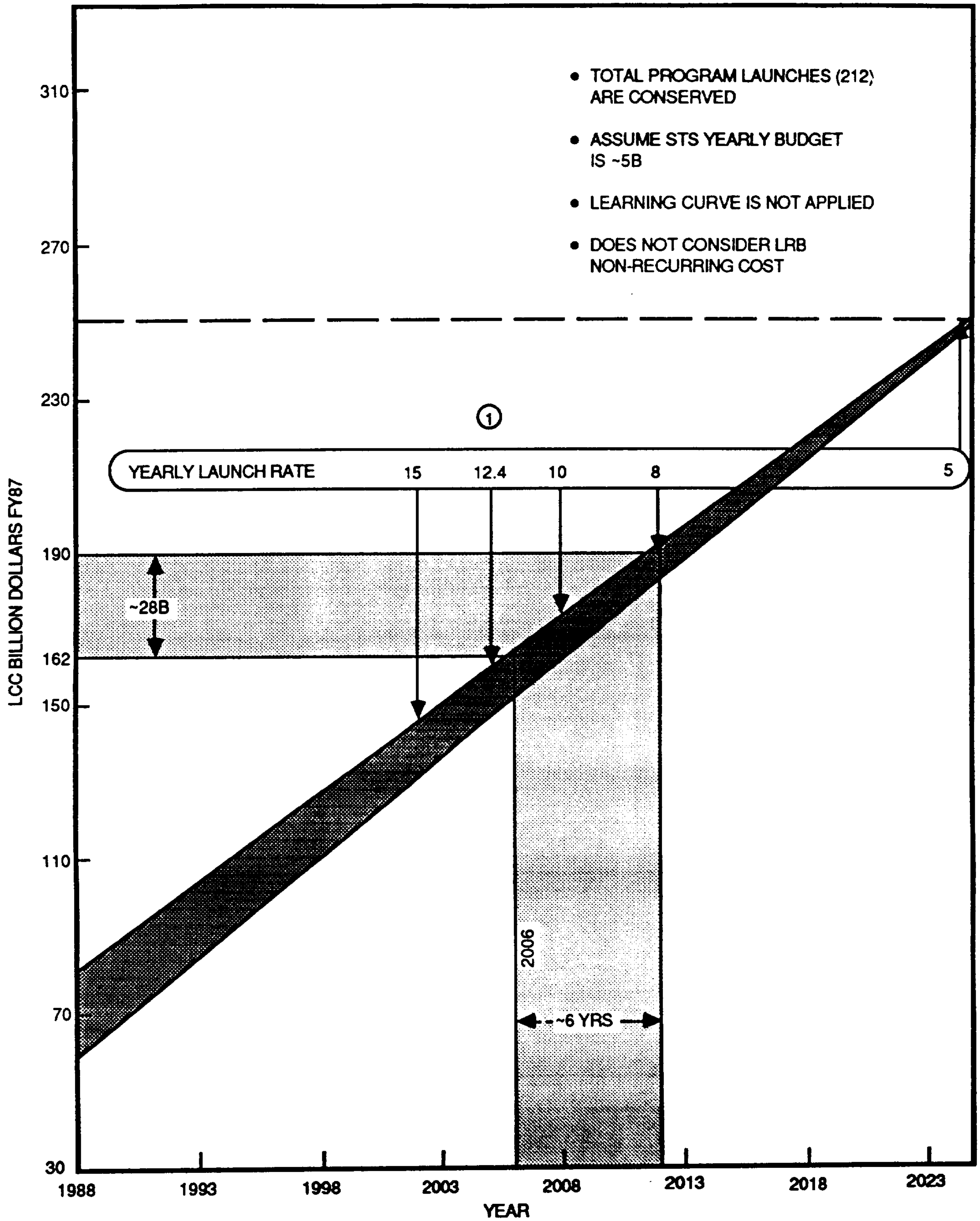

① LAUNCH RATE IS 186
LAUNCHES / 15 YEARS = 12.4

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Figure 4.1.2-2. Approximate STS LCC and Program Life Sensitivity to Launch Rate.

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page to be expressed in terms of dollars and years.

It is seen (Figure 4.1.2-2) that a variation in launch rate from twelve (12) to eight (8) per year requires an additional $28 billion dollars and six (6) extra years! Therefore, the STS life cycle cost is very sensitive to achieving the "designed to launch rate" for a fixed number of planned launches.

4.1.2.1 STS Sensitivity To Transition

The transition period is illustrated in Figure 4.1.2.1-1. In a manner similar to that discussed above for mechanism two (2), an LCC impact due to slippage in the launch schedule during transition can be derived. It shows a one-year slip in the manifest could be worth about $5 billion dollars!

4.1.2.2 Launch Rate Capability

KSC's ability to generate scheduled launch rates is dependent on the degree of achieved ground processing friendliness, planning effectiveness, management effectivity, and the degree of deviation from the planned generic ground processing flow. The booster prime contractor principally influence the booster design attributes which control ground processing friendliness. It is a conclusion of Volume II, Section 4 that the degree of achieved ground processing friendliness will greatly influence the achieved launch rate, thereby significantly influencing the recurring cost portion of the STS LCC.

Figure 4.1.2.2-1 shows the time allocated to the serial ground processing flow involving the SRB in the Shuttle Operations Mission Planning office "KSC Shuttle Planning Assessment Report for STS 26 through STS 77", March 15, 1988. It appears that all LRB candidates with proper GSE/LSE and facilities in place can meet the allocated time in theory. Therefore, first order recurring costs are invariant to the LRB configuration (option). But LCC is very sensitive to booster ground processing delays and achieved ground processing times.

The long and short term recurring cost risk can be substantially reduced if vigorous studying and planning is accomplished early, before Phase B, and if the results are incorporated as the KSC ground processing requirements in the LRB System Specification and LRB Phase B, C, and D statement of work (see Volume II Section 3-5).

In order to reduce long term (STS LCC) risk the LRB must achieve processing times which are less in duration than those planned for the Post 51-L SRB. A smooth LRB transition will reduce the short term cost risk.

	TRANSITION					
YEAR	1	2	3	4	5	CUM
PLANNED LAUNCHES	14	14	14	14	14	70
LRB	3	6	9	12	14	44
SLIP	-	3	6	9	12	30
SRB	11	8	5	2	0	26
TOTAL LAUNCHES	11	11	11	11	12	56

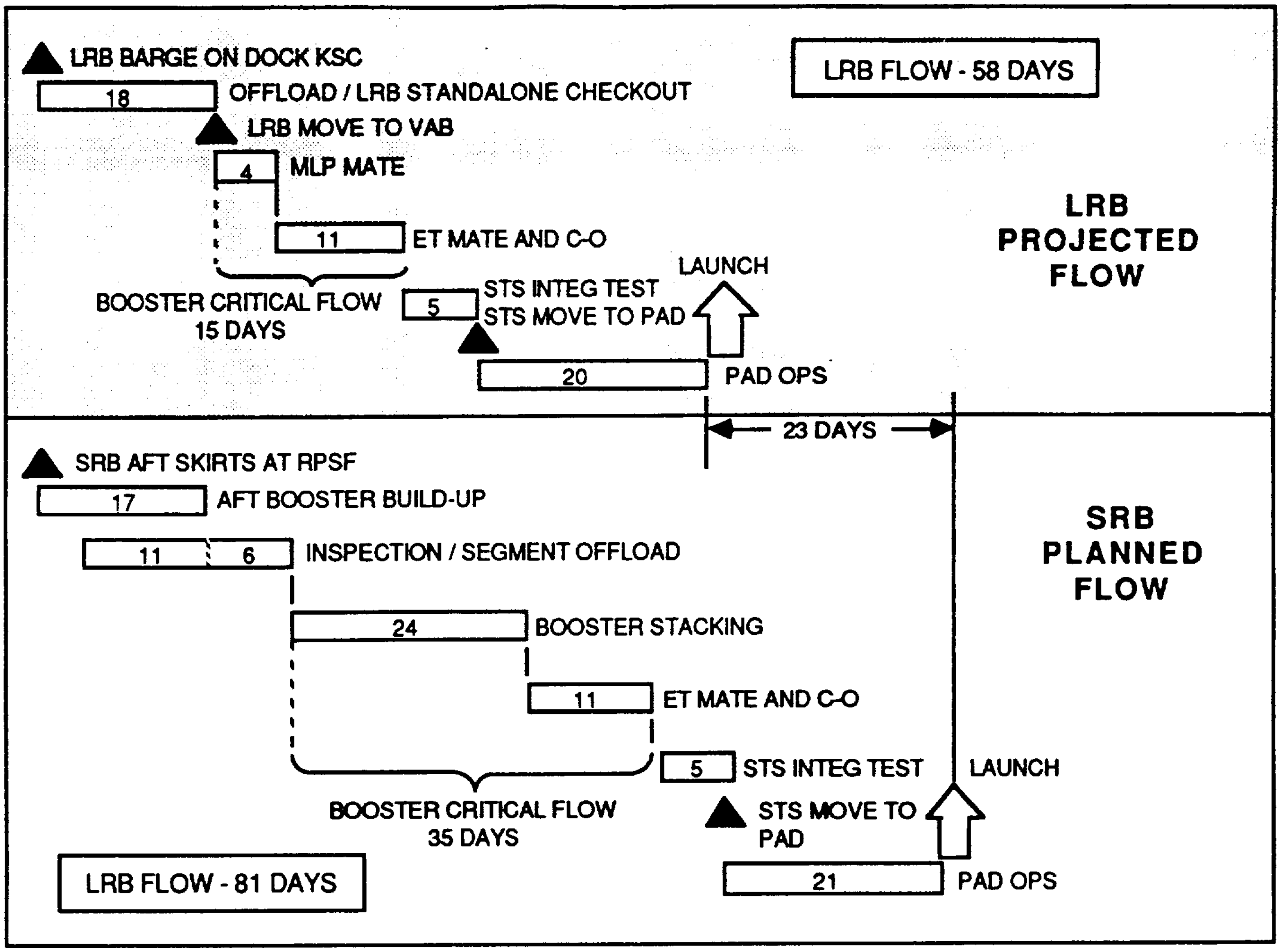
−Δ 14 LAUNCHES

- LRB LAUNCH RATE IS CONSTRAINT BY PROCESSING, FACILITIES, AND TRANSITION ACTIVITIES (INCLUDING ACTIVATION DELAYS) AND IS BELIEVED TO HAVE LITTLE RESILIENCY

- SRB PROGRAM MAY HAVE SOME CAPACITY TO MAKE UP SOME OF THE LRB SHORTFALL. HOWEVER, DURING TRANSITION SRB PROCESSING IS UNDERGOING PHASE OUT, GREATLY DEGRADING ITS RESILIENCE TO ACCOMMODATE A YEARS DELAY TO TRANSITION

- AT A 5B PER PROGRAM YEAR COST, A ONE YEAR SLIP COULD COST THE PROGRAM 5B TO MAKE UP OR THERE WOULD BE 14 LESS LAUNCHES IN THE LIFE CYCLE

Figure 4.1.2.1-1. Potential Cumulative Launch Rate Sensitivity to One Year Slip in LRB.



NOTE: SRB RETRIEVAL, DISASSEMBLY, REFURBISHMENT AND REMANUFACTURING ARE NOT SHOWN.

- FLOW TIMES FOR EVERY STS FLIGHT ELEMENT HAVE HISTORICALLY EXPERIENCED ENORMOUS GROWTH BETWEEN DESIGN PLANNING AND IMPLEMENTATION.
- LRB SHOWS A 20-DAY DECREASE IN FLOW DURING INITIAL STUDIES.
- ACHIEVED FLOW CANNOT EXCEED 35 DAYS.

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Figure 4.1.2.2-1. Generic LRB/SRB Process Flow Comparison.

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4.2 NON-RECURRING COST ANALYSIS

STS LCC are sensitive to the KSC non-recurring cost for facilities, GSE, and LSE. A cursory analysis shows the KSC LRB non-recurring cost to be greater than 1 billion dollars and less than $3 billion dollars. This represents between 5% and 15% of LRB LCC! This variance is due to potential facility impacts and requirements (at KSC) sensitive to the selected booster option.

4.2.1 Facility Impact and Requirement Sensitivity To Booster Diameter

The MLP and Pad facility cost impacts are significant and are most sensitive to booster diameter. The two exhaust holes on the existing MLP are not sized properly for the LRB.

Changes in booster placement are a function of their diameter. The impacts range from requiring modifications to the MLP to abandoning the MLP and building new MLPs to accommodate the changes to the exhaust hole placement and size due to LRB skirt diameter. However, schedule constraints originating from the transition requirements dictates building new (2) MLPs. Therefore, the sensitivity to booster diameter is ground ruled out - LRB will require two new MLPs costing in excess of 173 million dollars each. The estimated time to construct each MLP is five years.

The new MLPs and LRBs with a diameter greater than 14 ft. present major technical problems to the launch pad. The side flame deflectors, rather than serving the original purpose to channel the flame, now becomes a flame trench extension which significantly increases weight and complexity. The required placement of the new deflectors necessitate they be portable and be removed to allow access for the crawler to deliver and retrieve the MLP. The new portable deflector is a major technical and schedule risk to the program. Early estimates of the flame deflector costs are $40 million dollars for two pads.

An alternative is to consider building a new Pad. However, current estimates for a new launch pad are $770 million (plus contingency=$1 billion) dollars. Pad construction time may exceed the activation period and would delay first launch and impact LCC.

The LRB diameter for all options impact the ET/Orbiter umbilicals and LSE due to interference and clearance constraints, i.e. ET Hydrogen vent. The LSE will require redesign and replacement, and is estimated to cost $100 million dollars per pad.

4.2.2 Facility Impacts and Requirements Sensitivity to Booster Length

Booster lengths major impact occurs at the Pad. Boosters which exceed 170 feet in length require new LSE at the Pad. Very preliminary estimates place the cost at $20 Million dollars per pad ($40M).

4.2.3 Facility Impacts and Requirements Sensitivity to Fuel

The LO2/RP-1 propellant booster options require two sets (1 per pad) of facilities which cost $112 Million. The LO2/LH2 option will cost $200 Million dollars.

4.3 LRB COST PROJECTIONS

A multitude of cost estimates were performed and evaluated as part of the LRB cost projection effort. Figure 4.3-1 illustrates the approach used.

The various costs generated are presented in Figure 4.3-2. A brief review of each estimate is presented below.

4.3.1. KSC Initial Conceptual Estimate

The source data for this estimate was the generated by a LSOC subcontractor, utilizing both LSOC WBS data and NASA data. SRB processing was examined and adjusted using early LRB processing timelines to arrive at a LRB processing cost. LSOC developed the non-recurring cost of facilities and combined the elements for the initial KSC LCC comparison/estimate of STS/LRB and STS/SRB.

It is believed this estimate was a good early attempt to identify cost elements and cost drivers. It did, however not encompass some of the more subtle cost mechanisms in place at KSC which drives the processing costs. For instance, manloading facilities to their designed level of performance. This early estimate did not recognize the limits of estimating KSC cost as a cost per flight multiplied by the flights per year.

Other weaknesses became apparent as the study progressed. Facility modifications and cost of new facilities grew as a better understanding of LRB processing was attained.

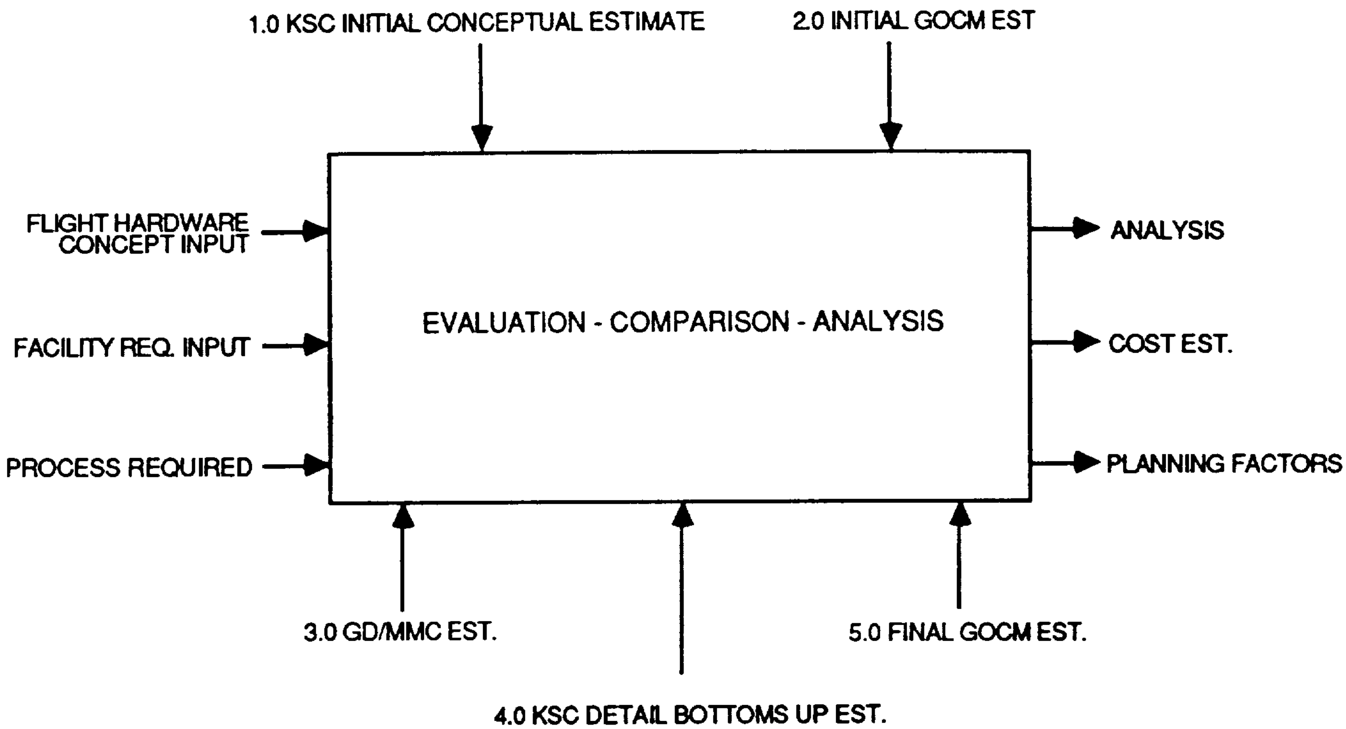

Figure 4.3-1. KSC Cost Generation, Evaluation and Comparison.

COST EST (FY 87 B $)		NON-RECURRING	RECURRING	SUB - TOTAL	ADJUSTMENT (1)	TOTAL
1 KSC INITIAL CONCEPTUAL ESTIMATE		.476	.501	.977	40%	1.368
2 INITIAL GOCM		NA SINGLE FLEET LRB SRB	NA	NA	NA	NA
3A GENERAL DYNAMICS		.337	.488	.825	40%	1.155
3B MARTIN MARIETTA		.324	.501	.825	40%	1.155
4 KSC BOTTOMS-UP ESTIMATE	(3)	.705	.974	1.70	NA (2)	1.70
	(4)	.826	.974	1.80 (1)	NA (2)	1.80
5 FINAL GOCM ESTIMATE	LRB	.716	.700	1.42	25% (5)	1.78
	SRB	.373	.472	.845	25% (5)	1.06
6 FINAL LRB COST ESTIMATE	(6)	.700	1.00	1.70	NA (2)	1.70
	(7)	1.00	1.00	2.00	NA (2)	2.00

(1) NASA FACTOR @ 40% (FEE @ 10%, GOVT SUPPORT @ 5% AND CONTINGENCY @ 25%)

(2) INCLUDES 40% IN SOURCE DATA

(3) RP-1/LOX

(4) LH2/LOX

(5) INCLUDES FEE & GOVT SUPPORT, MUST APPLY CONTINGENCY

(6) MIN VALUE

(7) MAX VALUE

Figure 4.3-2. KSC LRB Life Cycle Cost Matrix.

4.3.2. Initial GOCM Estimate

The initial GOCM estimate was very useful. It calculated costs for two scenarios. The first was an all STS/SRB fleet, the second was an all STS/LRB fleet. GOCM (initially) could not model the study's mixed fleet scenario. However, GOCM did employ learning curves, Post 51-L processing, and advance technology.

GOCM proved to be a good sounding board for the independent cost estimates (bottoms-up). The facility cost generating capability was given high regard by the study group. The initial estimates were good for comparative purposes. It showed the LRB had a substantial Life Cycle Cost saving potential.

4.3.3 General Dynamics Estimate

The General Dynamics KSC LCC for LRB ground processing was provided to LSOC in their final study report. Little insight into the cost generation was provided. The GOCM was used in Part B of their cost estimate.

4.3.4 Martin Marietta Company Estimate

The Martin Marietta Company used the initial LSOC conceptual cost estimates dollar value in their total life cycle cost estimate. Subsequent cost generation analysis is unknown.

4.3.5 KSC Detail Bottom-up Estimate

This cost estimate utilized the LRB study findings and products as source data. Timelines provided processing manpower and shifts. Facility requirements had estimated costs which were used in developing the non recurring cost. The strength of this estimate is in the resolution derived and completeness of study that was undertaken. This effort did not extrapolate costs based on the cost per flight, but rather manloaded the facility and costed the capability.

It is felt this is a more complete and accurate cost estimate, than was previously performed, and was used in large part to derive the final estimate.

4.3.6 Final GOCM Estimate

GOCM was modified to perform an STS - LRB and SRB mixed fleet cost estimate. It was also calibrated and errors were corrected. GOCM was found to be 80% accurate and to have realistically covered the cost generation mechanisms in place at KSC. The final cost estimates included new facility CERs (LRB peculiar facilities). The final GOCM cost estimates were a major contributor to the final estimates.

4.4 LRB COST ESTIMATE

4.4.1 Final LRB Cost Estimate

The "bottoms-up" cost estimate is $1.8 billion dollars. GOCM supports this cost estimate. LSOC believe that the actual cost is between $1.7 to $2 billion dollars. If a set of new (2) launch pads are required the estimate increases to $2.7 to $3 billion dollars.

The recurring cost estimates are insensitive to booster option, but very sensitive to achieved launch rate. In depth follow-on study and evaluation is recommended before and during OT&E (Phase B, C and D). More sensitive study tools (cost and schedule models) may be needed in order to perform these studies and evaluations. Their development is recommended.

4.5 COST OVERVIEW

The STS/SRB will need additional facilities according to GOCM to insure it has the capability to support a launch rate of 14 per year. The GOCM achieves this launch rate by adding a new VAB high bay and fourth MLP.

KSC is planning to achieve the launch rate in a different manner. They plan to perform off-line stacking on a MLP and to acquire an additional OPF bay.
The important conclusion reached is: the STS/SRB configurations needs a large non-recurring expenditure to achieve the planned launch rate. This applies to mixed booster fleet operations and single STS/SRB fleet booster operations. Therefore, the delta cost shown for mixed fleet and SRB fleet costs in Figure 4.5 can not be considered in the comparison of LRB and SRB costs at KSC.

The utilization of LRB on the Shuttle presents an additional $716M non-recurring (besides the SRB $373M) cost. The Figure 4.5 costs needs to be inflated by 25% to be in the same terms as Figure 4.3-2. The final GOCM STS/LRB and STS/SRB costs are presented in Figure 4.3-2. The

SCENARIO	NON-RECURRING COST	RECURRING COST	TOTAL COST
MIXED FLEET	389 (716) ①	5,109	5498 (5825)
SRB FLEET	373 ②	5,236	5609
DELTA	16.0 M	127.0 M	111 M (219)
LRB (Alone) ③	716	700	1416
SRB (Alone) ③	373	472	845

NOTE: NO LEARNING HAS BEEN APPLIED. ALL COSTS FY 87 DOLLARS.

① ONE NEW MLP, HORIZONTAL PROCESS FACILITY, 1VAB HIGH BAY = 389 M, PLUS 1 EXTRA MLP AND MODS TO PAD 327 M (GOCM DATA APPLIED TO MEET LRB / KSC CONSTRAINTS)

② FOR SRB TO ACHIEVE 14 LAUNCH PER YEAR REQUIRES 1 NEW MLP OR EQUIVALENT, 1 VAB HIGH BAY ACCORDING TO GOCM.

③ BOOSTERS ALONE DO NOT EXPERIENCE THE ECONOMIES OF SCALE AS THEY DO IN THE STS PROGRAM.

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Figure 4.5. GOCM KSC STS Life Cycle Cost.

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GOCM STS/LRB cost could have been adjusted further with a pre-51-L error correction applied in the post-51-L environment (20% discovered during calibration) which would bring the total Life Cycle Cost estimates to $2B. However, this adjustment was not applied.

Accuracy is not believed to be an issue with these estimates. However, the degree of completeness is a concern. The final estimate is between the "bottoms-up" estimate and the GOCM estimate. It was rounded up to an upper value of $2 billion dollars. It is believed this buffer might account for cost element oversights.

Incorporating the Final LRB KSC cost estimate and the General Dynamics (removed KSC cost) estimate into the projected LCC in Figure 4.1.2-2, we arrive at a new STS/LRB LCC: $182B. Therefore, the previously performed sensitivity analysis (Figure 4.1.2-2 and 4.1.2.1-1) could be updated and would be expected to show an approximate 12% greater sensitivity.

4.5.1 Recurring Costs in Comparative Terms

Comparing SRB vs. LRB recurring cost in equivalent terms is difficult for two reasons. First, the distribution of assumed cost varies from one booster program to another. For instance, MSFC assumes the solid booster cost which encompasses fuel. The LRB will be fueled at KSC. KSC assumes these costs. Second, SRB processing has undergone an unquantified change since pre-51-L to present (post-51-L). Therefore, comparing the predicted LRB costs with pre-51-L actual SRB costs is incorrect.

Adjusting the "bottoms-up" LRB estimate for SRB comparison (fuel, spares, transition) the $.97B dollar recurring cost decreases to $.58B.

Adjusting SRB 1985 actual recurring costs for future equivalent performance with the LRB (1.4 greater processing time assumed, O&M for an additional 185M of SRB facilities to achieve 14 launches/year, and adding one civil service/non SPC person for every four SPC person) a $.74B recurring cost is arrived at.

Adjusting the GOCM SRB recurring cost with a correction factor based on the measured accuracy for 1985, an SRB recurring cost of $.59B is arrived at. Again there is uncertainty associated with the post-51-L environment.

In as near equivalent terms as possible the LRB and SRB recurring processing costs for 15 years of operation are:

LRB $.59B - $.70B
SRB $.59B - $.74B

It is noted the above costs are not the KSC recurring cost (which are higher). It is also noted that there is uncertainty associated with post-51-L SRB costs. GOCM cost for the STS/SRB vs. STS/LRB shows the STS/LRB recurring cost is $127M more affordable.

4.5.2 KSC Delta Booster Costs Mixed Booster Fleet vs. SRB Booster Fleet

If KSC were to maintain (only) STS/SRB operations it would experience its current recurring costs and an additional new facility recurring and non-recurring cost.

Implementing the LRB at KSC encompasses the above costs plus the LRB peculiar costs and the transition peculiar costs. The delta between these two scenarios is approximately:

Mixed Booster Fleet	SRB
716M NR Mixed Booster Fleet	
373M NR SRB Booster Fleet	373M
1.100B	
-0.127 Rec.	
0.970B	.373B

Delta STS/SRB, STS/LRB KSC LCC is: ~ .6B (LRB more expensive).

4.5.3 Final KSC LRB Cost Conclusion

In summary the following cost conclusions have been reached:

1. Upper bound for LRB LCC at KSC is 2B dollars (NR~1B, R~1B)
2. KSC recurring costs are insensitive to LRB option
3. KSC non-recurring costs are sensitive to LRB option
4. STS overall LCC is sensitive to achieved launch rate, which translates to flight element processing friendliness, i.e. LRB
5. There are potential cost escalators, i.e. Pad, $1B

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Gordon E. Artley, Lockheed Study Manager
L.P. Scott, Lockheed Deputy Study Manager
W.J. Dickinson, NASA Study Manager

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Lockheed Space Operations Company
Advanced Projects Office , LSO-003
1100 Lockheed Way, Titusville, FL 32780

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13. ABSTRACT *(Maximum 200 words)*

The impacts of introducing Liquid Rocket Boosters (LRB) into the STS/KSC Launch environment are identified and evaluated. Proposed ground systems configurations are presented along with a launch site requirements summary. Pre-launch processing scenarios are described and the required facility modifications and new facility requirements are analyzed. Flight vehicle design recommedations to enhance launch processing are discussed. Processing approaches to integrate LRB with existing STS launch operations are evaluated. The key features and significance of launch site transition to a new STS configuration in parallel with on-going launch activities are enumerated.

The LRB Integration Study Final Report is presented in Five volumes as follows:

VOL I Executive Summary
VOL II Study Summary
VOL III Study Products
VOL IV Reviews and Presentations
VOL V Appendices

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