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SPACE TRANSFER VEHICLE CONCEPTS AND REQUIREMENTS STUDY

Phase I Final Report
Volume III, Book 1
Program Cost Estimates
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The National Aeronautics and Space Administration
George C. Marshall Space Flight Center
By
Boeing Aerospace & Electronics
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FOREWORD

This final report of the first phase of the Space Transfer Vehicle (STV) Concept and Requirements Study was prepared by Boeing for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-37855. The study was conducted under the direction of the NASA Contracting Officer Technical Representative (COTR), Mr Donald Saxton from August 1989 to November 1990, and Ms Cynthia Frost from December 1990 to April 1991.

This final report is organized into the following seven documents:

Volume I EXECUTIVE SUMMARY

Volume II FINAL REPORT
- Book 1 - STV Concept Definition and Evaluation
- Book 2 - System & Program Requirements Trade Studies
- Book 3 - STV System Interfaces
- Book 4 - Integrated Advanced Technology Development

Volume III PROGRAM COSTS ESTIMATES
- Book 1 - Program Cost Estimates (DR-6)
- Book 2 - WBS and Dictionary (DR-5)

The following appendices were delivered to the MSFC COTR and contain the raw data and notes generated over the course of the study:

Appendix A	90 day "Skunkworks" Study Support
Appendix B	Architecture Study Mission Scenarios
Appendix C	Interface Operations Flows
Appendix D	Phase C/D & Aerobrake Tech. Schedule Networks

The following personnel were key contributors during the conduct of the study in the disciplines shown:

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CONTENTS

ACRONYMS

AC	attitude control
ACS	attitude control system
AIL	avionics integration laboratory
ALS	Advanced Launch System
APU	auxiliary power unit
ASE	advanced space equipment
ASIC	application-specific integrated circuit
ATC	active thermal control
ATDRSS	advanced TDRSS
BIT	built-in test
BOLT	Boeing Lunar Trajectory Program
CASE	computer-aided software engineering
CNDB	civil needs database
CNSR	comet nucleus sample return
CPCI	computer program configuration item
CT	communications and tracking
CTE	coefficient of thermal expansion
CWBS	contract work breakdown structure
DAK	double aluminized Kapton
DDT&E	design, development, test, and evaluation
(delta) T	change in event duration
(delta) V	change in velocity
DoD	Department of Defense
DMR	design reference missions
DRS	design reference scenario
DSN	deep space network
ECLSS	environmental control and life support system
EOS	Earth observing system
EPS	electrical power system
ESA	European Space Agency
ETO	Earth to orbit
EVA	extravehicular activity
FAIT	final assembly, integration, and test
FC	fluid control
FEID	flight equipment interface development
FEPC	flight equipment processing center
FOG	fiber-optic gyro
FSD	full-scale development
GB	ground based
GC	guidance control
GEO	geosynchronous orbit
GFE	Government-furnished equipment
GLOW	gross liftoff weight
GNC	guidance, navigation, and control
GO	ground based, on orbit

GPS	global positioning system
GSE	ground support equipment
HEI	Human Exploration Initiative
HEO	high Earth orbit
HESR	Human Exploration Study Requirements
HLLV	heavy lift launch vehicle
ICI	Integrated Systems Incorporated
ILD	injection laser diode
IMU	inertial measurement unit
IUS	Inertial Upper Stage
IVA	intravehicular activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAD	liquid acquisition device
LAN	local area network
LCC	life cycle cost
LCD	liquid crystal display
L/D	lift to drag
LECM	lunar excursion crew module
LED	light-emitting diode
LEO	low Earth orbit
LES	launch escape system
LEV	lunar excursion vehicle
LLO	low lunar orbit
LMS	lunar mission survey
LO	lunar orbiter
LOD	lunar orbit direct
LOI	lunar orbit injection
LOR	lunar orbit rendezvous
LOX/LH	liquid oxygen/liquid hydrogen
LSC	launch support and control
LSS	lunar surface system
LTS	lunar transportation system
LTV	lunar transfer vehicle
MEOP	maximum expected operating pressure
MET	mission elapsed time
MEV	Mars excursion vehicle
MLI	multilayer insulation
MPS	main propulsion system
MSFC	Marshall Space Flight Center
MTPE	mission to planet Earth
MTV	Mars transfer vehicle
NEP	nuclear energy propulsion
NPSH	net positive suction head
NTR	nuclear thermal rocket
ORU	orbit replaceable unit

O&S	operations and support
P/A	propulsion/avionics
PC	propulsion control
PCM	parametric cost model
PDT	product development team
PODS	passive orbital disconnect strut
PSS	planet surface system
PVT	pressure-volume-temperature
PWBS	project work breakdown structure
RCS	reaction control subsystem
RFP	request for proposal
RLG	ring laser gyros
RMS	remote manipulator system
RTV	room temperature vulcanizating
SB	space based
SDF	software development facility
SEI	Space Exploration Initiative
SEP	solar energy propulsion
SEU	single-event upset
SG	space/ground
SIP	strain isolation pad
SIRF	spaceborne imaging radar facility
SIRTF	Space IR Telescope Facility
SLAR	side-looking aperture radar
SOS	silicon on sapphire
SRM	solid rocket motor
SSE	space support equipment
SSF	Space Station Freedom
STIS	Space Transportation Infrastructure Study
STS	space transportation system
STV	Space Transfer Vehicle
TDRSS	tracking and data relay satellite system
TEI	trans-Earth injection
TLI	translunar injection
TMI	trans-Mars injection
TPS	thermal protection system
TVC	thrust vector control
TVS	thermodynamic vent system
USRS	Upper Stage Responsiveness Study
VHM	vehicle health monitoring
VHMS	vehicle health management system
V&V	verification and validation
ZLG	zero lock gyro

1-1.0 COSTING APPROACH, METHODOLOGY, AND RATIONALE

1-1.1 PARAMETRIC COSTING METHODOLOGY

The Space Transfer Vehicle (STV) Concepts and Requirements Study, contract NAS8-37855, included a task for cost estimate and program planning analysis in the NASA-provided statement of work to Boeing Aerospace & Electronics. The task 5.4 title for this activity was "Programmatics." The Boeing-Seattle STV program plan identified this activity as task 4.

Cost Analysis Team Members. The Boeing cost analysis team consists of four members: Mr. Al Peffley is the task 4 technical leader; Mr. Hal Boggs performed early parametric cost estimates using the Boeing proprietary cost model; Mr. Thom Wolter completed the cost modeling support tasks after Interim Review number 2; and Mr. Greg Paddock, engineering systems analyst.

Mr. Paddock developed and operated the STV life cycle cost (LCC) model during the study. The model is a large Excel© spreadsheet program.

Program Definition Team Members. The program schedules development and program planning analysis tasks are accomplished by the Program Planning organization within Boeing Space Systems Division. The three key member of this group that perform the program planning and schedules tasks are Mr. Don Benson, Ms. Lori Todd, and Mr. Bob Croken. Don Benson and Bob Croken provide both life cycle and study schedules for management and cost analysis uses. Ms. Todd developed the program schedule logic networks using Open Plan application software.

The rest of the Boeing-Seattle team provided inputs to the parametricians and planners as the study progressed. Boeing-Huntsville Civil Space Group, managed by Mr. Gordon Woodcock, also provided Space Station and Mars program schedules and in-space cost factors information in a timely manner.

NASA Customer Interfaces. Ms. Saroj Patel and Mr. Mahmoud Naderi were the NASA MSFC technical focal points for the MSFC Engineering Cost Group (PP03). The schedules effort is monitored by Mr. Steve Spearman (Office PP02). Mr. Don Saxton was the STV study COTR. He provided the majority of the program-level scheduling groundrules during this NASA-Boeing study. Ms. Cynthia Frost is the current COTR.

1-1.1.1 Boeing Parametric Cost Modeling Support

Mr. Hal Boggs began the parametric cost model (PCM) setup by estimating the lunar transfer vehicle (LTV) and lunar excursion vehicle (LEV) hardware. The initial LTV/LEV was described in the NASA 90-Day Study, produced by the "Skunkworks" special study teams in late 1989. Mr. Boggs also ran a verification check of the Boeing PCM using Apollo lunar module cost data analyzed by Eagle Engineering, Inc. (reference: NASA contract NAS 9-17878; March 30, 1988). The early STV cost analysis exercises helped to identify LTV/LEV high-value subsystems and also enabled the Boeing team to calibrate the Boeing PCM global inputs.

Mr. Wolter operates both the Boeing proprietary PCM and the GE Price-H © cost models (independent assessments are accomplished with GE Price). The PCM runs require mass properties and technical description data from STV project design engineers. The Boeing PCM is used to develop and document design, development, test, and evaluation (DDT&E) and theoretical first unit (TFU) estimates for STV system acquisition cost evaluations. The Boeing "Ranger" cost risk model (a Boeing proprietary estimating tool) is also used for phase C/D cost estimate uncertainty analyses (see section 1-1.6 for further explanation of the Ranger modeling and analysis technique).

Mr. Peffley uses the TFU estimates and operation and support inputs from STV study task 3 to generate the recurring cost estimates for the LCC summaries. The LCCs are developed initially in constant-year dollars. The constant-year dollars estimates are escalated using NASA-provided inflation indices.

1-1.1.2 Estimating Techniques Overview

The estimating technique used to support STV system, subsystem, and component cost analysis is a mixture of parametric cost estimating and selective cost analogy approaches. The parametric cost analysis is aimed at developing cost-effective aerobrake, crew module, tank module, and lander designs with the parametric cost estimates data. This is accomplished using cost as a design parameter in an iterative process with conceptual design input information.

The Boeing parametric estimating approach segregates costs by major program life cycle phase (development, production, integration, and launch support). These phases are further broken out into major hardware subsystems, software functions, and tasks according to the STV preliminary program work breakdown structure (WBS), which has been jointly developed by NASA and Boeing (see Volume III, Book 2).

The WBS is defined to a low enough level of detail by the Boeing study team to highlight STV system cost drivers. This level of cost visibility provided the basis for cost sensitivity analysis against various novel and state-of-the-art design approaches aimed at achieving a cost-effective design. Section 1-1.7 contains WBS trees for reader reference.

Boeing Cost Model Description. The Boeing PCM has been developed over the past 15 years at Boeing. PCM is designed specifically for advanced aerospace systems estimating. PCM is used to estimate contractor manpower and dollar resources required for development and first unit production of a variety of space, missile, and military aircraft systems. The model cost estimating relationships (CER) contain historical labor-hours and resource cost data on Boeing commercial and military programs for the system integrator and hardware make item tasks.

Once the production program delivery schedule is established, PCM can also be used to develop production lot buy estimates. Learning curves can be selected and applied at the component and subsystem levels.

Boeing PCM requires the following hardware-related inputs: item classification; weight, power level, or square footage design parameters; selected level of complexity to design and produce system elements; item and shipset quantity; learning curves by hardware item; dollar estimate throughputs; a factor consideration for using existing designs (off-the-shelf factor); and a technology maturity-level factor. The hardware categories are displayed in Figure 1-1.1.2-1. The PCM engineering technology maturity-level table is shown as Figure 1-1.1.2-2.

Additionally, the cost model permits the use of material complexity scaling factors. The material factors are applied to hardware items that will require the incorporation of structural composites (such as graphite polyimides) or special alloy metals (e.g., titanium alloys, Rene 41, and Columbium).

The primary PCM programmatic or "global" inputs are task-direct labor wraparound rates (in constant-year dollars); program support labor complexity index values for "below-the-line" labor functions (e.g., system engineering and integration, software labor, and system test labor); schedule compression factor; tooling-level factor; final assembly and checkout factor, and class I change factor.

Figure 1-1.1.2-3 is an example of the PCM global inputs sheet. The platform level selected for the STV hardware estimates is "manned space." The software estimate for development and flight software was developed outside the Boeing PCM system.

Most of the avionics and propulsion engine or thruster hardware items were input as throughput dollars to the parametric cost model. The plumbing hardware and power distribution hardware were estimated using PCM system CERs.

Boeing Cost Model Output. For each estimated STV hardware item (with design parameter inputs), PCM generates man-hour estimates for engineering design, developmental shop technicians, manufacturing shop direct labor, and manufacturing planning labor. PCM. It then generates dollar estimates for these

CATEGORY DESCRIPTION		CATEGORY DESCRIPTION	
Inputs In Pounds Unless Otherwise Noted			
MECHANICAL		ELECTROMECHANICAL	
M1	Fabricated Part (sheet metal)	X1	Solar Panels (Sqft)
M2	Fabricated Part (casting)	X2	Fuel Cells (Watts)
M3	Thermal Blankets (Sqft)	X3	Electric Motors & Generators
M4	Secondary Structure	X4	Antenna (non dish)
M5	Tanks	X5	Antenna (dish)
M6	Primary Structure	X6	Control Moment Gyro
M7	Plumbing	X7	IMU/IRU
M8	Heat Exchanger	X8	Sun/Star Tracker
M9	Pumps & Gear Boxes	X9	Tape Recorder
M0	Mechanism		
ELECTRICAL		PROPULSION	
E1	Cabling	P1	Empty
E2	Battery	P2	Turbine
E3	Power Conditioning	P3	Solid Rocket
E4	Signal Conditioning	P4	LOX/RP Rocket (Lb Thrust)
E5	Signal Interface Unit	P5	LOX/LH Rocket (Lb Thrust)
E6	Computer	P6	Thruster System
E7	Receiver	INT	Subsystem Integration
E8	Transmitter/Transponder	ASY	Subsystem Assembly

Figure 1-1.1.2-1. Hardware Category Selection Guide

PCM

Engineering Technology Maturity Level

Level	Description	Design Factor
1*	Qualified off-the-shelf hardware design	0.30
2	Engineering model tested in actual mission environment	0.45
3	Prototype model tested in relevant environment	0.65
4	Preprototype, engineering model tested	0.75
5	Component brassboard tested	0.80
6	Critical function/characteristic demonstrated	0.85
7	Conceptual design tested analytically or experimentally	0.90
8	Concept design formulated	1.00
9	Basic principles observed and reported	----
10	Basic principles not identified	----

* At this maturity level, an appropriate "% of components available OTS" should be used on the hardware specifics input sheet.

Figure 1-1.1.2-2. PCM Engineering Technology Maturity Level

PCM GLOBAL INPUTS

Revision 12

File Name ______

Year dollars ______

START

CASE

DWRAP

Engr | DevShop | BFL | MfgEngr | QA | Tooling | Remote | ProgDirect | ProgMgmt

PWRAP

BFL | MfgEngr | QA | Tooling | Engr | Remote | ProgDirect | ProgMgmt

SWRAP

Engr | DevShop | BFL | MfgEngr | QA

IWRAP: BCAC | BECO | BMAC

FACTORS

DS/Engr | QA/Mfg | MfgEngr | ProgBusSupt | MfgC.C. | EngSuprt | Rework | Misc/pics | CaptiveShop

ASUPPORT COMPLEXITY

SE&I | Software | SysTest | SEDesign | SEMfg

BSUPPORT COMPLEXITY

Tooling | Logistics | Lia/ProdEng | Data

FINAL ASSY & CHECKOUT

Factor | PugSnd% | Remote% | Subcon% | GFE%

SPARES %

Boeing | Subcon | GFE

FLIGHT TEST SUPPORT

Hours | Remote%

PLATFORM: PlatNo.

MISC

Classl | Qty/Lc | Scrap/Changes

SCHEDULE: Engr± % | Mfg ± %

OPTIONAL INPUTS

THRUPUT ______ : Engr | $M | Mfg

THRUPUT ______ : Engr | $M | Mfg

SOFTWARE ______

PSE: Engr | $M | Mfg

Figure 1-1.1.2-3. PCM Global Inputs

labor categories based on the wrap rates from the cost model's global inputs section.

PCM also produces man-hour and dollar estimate outputs for support functions below the basic hardware estimates (sometimes called "below-the-line" costs). Final assembly and checkout, system integration, software engineering, quality control task-loaded support, system ground test, peculiar support equipment design/manufacturing, tooling and special test equipment, spares, liaison engineering, and data hours/dollars are estimated from the resultant design and manufacturing direct hours outputs with labor-to-labor hours cost-estimating relationships.

System Trade Study Support Approach. Because of the high level of definition associated with early trade study inputs, specific hardware complexity evaluation inputs yielded to a more nominal value approach. This was done to accomplish over 108 separate hardware flight element estimates in 2 weeks (development and TFU runs).

For example, even though each hardware flight element has different mass properties, all of the candidate systems were defined with the following inputs:

1. The input for the level of complexity, both developmental and manufacturing, was entered across the board as a level 5 (on a scale of 1 to 10). A 5 is historically reflective of a typical Boeing space platform program.
2. Off the shelf is defined to be that portion of the design that has already been proven or that portion of a manufactured item that is currently available. This input was entered as a 0% for the trade studies estimates.
3. The engineering technological maturity level was input consistently as a factor reflective of a prototype model tested in a relevant environment.
4. There was assumed to be no learning curve application.
5. A schedule variation was applied reflecting a engineering schedule that was 15% shorter than a theoretically optimal schedule.

Boeing Cost Model Database Overview. The database from which the cost estimating relationships for the Boeing proprietary PCM were derived is comprised of over 1,100 data points from a wide variety of aerospace programs. Hardware programs contained in the database are comprised of space vehicles, planet surface system hardware, space launch vehicles, tactical and strategic missile systems, commercial aircraft, military aircraft, helicopters, and aerospace ground systems hardware.

The data is not limited to Boeing commercial and military information only, but it also contains hardware data from other aerospace industry sources. In addition (as previously mentioned), the database has been designed for segregation of hardware to the line replaceable unit (LRU) level, the subsystem level, and the system level. This segregation allows for the development of estimates at varying levels of program definition.

Each hardware category included in the database is designed to store five major areas of cost and non-cost information. These key areas include physical hardware characteristics, performance characteristics, schedule information, cost and man-hour data, and related programmatic information.

Within each of these key areas the data are further defined. For example, physical hardware characteristics may include weight, square footage, volume, descriptions of the mechanical assembly and circuit boards, complexities, and so forth. Also, segregation of the data by program phase and generic hardware classification allows us to best model almost any aerospace major program or platform scenario.

Space hardware technical and historical cost data included in PCM are from such programs as Lunar Orbiter, MVM, Lunar Rover, Saturn S1-C, IUS, S3 Small Satellites (USAF), Burner II, SESP (USAF), and Viking systems. Some Centaur and shuttle orbiter subsystem data are used for analogy and cost comparison purposes.

In addition to these space programs, other programs contained in the database include X-20 Dynasoar, SST, Air-Launched Cruise Missile (ALCM), Short Range Attack Missile (SRAM), most of the Boeing Commercial Airplane Group programs, AWACS, Minuteman, and a variety of small military aerospace systems.

The database is periodically being updated to maintain the most current cost estimating relationships possible. This parametric database is maintained by the same people who develop and maintain the parametric models used to estimate the STV program. This ensures that the people who best understand the data are also developing the estimate for the STV study.

Boeing Cost Model Validation Exercise. In April 1989, the PCM staff at Boeing ran a series of validation runs using the U.S. Air Force Inertial Upper Stage (IUS) program historical data for the full-scale development (FSD) phase. The results were that the overall program estimate out of PCM was 19.6% higher than the IUS FSD actuals (including class I changes.) This variance is acceptable within the expected accuracy range of a phase A planning estimate (i.e., plus or minus 25%).

1-1.2 GROUNDRULES AND ASSUMPTIONS

The first STV system estimates were developed in constant-year, 1989 dollars, in accordance with the statement of work in the STV study contract. During the study performance period the estimates were changed to 1991 dollars at the request of the customer technical interface. Since the STV life cycle cost trade study model was developed with cost data in 1989 dollars, the early architecture trade study results were presented in 1989 dollars. STV system estimates were developed in 1991 dollars after Interim Review number 3.

Other program-level estimating factors for the STV program were provided by the Cost Analysis Group at MSFC. These factors are a requirements change factor at 30% to 35%, a contractor fee allowance at 8% to 10% (originally we used only 10%), and a NASA program support factor of 5% to 15% (the percentage varies depending on the type of hardware). The factors used for cost estimating are documented for each review in section 1-2.0.

1-1.2.1 System Definition Groundrules

The vehicle hardware design candidates are selected according to system requirements evolving from the NASA 90-Day Study, released in early 1990. The primary focus for this STV study is directed by NASA to be the accomplishment of the lunar transportation system (LTS) mission, with parallel evolution to other NASA/DoD missions and eventual evolution to some Mars transportation system mission elements. The civil needs databases (CNDB) for FY1989 and FY1990 were used as mission models for STV program cost and schedule analyses.

U.S. space program goals set in the Presidential speech of George Bush of a return to the Moon between 2001 and 2005 influenced the program planning assumptions and resulting cost estimates. Throughout the study, the NASA and contractor team members attempted to meet both the CNDB and Presidential goals. As Space Exploration Initiative funding was delayed by Congress, the start of phase C/D and deployment schedules have slipped to later years several times during the course of the 1-year study period.

Figure 1-1.2.1-1 contains the original program master schedule parameters assumed at the beginning of the study. The final master program schedule is shown as Figure 1-1.2.1-2. Program schedules are also described in the "Integrated Advanced Development Plan," Volume II, Book 4. The start of phase C/D and preliminary design review (PDR) dates slid 1 year twice during the study period. Figure 1-1.2.1-3 depicts the CNDB FY90 mission model used to generate final STV LCC estimates.

1-1.2.2 Hardware Groundrules

The Boeing PCM requires a platform selection. The manned space platform level is selected as a groundrule for the STV because the LTS vehicle has 21 manned flights to the Moon out of 25 total flights (4 sorties are cargo-only flights.) The platform level was changed to unmanned space for derivative kit hardware that is used on the single-engine expendable vehicle configuration (NASA/DoD missions to geosynchronous orbit and high Earth orbit.) These platform groundrules drive development, non-recurring production, recurring unit hardware, and operations maintenance cost estimates.

The engine estimates include both an RL10 derivative for expendable vehicle missions and an advanced space engine (ASE) for the LTS mission. The requirements for a minimum of five reuses of reusable STV flight equipment and a 6-month surface stay time on the Moon (with reliable restart and housekeeping capabilities) influence both the ASE cost estimates and the other subsystems hardware estimates. The hardware estimates were calculated with development and manufacturing hardware complexity levels that relate to equipment protected against single-event upsets (SEU) and single-string failures. Redundancy assumptions were imposed on all safety, flight, and mission critical subsystems in the estimates (electrical/electronic and engines).

The crew size of four people for the LTS missions and a LTS cargo manifest document from NASA-JSC planetary surface systems defined the hardware performance and cost estimate inputs. A LTS cargo goal of 34 metric tons sized the largest STV cargo derivative vehicle for estimating.

BOEING

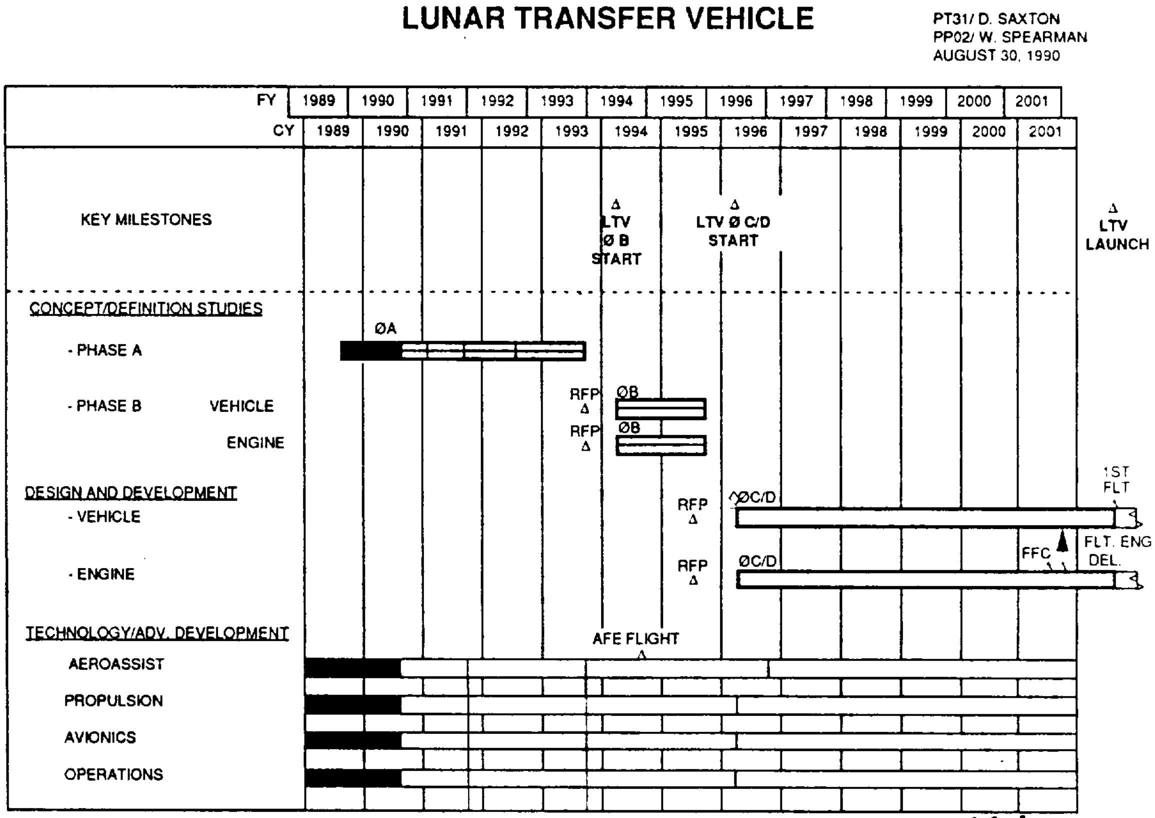


Figure 1-1.2.1-2. Lunar Transfer Vehicle

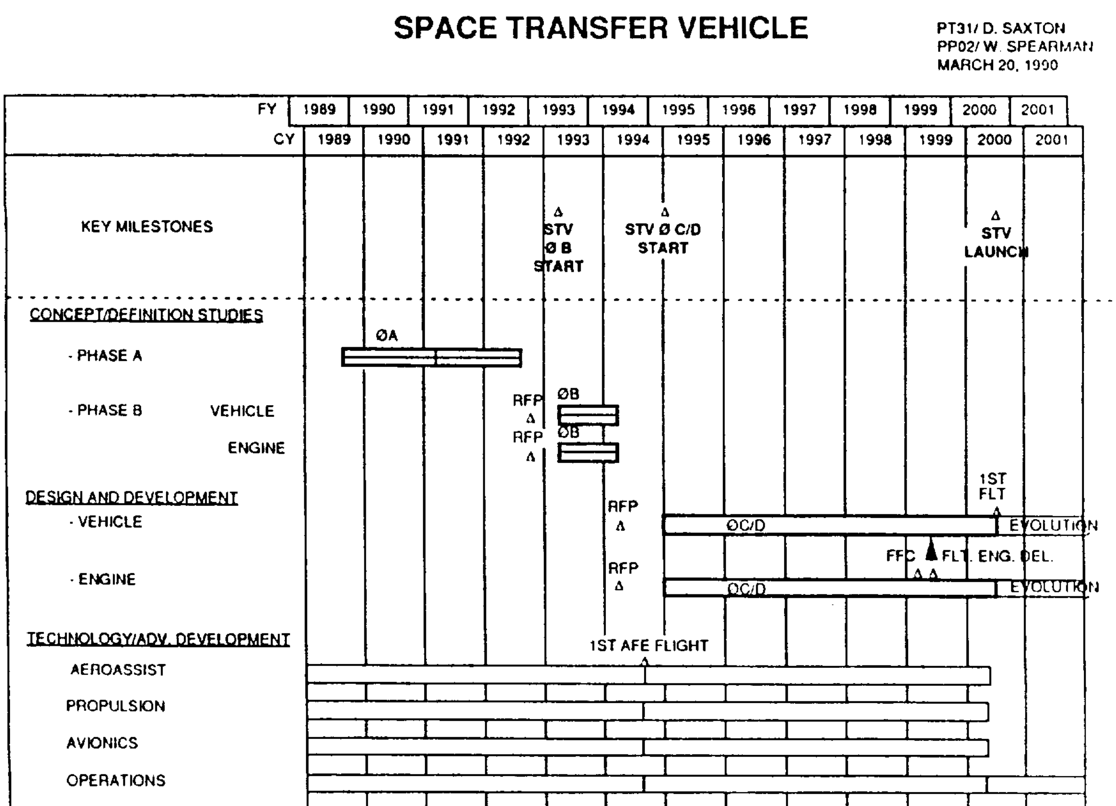


Figure 1-1.2.1-1. Space Transfer Vehicle

CNDB FY90 Changes Overview

DRM	Launch Year												Total
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
L1	0	0	0	1	1	0	0	1	0	0	0	1	4
L2	0	0	0	0	0	1	1	0	1	1	1	0	5
P1	0	0	1	0	2	2	0	0	1	0	0	0	6
G1	0	0	1	1	1	0	1	0	1	0	1	0	6
~~G2~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~0~~	~~0~~	~~3~~
~~S1~~	~~0~~	~~0~~	~~1~~	~~0~~	~~1~~	~~0~~	~~0~~	~~1~~	~~0~~	~~1~~	~~0~~	~~0~~	~~4~~
~~T1~~	~~0~~	~~0~~	~~4~~	~~4~~	~~5~~	~~6~~	~~6~~	~~5~~	~~4~~	~~5~~	~~4~~	~~7~~	~~50~~
~~N1~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~
~~G1~~	~~0~~	~~0~~	~~0~~	~~1~~	~~0~~	~~1~~	~~2~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~4~~
Total	0	0	2	2	4	3	2	1	3	1	2	1	21

- Augmented Mission Set Is Eliminated:
  - Unmanned polar platform servicing
  - Manned GEO platform servicing
  - Nuclear debris disposal
  - Manned sample capsule return

DRM	Launch Year										Total
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
L1	0	0	0	0	0	0	0	0	0	0	0
L2	1	1	1	1	1	1	1	1	1	1	10
P1	1	0	0	2	0	0	0	0	0	0	3
G1	0	0	0	0	0	0	0	0	0	0	0
Total	2	1	1	3	1	1	1	1	1	1	13

Total 2001 to 2010	21
Total 2001 to 2020	34

Design Reference Mission (DRM) Codes:

L1 - Lunar Cargo Mission
L2 - Manned Lunar Mission
P1 - Planetary Orbit/Exploration Mission
G1 - Geosynchronous Payload Mission

- CNDB FY90 Version Highlights:
  - Base of 476 events + 64 expansion flights is reduced to only those flights that pertain to planned STV capabilities.
  - Expanded model = "Option 5" Space Exploration Initiative
    - CNDB FY90 LTS elements do not match preferred contractor/NASA MSFC hardware 1.5 stage configurations.
    - CNDB assumes multiple HLLV launches per LTS mission.

Figure 1-1.2.1-3. CNDB FY90 Changes Overview

An architecture study of many different vehicle configurations was conducted first. Cost was one of the criteria for configuration selection. During this period of cost analysis, many cost model factors were set at mid-range levels (nominal levels) to facilitate the selection process (over 200 potential LTS configuration candidates were chosen to be evaluated for downselect). The results of the life cycle cost trade studies are further described in section 1-1.9 of this book.

1-1.2.3 Hardware Test Quantity Groundrules

In general, each STV configuration was estimated with its own unique test hardware quantity matrix until the final review. The architecture trade estimates contain more test hardware quantities than the estimates produced for the last two interim reviews in the study. The final phase C/D test hardware quantities used for the ground- and space-basing concepts are shown as follows:

STV Core Stage Development Test Quantity Assumptions

1 Combined Qualification/Pathfinder Unit.
2 Equivalent Core Stage Ground Test Units.
- 1 Static Test Vehicle (in parts).
- 1 Dynamic Test Vehicle (to failsafe).
1 Small Stage Derivative Flight Test Vehicle (NASA/DoD).
1 LTS Manned Configuration Flight Test Vehicle (unmanned flight tests with autonomous crew module functions).
1 LTS Cargo Flight Test (to the Moon and return).

---
5 Total Equivalent Core Stage Vehicles.

Avionics subsystem equipment, power distribution, cryogenic tankage, and other control subsystems hardware (which are required at more than one development laboratory site during development) are estimated with one or two additional shipsets for vendor, integrator, and Government test requirements. The crew module test hardware quantities were smaller (three to four units) because the preliminary test plan does not require as many manned flight test articles to prove the reusable crew module hardware functions meet the LTS specifications.

The space-based vehicle aerobrake test hardware quantity of six equivalent units includes one unit for an aeroassist flight experiment 2 (AFE 2) test during phase C/D; two equivalent units of parts for for a mockup, thermal, and ground test activities; one dynamic failsafe test unit; one qualification/pathfinder unit (will also be a flight test spare); and one LTS flight test prototype unit.

Engine test quantities are included in the vendor development estimates for the RL10 derivative (small stage mission engine) and the ASE (LTS mission engine) for vendor preflight and qualification test firings. Additional engine quantity of four RL10 derivatives and nine ASE units is estimated for system-level testing at MSFC or LeRC engine test stands, a six-engine cluster test at the NASA Stennis test site (engines will be refurbished as flight test program spares after cluster tests), and the flight test program vehicles.

1-1.2.4 Earth-to-Orbit Delivery Cost Assumptions

No other program synergisms, except the availability of a 71 to 120 metric ton capability booster system, are assumed for space-based and ground-orbital-based LTS configurations. The ground-based LTS derivative, which is delivered to low Earth orbit (LEO) in one piece, requires a very large heavy lift launch vehicle (HLLV) in the 250 metric ton range. The Earth-to-orbit (ETO) cost estimates in the life cycle cost analyses are a high-value item; Boeing and NASA looked at several factors to capture this system deployment cost. Final NASA-provided groundrules for ETO booster costs are selected as $2,500/lb. for HLLVs in the 71 metric ton class and $1,300/lb. for boosters in the 110 to 250 metric ton class. Martin and Boeing both used these factors in the final report estimates.

Early architecture studies looked at much lower ETO costs, but the HLLV estimates are now consistently applied across all candidate LTS configuration estimates. Therefore, in "relative" ETO dollars, the LCC trade study results are still valid for the downselect process.

1-1.2.5 Summary of Top-Level Program Factors

Figure 1-1.2.5-1 is a summary table of the program-level factors applied to the STV life cycle cost estimates in this study.

NASA PROGRAM SUPPORT FACTORS APPLICATION

STV System Element	Requirements	Fee	Gov. Support
DDT&E:			
New Transfer Vehicle	30%	10%	5%
Vehicle Drop Tanks	30%	10%	5%
Crew Module	30%	10%	15%
GO Tanker (LOX)	30%	10%	5%
System Engr. & Integr.	-	10%	5%
Facilities (Gov. Funded)	20-25%	10%	5%
Production:			
All Hardware	30%	10%	5%
Operations:			
All Tasks	25%	10%	-

Figure 1-1.2.5-1. NASA Program Support Factors Application

1-1.3 CONCEPTUAL DESIGN DESCRIPTIONS

A STV study team of designers and subsystem architects provides the cost analysis staff inputs for the hardware development and production estimates. The design and system integration characteristics are depicted by conceptual drawings, mass properties estimates, preliminary equipment lists (subsystem level), and mission scenario pictures and timelines.

These descriptions are used, with the mission model groundrules and program descriptions and assumptions, to develop both the parametric cost estimates and the operation and support planning estimates. The avionics conceptual design descriptions also drive the software definition and resulting flight software estimates.

The "Configuration and Subsystem Trade Studies" section (see Volume II, Book 1, section 3.0) of this report contains a complete summary of the concept design candidate process and pictures of the design families. The initial family descriptions were refined through the trade studies process (cost, schedule, performance, and operations risk assessments) down to a final set of two, optimized 1.5-stage STV configurations for the lunar mission. The final selected configurations and their respective summary weight statements are shown in Figures 1-1.3-1 and 1-1.3-2.

The additional CNDB missions for GEO and HEO sorties, with other NASA or DoD payloads, require a derivative smaller than the lunar mission configuration. This smaller STV derivative vehicle is created using a descent droptank set from the lunar mission vehicle, replacing the ASE propulsion unit with an RL10-A4 derivative engine, replacing the cryogenic crossfeed fluid supply system with a less complex fluid supply kit, and adding a military standard avionics wafer kit for vehicle navigation and control. Figure 1-1.3-3 contains the small stage derivative description summary used for the final life cycle cost estimates.

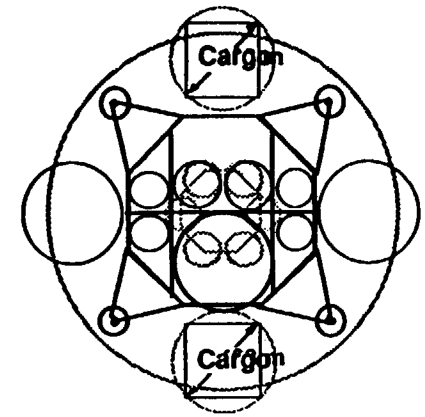
STV

MSFC- BOEING

SPACE BASED MASS SUMMARY

Vehicle Design

	Lunar Piloted Mission							
	Core Stage			TLI Drop-Tankset		LD Drop-Tankset		Lunar Surface Cargo
	Lander	Crew Module	Aero-Brake	Module #1	Module #2	Module #1	Module #2	
Structure and Mechanisms	1935	1496	2082	884	884	474	474	
Tankage - Main	583	-	-	1089	1089	597	597	
Protection	437	509	1477	642	642	385	385	
Propulsion - Main	2126	-	-	393	393	257	257	
Propulsion - Reaction Control	347	-	-	-	-	-	-	
Power Source	374	-	-	-	-	-	-	
Wiring & Electrical Interface	433	272	-	-	-	-	-	
Guidance, Navigation & Control	464	-	-	23	23	23	23	
Communication & Data Handling	422	124	15	35	35	39	39	
Displays & Controls	-	108	-	-	-	-	-	
Environmental Control	-	762	-	-	-	-	-	
Personnel Provisions	-	635	-	-	-	-	-	
Weight Growth Margin	1068	586	536	460	460	266	266	0
Total Dry Mass	**8189**	**4492**	**4110**	**3526**	**3526**	**2041**	**2041**	**9870**
Crew, with Suits	-	800	-	-	-			
Non-Propellant Consumables	-	291	-	-	-			
Non-Cargo Items - Residuals	332	-	-	781	781	374	374	
Inert Mass	**8521**	**5583**	**4110**	**4307**	**4307**	**2415**	**2415**	**9870**
MPS Usable Propellants	20967	-	-	63452	63452	27500	27500	
RCS Usable Propellants	137	-	-	102	102	152	152	
EPS Usable Reactants	242	-	-	5	5	391	391	
Other - losses, etc	107	1800	-	3168	3168	343	343	
Total LEO-Assembled Mass	29974	7383	4110	71034	71034	30801	30801	
	41467			142068		61603		9870
	255007							



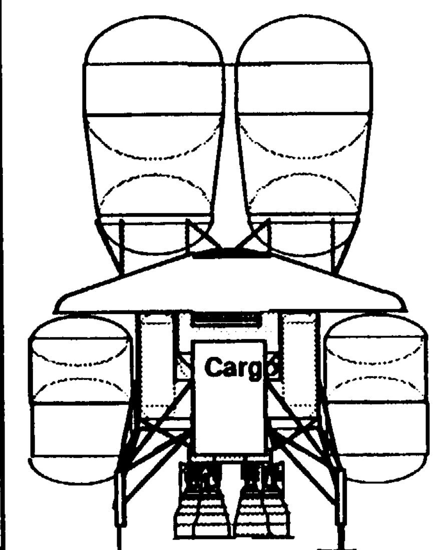


Figure 1-1.3-1. Space-Based Mass Summary (Sheet 1 of 2)

STV SPACE BASED MASS SUMMARY (CONCLUDED)

Vehicle Design

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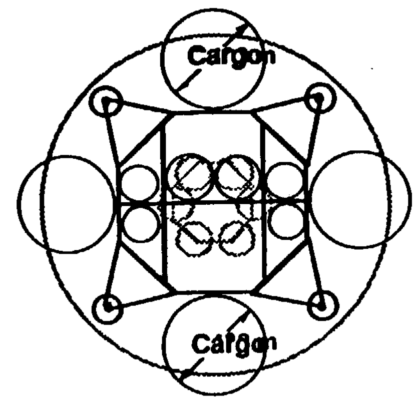
	Lunar Cargo Mission - Unmanned					
	Core	TLI Drop-Tankset		LD Drop-Tankset		Lunar Surface Cargo
	Lander	Module #1	Module #2	Module #1	Module #2	
Structure and Mechanisms	1935	884	884	474	474	
Tankage - Main	583	1089	1089	597	597	
Protection	437	642	642	385	385	
Propulsion - Main	2126	393	393	257	257	
Propulsion - Reaction Control	347	-	-	-	-	
Power Source	374	-	-	-	-	
Wiring & Electrical Interface	433	-	-	-	-	
Guidance, Navigation & Control	464	23	23	23	23	
Communication & Data Handling	422	35	35	39	39	
Displays & Controls	-	-	-	-	-	
Environmental Control	-	-	-	-	-	
Personnel Provisions	-	-	-	-	-	
Weight Growth Margin	1068	460	460	266	266	0
Total Dry Mass	**8189**	**3526**	**3526**	**2041**	**2041**	**52683**
Crew, with Suits	-	-	-			
Non-Propellant Consumables	-	-	-			
Non-Cargo Items - Residuals	332	781	781	374	374	
Inert Mass	**8521**	**4307**	**4307**	**2415**	**2415**	**52683**
MPS Usable Propellants	21327	64887	64887	28212	28212	
RCS Usable Propellants	126	116	116	106	106	
EPS Usable Reactants	0	0	0	0	0	
Other - losses, etc	0	2624	2624	68	68	
Total LEO-Assembled Mass		71934	71934	30801	30801	
	29974	143868		61603		52683
	288127					



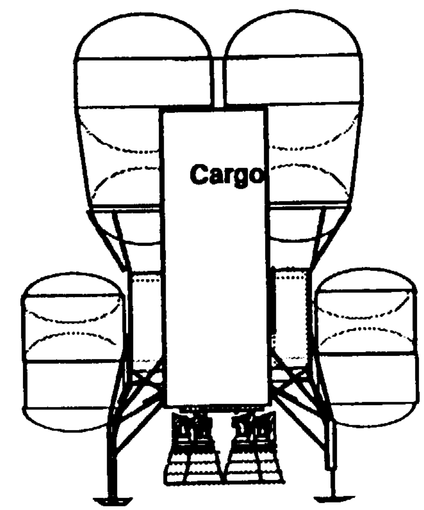
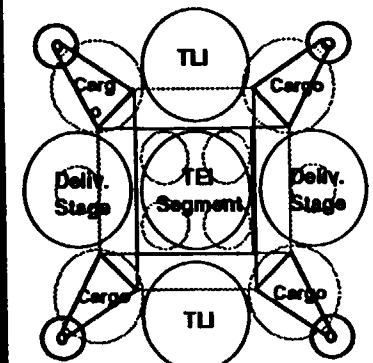


Figure 1-1.3-1. Space-Based Mass Summary (Sheet 2 of 2)

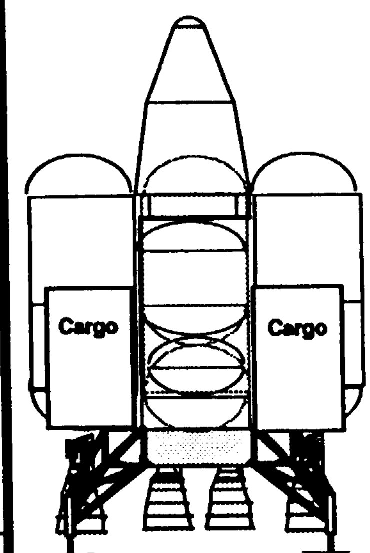
Ground-Based STV Mass Summary - Lunar Piloted
Cost & Programmatic Splinter Session

STV Mass Summary
Ground-based Vehicle — Lunar Piloted Mission — All mass in kg

	Core Vehicle							Drop-tanks		
	TEI Segment				Delivery Segment					
	Crew Mod	Av. Pallet	Tankset	Prop Mod	Lander	D Stg #1	D Stg #2	TLI Tnkst #1	TLI Tnkst #2	Delivered Cargo
Structure and Mechanisms	3341	155	505	483	1206	502	502	433	433	
Structures & Mechs - Landing gear	281	-	-	-	741	-	-	-	-	
Tankage - Main	-	-	385	-	-	659	659	659	659	
Protection	1315	116	378	-	82	570	570	570	570	
Propulsion - Main	-	-	376	917	828	545	545	380	380	
Propulsion - Reaction Control	162	-	-	-	-	190	190	-	-	
Power Source	-	374	-	-	-	-	-	-	-	
Wiring & Electrical Interface	272	265	28	56	78	39	39	28	28	
Guidance, Navigation & Control	130	464	-	-	-	-	-	-	-	
Communication & Data Handling	189	391	37	21	19	37	37	37	37	
Displays & Controls	108	-	-	-	-	-	-	-	-	
Environmental Control	813	-	-	-	-	-	-	-	-	
Personnel Provisions	635	-	-	-	-	-	-	-	-	
Weight Growth Margin	1087	265	256	222	443	381	381	316	316	0
Total Dry Mass	8333	2030	1965	1699	3397	2923	2923	2423	2423	11630
Crew, with Suits	800	-	-	-	-	-	-			
Non-Propellant Consumables	308	-	-	-	-	-	-			
Non-Cargo Items - Residuals	15	-	275	92	435	542	542	527	527	
Inert Mass	9456	2030	2240	1791	3832	3465	3465	2950	2950	11630
MPS Usable Propellants	-	-	17294	-	-	44592	44592	44676	44676	
RCS Usable Propellants	44	-	97	-	-	153	153	100	100	
EPS Usable Reactants	2	-	151	-	-	396	396	149	149	
Other - losses, etc	1800	-	75	-	-	296	296	515	515	
Total LEO-Assembled Mass	11302	2030	19857	1791	3832	48902	48902	48390	48390	
	34980				101637			96780		11630
	245026									



Top View



Side View

1-17-91

Figure 1-1.3-2. Ground-Based STV Mass Summary - Lunar Piloted

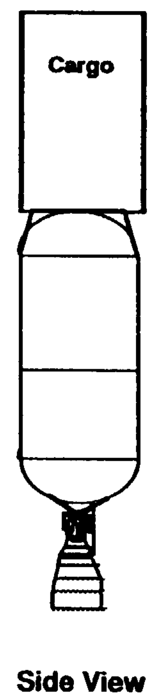
STV Ground-based STV Small StageSummary - GEO Delivery/Tug

MSFC- BOEING

Cost & Programmatic Splinter Session

STV Mass Summary — All mass in kg
Ground-based Vehicle — Unmanned Delivery

	Core Vehicle Delivery Segment Av. Pallet	Core Vehicle Delivery Segment D Stg #1	Delivered Cargo
Structure and Mechanisms	134	502	
Structures & Mechs - Landing gear	-	-	
Tankage - Main	-	659	
Protection	116	570	
Propulsion - Main	-	545	
Propulsion - Reaction Control	-	190	
Power Source	381	-	
Wiring & Electrical Interface	211	39	
Guidance, Navigation & Control	192	-	
Communication & Data Handling	216	37	
Displays & Controls	-	-	
Environmental Control	-	-	
Personnel Provisions	-	-	
Weight Growth Margin	188	381	0
Total Dry Mass	1438	2923	24000
Crew, with Suits	-	-	
Non-Propellant Consumables	-	-	
Non-Cargo Items - Residuals	-	542	
Inert Mass	1438	3465	24000
MPS Usable Propellants	-	44592	
RCS Usable Propellants	-	153	
EPS Usable Reactants	-	396	
Other - losses, etc	-	296	
Total LEO-Assembled Mass	1438	48902	
	50340		24000
	74340		



The tug and small stage designs are simple & cost effective.

Theoretical First Unit (TFU) Estimate:

Basic Stage	$	31.2 M
Avionics Kit		18.1
RL10-A4+		2.9
Total (91$)	$	52.2 M

1-17-91

Figure 1-1.3-3. *Ground-Based STV Small Stage Summary - GEO Delivery and Tug*

BOEING

1-1.4 TEST AND OPERATIONAL DESCRIPTIONS

The test plan for STV derivatives development is devised to prove that each element of the system will work according to defined national needs and system requirements. NASA specifications and requirements documents will be used to evaluate the hardware. Established and proven system testing techniques from the STS and Apollo programs are assumed in the estimating groundrules. Existing ground test facilities at NASA, DoD, and contractors around the United States will be used to the greatest extent possible.

Special ground test facilities areas of concern (considering the large size of these vehicles and their potential aeroassist temperature operation levels) are adequate thermal protection systems test facilities, special wind tunnel testing requirements, and low-gravity fluid transfer test facilities (recent NASA budgets for fluid management technology lab work and facilities have been reduced to the zero level).

The test plans vary significantly between the ground-based and space-based vehicle concepts. The biconic and space crew modules are dramatically different in operational concept and physical description. Testing of the biconic crew module requires high heat reentry tests before man can be included in the flight. The space-based crew module requires provisions for long in-space exposure time of 5 years to operate from a Space Station or dedicated LEO node.

These two basic concepts require extensive environmental and dynamic testing for support of the operational capabilities evaluation process. Both concepts will be complex to test; each concept in its own, unique way. The STV aerobrake (space-based concept) and the biconic crew module require new, national ground test facilities to prove out the thermal capabilities of the two designs.

Five-Phase STV Test Plan. The STV hardware and software configuration test plan is basically a five-phase process.

Preliminary STV Ground Test Plan. The first STV testing phase would be a static/brassboard ground test program for all hardware elements. This phase also includes hardware and software test plans development. Some proof-of-concept demonstrations can be completed for candidate subsystems and off-the-shelf application software before downselect to a single subsystem design.

The second phase includes dynamic ground testing of structural and electronics subsystems and major software modules testing with the avionics. This second phase includes a full-up, cluster test of the lunar transportation system advanced engines.

STV Flight Test Descriptions Used for Estimates. The third phase includes a flight test of the small derivative stage configuration with flight-critical avionics certification and qualification. This phase includes the first pathfinder test of the system flow at the operational launch site. The small vehicle flight test can include the insertion of an actual NASA or DoD payload.

The fourth stage includes lunar configuration flight testing in two additional STV flight tests. The flight tests for aerobrake are accomplished on a separate aeroassist flight experiment (AFE) number 2 (not estimated in the Boeing STV LCC estimate) and on an unmanned STV test vehicle (flight test vehicle number 2). The ground-based vehicle requires an unmanned test of the biconic module on the second test flight in addition to 10 launch escape system (LES) independent test flights on a Delta-class launch vehicle.

The fifth and final stage is a major flight test to the Moon and back. The third test flight includes an all-up test of the LTS cargo vehicle configuration to the Moon and back. This third flight test could carry a crew module (unmanned) and a small functional payload (e.g., surveying equipment, setup supplies, communications gear, science gear). This third flight test could carry the JSC PSS Flight 0 equipment (but at a very high risk to the overall success of the program if the payload unloader is lost by a STV system failure during the third flight test).

Hardware quantities were included in the cost estimates for all five testing phases. Ground test hardware is available at the end of testing (if not failsafed or overstressed) as spares only. The flight test hardware will be new test hardware. All reusable flight test hardware, recovered as residual test equipment, will be available for spare parts (after refurbishment) in the operational phase. Figures 1-1.4-1 and 1-1.4-2 are examples of the hardware test requirements matrices developed for a STV space-based configuration in a full-scale development phase C/D test program. Matrices like these were developed for all system flight elements.

Transition From Flight Test to Operational Capability. The preliminary STV system requirements for the operational system are described in this final report in section 2-2.0, Volume II. The first flight test proves the evolutionary capability to perform high-energy upper stage missions with one RL10 derivative engine and the smallest avionics suite. The final flight test (flight test 3) of the phase C/D plan will provide final proof of meeting the primary lunar mission requirements. Flight test 3 will be a complete LTS vehicle round trip with a multiple-engine vehicle droptanks and a lunar surface payload delivery (unmanned).

The plan to bridge the end of the DDT&E test program with the operational system activation is completed at test flight number three, for both LTS/STV basing concepts. A three-step flight test plan for the ground-orbital system is shown in section 1-2.4 of this document (IR #5 data). Time phasing for the three space-based flight tests would be similar in duration and sequence, even though the content of each flight test will be different from many of the ground-orbital test requirements.

Summary. The STV test program will require two ground test phases and three flight test phases to complete. The flight test phases will verify two operational vehicle designs: one for high-energy upper stage missions (using a small, single-stage STV derivative with one engine) and one for lunar transportation system missions (using a more complex vehicle with six advanced space engines).

Matricies of test article usage were developed for each flight element.....

STV Transfer Stages

Preflight Test Hardware

Article: \ Function:	Structures tests/ loads verification	Thermal tests/ loads verification	Aerobraking tests	Power systems tests	Avionics/CAD test/ verification/development	ECLSS tests	Impact attenuation tests/ stabilization (ballistic)	Interface verification	Propulsion system tests	Ground handling/recovery procedures development	Ergonomics/ human factors	Procedures development	Crew training	Public relations	Stack integration tests	Space Operations tests	Notes:
I. Engineering Mockups			○		○		●	●		○	●	○	○	●	●	○	
IIa. Flight Simulator - Static																	-No Hdwr-
IIb. Flight Simulator - Dynamic																	-No Hdwr-
III. "Iron Bird"/SIL		○		●	●			●				○			●		
IV. Neutral Bouyancy Mock up							○	○			○	●	●			●	
Va. Structural Test Article(s)	●						●	○									
Vb. Thermal Test Article(s)		●															
Vc. Aero-Aerothermal Test Article(s)																	-No Hdwr-
Vd. Main Propul Test Article(s)								○	●								
VI. Pathfinder								●		●		●			●	●	
VII. Certification/Prototype					○					○	○	○			○	○	
VIII. Subsystem development hdwe.		●		●	●			○	●								

Primary use: ● Secondary Use: ○

Figure 1-1.4-1. STV Transfer Stages

Different test articles for each flight element required different usage.....

Aerobrake

Ground & Pre-FlightTest Hardware

Article: \ Function:	Structures tests/loads verification	Thermal tests/loads verification	Aerobraking tests	Power systems tests	Avionics/C&D test/verification/development	ECLSS tests	Impact attenuation tests/stabilization (ballistic rv)	Interface verification	Propulsion system tests	Ground handling/recovery procedures development	Ergonomics/human factors	Procedures development	Crew training	Public relations	Stack integration tests	Space Operations tests	Notes:
I. Engineering Mockups			○		○		●	●		○	●	○	○	●	●	○	
IIa. Flight Simulator - Static																	-No Hdwr-
IIb. Flight Simulator - Dynamic																	-No Hdwr-
III. "Iron Bird"/SIL					●			●				○			●		-RCS + sensors-
IV. Neutral Bouyancy Mock up							○	○			○	●	●			●	
Va. Structural Test Article(s)	●						●	○									
Vb. Thermal Test Article(s)		●															
Vc. Aero-Aerothermal Test Article(s)			●					○									
Vd. Main Propul Test Article(s)																	-No Hdwr-
VI. Pathfinder								●		●		●			●	●	
VII. Certification/Prototype					○					○	○	○			○	○	
VIII. Subsystem development hdwe.	●	●	●		○			○									-TPS + sensors-

The aerobrake testing will be in concert with AFE testing

Primary use: ● Secondary Use: ○

Figure 1-1.4-2. Aerobrake

1-1.5 SPARES ESTIMATING

The STV program spares estimating was accomplished by first reviewing the critical spares lists for other space programs. Specifically, NASA program offices, vendors, and Boeing logistics organizations were requested to provide spares and critical parts lists for cryogenic engines, avionics, and space vehicles. The initial and replenishment spares were then estimated as a percentage of hardware estimated cost from the Boeing PCM. The percentage selected for expendable hardware was 3%. The percentage selected for estimating reusable hardware spares is 9% to 10%, depending on the use of the flight element, where it is based, and its subsystems content.

Historical Reference Documents. A critical items list report (Boeing document D290-10213-1) from the Inertial Upper Stage program was used as a reference document in the STV study for developing the preliminary STV upper stages critical items listing. The list was then changed to include advanced avionics elements and supplemental data from Pratt & Whitney for the STV cryogenic engine and fluid supply subsystems. A Centaur/Atlas RL10 critical items spares list was added to the reference data. Spares information for the larger SSME cryogenic units used on the STS orbiter was also obtained from Rocketdyne as an analogy to the advanced space engine.

Several people at Johnson Space Center in Houston were called for inquiries on STS orbiter spares concerning the fuel cells, life support systems, and electromechanical hardware components. STS orbiter repair and refurbishment information from shuttle flights STS 31 and STS 51 were also used to identify space vehicle subsystems that require the most servicing and spare parts requirements.

In addition to space programs data, the Boeing Commercial Airplane Group division was contacted to acquire information on commercial air carrier spares requirements. With high-volume flight rates, spares for commercial aircraft were 13% to 19% of hardware procurement costs.

Rationale for Factors Selection. Considering this historical data, and the projected CNDB '89 and '90 mission model sortie rates, the percentage selections (3%, 9%, and 10%) were considered reasonable for preliminary STV life cycle cost estimates. The launch rates and sortie count dropped in the CNDB FY '90 report, thus reducing the opportunity to operate more reusable STV hardware in the operation and support (O&S) phase of the system.

The high end percentage of 19% for commercial airplane transportation systems was not considered a good analogy to STV operations requirements. The minimum "five reuses" groundrule for reusable STV hardware or the projected use of a large quantity of expendable STV hardware flight elements indicates the application of smaller spares percentage factors for both mission categories is more reasonable.

Summary of Spares Estimating Information. An example of a critical items list for a STV small stage is shown in Figure 1-1.5-1. Spares factors used for this analysis are as follows:

1. DDT&E
   a. Expendable Hardware - 3% spares factor.
   b. Reusable Hardware - 9-10% spares factor.
2. Production (Replenishment Spares)
   a. Ground-Based Systems - 3% spares factor (PSE + Flt. Hardware).
   b. Space-Based Systems - 10% spares factor (PSE + Flt. Hardware).

LIST FOR SPARES ESTIMATING (FACTORY/DEPOT/ETR)

NOMENCLATURE	EXPECTED GRD. FAIOURES IN 18 SHIPSETS	LAUNCH CRITICALLY CATEGORY	LOT BUY #1 PROV. QTY. ESTIMATE	(89$M) EST. COST	VIF SWAPOUT CAPABILITY	REMARKS
(1) VEHICLE LEVEL						
HEUS SEPARATION NUT SET (1)	4	MC/TC	2 SETS	.5	NO	LOW IUS FAILURE, BUT DESIRED NEW
HEUS LASER PYRO UNIT (2)	20	MC/TC	2 UNITS	1.5	NO	DESIGN, NO FAILURE HISTORY
(2) NAV. & GUID/CONTROL						
IMU/FLT. COMP./GPS (1)	185	MC/TC	4 UNITS	8.0	YES	REDUNDANT, SIMILAR TO SCU HISTORY
TVC ACTUATOR (2)	50	MC	4 SETS	.4	NO	IUS HISTORY IS APPLICABLE
TVC CONTROLLER (1)	50	MC	4 SETS	.7	NO	" " " "
POTENTIMETER-TVC	15	MC	2 SETS	.1	NO	IUS HISTORY IS APPLICABLE
(3) DATA MANAGEMENT						
FAULT-TOLERANT PROCESSOR	100	MC/TC/SC	4 UNITS	2.6	YES	45% IMPROVEMENT FROM IUS = 185
S/C INTERFACE UNIT (1)	50	MC/TC	4 UNITS	3.2	YES	IUS SIU HISTORY ANALOGY
DM CABLE ASSY. (1)	40	MC/TC	4 SETS	.8	NO	40% OF IUS HISTORY = 176,
S/C INTERFACE CABLE (1)	30	MC/TC	4 SETS	.1	NO	OTHER 106 FAILURES TO POWER
(4) TELEMETRY, TRACK, & COM						
SGLS TRANSPONDER (1)	100	MI	4 UNITS	3.2	YES	25% IMPROVEMENT FROM IUS - 133
S-BAND AMPLIFIER (1)	60	MI	4 UNITS	2.3	NO	SAME AS IUS 20 W. AMP.
S BAND ANTENNA (2)	30	MI	4 UNITS	.1	NO	IUS HISTORY (OMN ANT.)
C-BAND TRANSPONDER (2)	100	MI	4 UNITS	.4	YES	SAME AS SGLS-S BAND
C-BAND ANTENNA (2)	30	MI	4 UNITS	.1	NO	IUS HISTORY (OMNI ANT.)
SGLS DIPLEXER	20	MI	2 UNITS	.1	NO	" "
RF SWITCH (3)	30	MI	4 UNITS	.1	NO	" "
RF SWITCH-FAIL SAFE	15	MI	2 UNITS	.1	NO	IUS HISTORY
RF CABLE	40	MI	4 CALBES	.3	YES	IUS HISTORY
(5) ELECTRICAL POWER						
POWER DIST. UNIT	60	MC/TC	4 UNITS		YES	45% IMPROVEMENT FROM IUS = 110
AVIONICS BATTERY	30	MC/TC	4 UNITS	.6	YES	IUS HISTORY
UTILITY BATTERY	20	MTC/SC	2 SHIPSETS	.3	YES	20% IMPROVEMENT FROM IUS = 24
POWR CABLE	100	MC/TC/SC	4 CABLES	1.0	YES	IUS HISTORY

PAGE 1 SUBTOTAL - $26.5M

Figure 1-1.5-1. STV Small Vehicle Upper Stage Critical Items (Sheet 1 of 2)

LIST FOR SPARES ESTIMATING (FACTORY/DEPOT/ETR)

NOMENCLATURE	EXPECTED GRD. FAIOURES IN 18 SHIPSETS	LAUNCH CRITICALLY CATEGORY	LOT BUY #1 PROV. QTY. ESTIMATE	(89$M) EST. COST	VIF SWAPOUT CAPABILITY	REMARKS
(6) PROPULSION-MAIN						
EXTENDABLE NOZZLE (1)	10	MC/TC	2	.3	NO	IUS EXTENDED CONE HISTORY
CONTROL ASSY. (1)		MC/TC	0	N/A	NO	PRATT & WHITNEY INPUT
INLET SHUTOFF VALVES (2)		MC/TC/SC	2	.1	NO	
PROPELLANT TANK - LH2(1)		MC	1	6.9	NO	BA&E INPUT FOR UNPLANNED EVENT
PROPELLANT TANK - L02(1)		MC	1	4.7	NO	" " " " "
IGNITER (1)	10	MC/TC	2	.1	NO	IUS MOTOR IGNITER HISTORY
PRESSURIZATION VALVE (1)		MC/TC/SC	0	N/A	NO	PRATT & WHITNEY INPUT
(7) REACTION CONTROL						
THRUSTER MODULE (16)	100	MC	4	.3	YES	IUS HISTORY
PROPELLANT TANK (1)	20	MC/SC	2	.2	NO	IUS HISTORY (16) + 25% (NBEW HOOKUP))
MANIFOLD (1)	10	MC	2	.1	NO	
ISOLATION VALVE	5	MC/SC	2	.1	NO	IUS HISTORY - MINIMAL IMPACT
(8) OTHER EQUIP.						
GPS DOWN CONVERTER	50	MC	4	1.1	YES	USED IUS SIGNAL INTERF. UNIT HISTORY
GPS ANTENNA	2	MC	-	0	YES	USED IUS MED. GAIN ANT. HISTORY
CYRO UMBIL. CONN. - ALS	10	MC/SC	2	.2	YES	ESTIMATE - NO HISTORY
MISC. INTERFACE BOXES	20	MC	4	.2	YES	SIMILAR TO IUS CONVERTER REG.
		SUBTOTAL -		$14.3M		
		SUBTOTAL, PAGE 1 (FORWARD)		26.5		
		GRAND TOTAL, LOT 1 SPARES		$40.8M		
		ESCALATION FACTOR		X 1.101		
		TOTAL (IN FY 91 DOLLARS)		$44.0M		

Figure 1-1.5-1. STV Small Vehicle Upper Stage Critical Items (Sheet 2 of 2)

1-1.6 MANAGEMENT AND COST AVOIDANCE

The STV program will require a cost management program that includes both risk management and cost risk abatement effort. The risk management program should be directed at hardware items and tasks that provide the most cost leverage. The cost risk abatement plan includes cost uncertainty estimates and cost avoidance strategies. These strategies are directed at the high-risk management areas defined in the technical and schedule risk assessments.

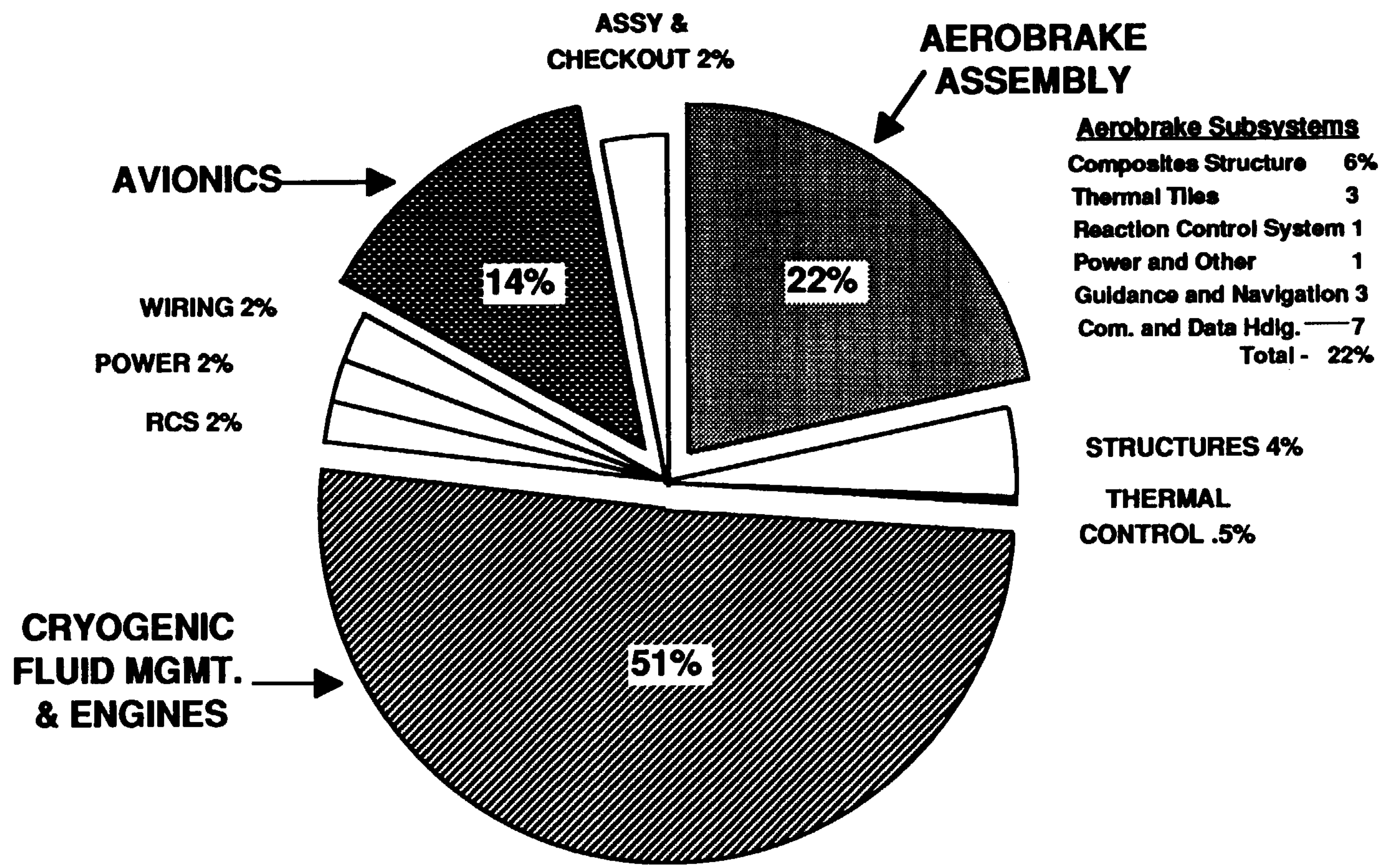
Ranger Cost Model Description. The Boeing Aerospace & Electronics division has a cost uncertainty model called "Ranger." The Ranger model is composed of statistical equations that produce skewed, unimodal cost range estimates based on inputs from the design and manufacturing staffs on the project.

The cost model inputs include the current Boeing parametric cost estimates, by subsystem, for the program to be analyzed. The Ranger cost model outputs include the high, 50/50, and low estimates, where the current estimate is the cost reference. The current estimate usually does not equal the 50/50 probability estimate, but lies somewhere in the uncertainty range from the highest to lowest estimate.

Cost Risk Evaluation Process Starting Point. The cost risk evaluation begins with identifying the higher cost leverage items in system development. Then the cost risk management activities are focused on items that contribute in total at least 80% of the development cost. Figure 1-1.6-1 illustrates the technology and risk high-value items for the space-based LTS core vehicle development. Note that the propulsion, fluid management, aerobrake, and avionics subsystems are the high-value items and areas with the highest technology leverage on system mission success (reliability/operability) and system cost.

STV Hardware DDT&E Cost Uncertainty Analyses. Several Ranger cost model runs for space-based and ground-orbital phase C/D development estimates were completed during the study. A summary of the results of the cost risk estimates is shown in Figure 1-1.6-2. The cost risk model output summaries

High leverage areas in development are Cryogenic Propulsion Systems, Aerobrake, and Avionics........



CORE STAGE EXAMPLE

Figure 1-1.6-1. Core Stage Example

Ranger Cost Risk Analysis
by LTS Flight Element (Before Factors Application)

(1991 Dollars in Millions)

	DDT&E Hardware Estimate*	Low	50/50	High
GROUND-ORBITAL	($ 20,759 Total)			
CORE STAGE (LTV)	3,897	3,222	4,028	4,846
CREW MODULE	2,580	2,143	2,663	3,196
TLI DROP TANKS	390	323	403	484
LOX TANKER	921	757	952	1,149

SPACED BASED	($ 24,594 Total)			
CORE STAGE (LTV)	4,304	3,559	4,514	5,366
AEROBRAKE	1,988	1,655	2,051	2,460
CREW MODULE	2,393	2,002	2,565	3,117
TLI DROP TANKS	390	323	403	484
LUNAR DESCENT TANKS	680	565	703	844

NOTE:
* PROGRAM ESTIMATE EXCLUDES SCHEDULE PENALTY & SOFTWARE
* PARAMETRIC COST MODEL OUTPUT EXCLUDES ADVANCED SPACE ENGINE AND NASA PROGRAM LEVEL FACTORS (REQUIREMENTS CONTINGENCY, FEE, NASA PROGRAM SUPPORT)

Figure 1-1.6-2. Ranger Cost Risk Analysis are displayed in constant-year, 1991 dollars in millions. These preliminary cost risk assessments are based on conceptual design descriptions and preliminary top-level STV phase C/D test plans.

Software and Advanced Space Engine Developments. The flight and simulation/training software estimates ranged from $1.5 billion to $1.875 billion (in 1991 dollars). Even though the Ranger model does not estimate the software element, these estimates are considered near the 50/50 point in the cost risk spectrum. Estimate accuracy is proposed as -10% to +50% until a more indepth study can be accomplished.

The advanced space engine (ASE) is considered a Government-furnished equipment item to the core stage prime integration contractor. Raw estimates have ranged (without program factors) from $400 million to $1.2 billion. The selected estimate of $675 million (in 1991 dollars), excluding program factors, is below the 50/50 point of the estimate ranges. More analysis is required.

1-1.7 WORK BREAKDOWN STRUCTURE TREES

The STV estimates are developed to a specific program work breakdown structure (WBS). The WBS is developed and organized to handle many different STV configuration candidates. The WBS dictionary and development requirements are submitted as Book 2, Volume III.

Figure 1-1.7-1 contains the summary-level WBS tree supplied by NASA for use on the STV study. This tree, and the NASA "90-Day Study" information reference description of a two-stage lunar vehicle, are used to develop the initial dictionary (presented at the midterm review). The shaded box in the WBS tree is expanded according to Boeing vehicle design and flight element descriptions. Some of the WBS tree boxes indicate cost estimate areas used to support life cycle cost trade studies during the STV study. Four of the boxes, "Earth to Orbit," "Low Earth Orbit," "Crew Training," and "Mission Control," are cost estimated at a very high level for evaluating STV Operation AND Support.

The final WBS dictionary was modified to include new hardware for a single-stage vehicle that is ground-orbital based and includes a separate LEO LOX tanker, a biconic reentry crew module with attitude control, and a crew module LES. The LES is also required for the ground-based STV configuration that does not need a tanker (both ground-based and ground-orbital STVs for the lunar transportation system are identical in system layout and description; the method of deployment is different.

Estimates are organized by the program WBS tree expansion items and traditional aerospace functional elements described in the Book 2 dictionary. None of the three final Boeing configuration candidates selected during the study use a LEV flight element. The LEV is still included in the WBS tree descriptions for future studies or for other contractor cost estimate inputs to NASA.

Figure 1-1.7-2 depicts the LTS project-level tree for the WBS. The LTS is depicted as a primary project of the overall STV program.

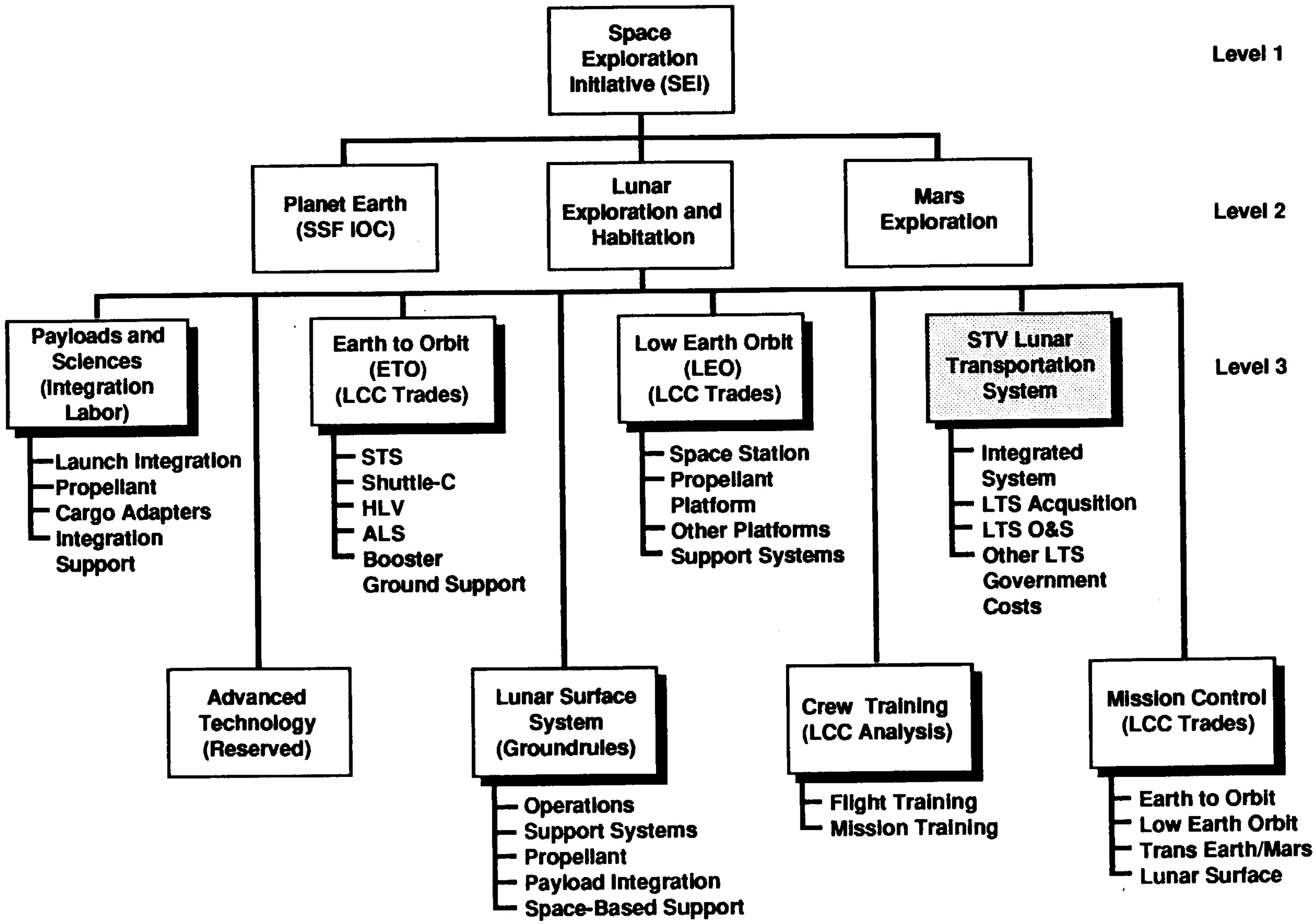

Space Exploration Initiative (SEI)
Level 1
Planet Earth (SSF IOC)
Lunar Exploration and Habitation
Mars Exploration
Level 2
Payloads and Sciences (Integration Labor)
Launch Integration
Propellant
Cargo Adapters
Integration Support
Earth to Orbit (ETO) (LCC Trades)
STS
Shuttle-C
HLV
ALS
Booster
Ground Support
Low Earth Orbit (LEO) (LCC Trades)
Space Station
Propellant Platform
Other Platforms
Support Systems
STV Lunar Transportation System
Integrated System
LTS Acqusition
LTS O&S
Other LTS Government Costs
Level 3
Advanced Technology (Reserved)
Lunar Surface System (Groundrules)
Operations
Support Systems
Propellant
Payload Integration
Space-Based Support
Crew Training (LCC Analysis)
Flight Training
Mission Training
Mission Control (LCC Trades)
Earth to Orbit
Low Earth Orbit
Trans Earth/Mars
Lunar Surface

Figure 1-1.7-1.

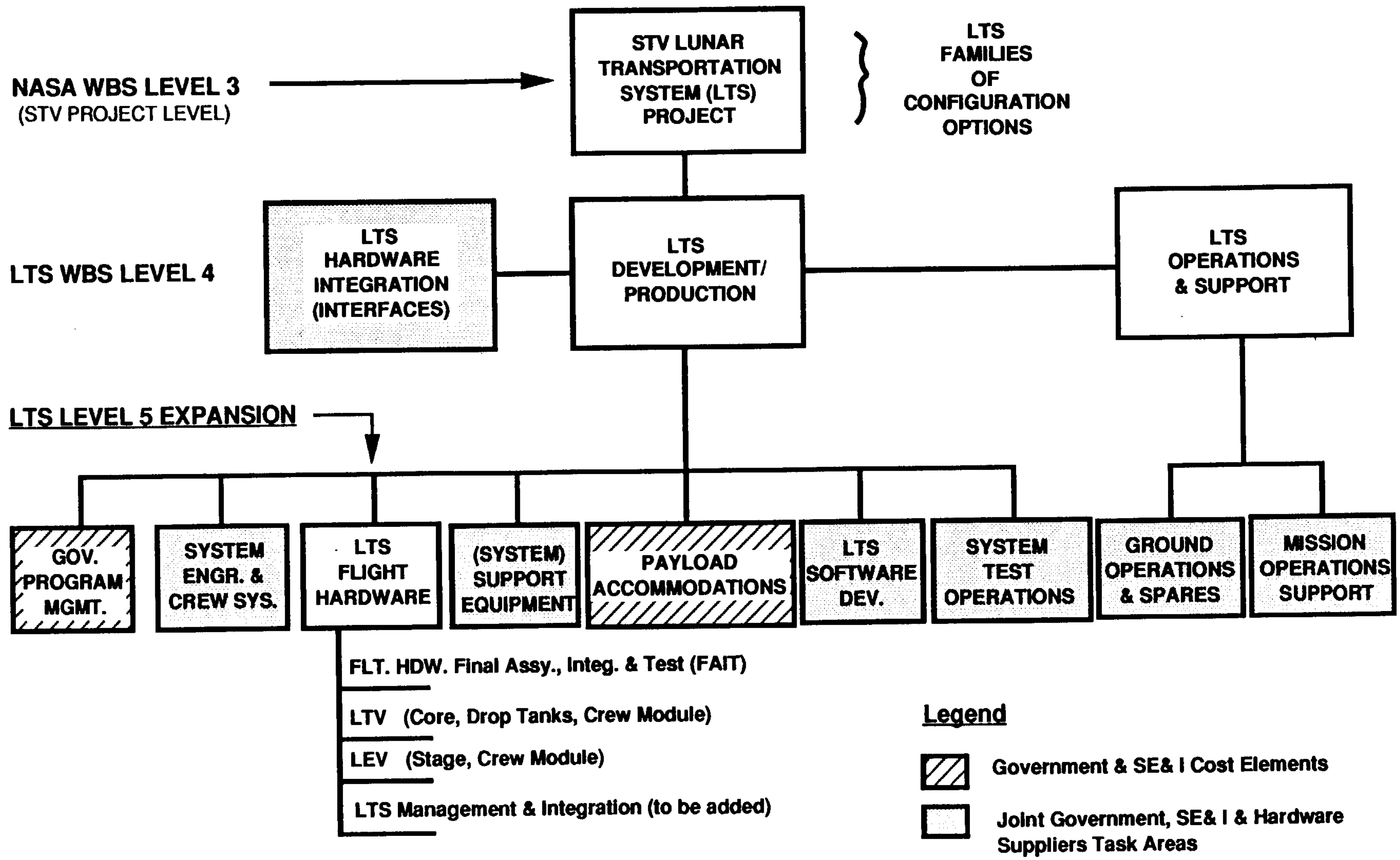


Figure 1-1.7-2.

BOEING

1-1.8 COST ESTIMATING RELATIONSHIPS SUMMARY

Acquisition Cost Estimating Techniques. The Boeing PCM contains proprietary cost estimating relationships (CERs) that are grouped into program WBS and functional cost element categories. These categories are flexible and can be used at a component input level. A summary of the basis of the estimates by system WBS element category is shown in Figure 1-1.8-1. The figure also includes a column that reveals the comparative methods used to check the PCM outputs for reasonableness.

The proprietary Boeing database used to create the Boeing PCM CERs includes both space and airplane hardware and program labor resources cost and schedule data from the early 1950s to the present. The database includes both commercial and Government contract programs, by platform type. Figure 1-1.8-2 is an example of the detail used as inputs to the proprietary CERs in the parametric cost model for a candidate LTS lander (core vehicle) design. During the early part of the study this level of definition was used. The figure shows top-level factors used for the vehicle architecture trade studies.

The final three preferred designs selected at the end of the study are estimated one level lower in detail for avionics subsystem elements. Technical maturity, off-the-shelf factors, material factors, and learning curves were also defined at the lowest level of detail in the final runs. The model provides for a direct download from the STV preliminary detailed weight statement by prenegotiated hardware WBS and design description item.

Operations Cost Estimating Parameters. Operation and support cost estimates are calculated using a number of estimating factors and parameters collected from many different sources in the aerospace community. NASA program factors described in the methodology and groundrules sections are applied at the system level, after PCM output estimates are generated. PCM-generated hardware estimates are combined with vendor information to estimate replenishment spares for refurbishment activities after a lunar mission flight. Ground facilities maintenance is estimated for annual budgets using a factor of 4% of the estimated facilities procurement cost (including equipment).

WBS Element	Basis of Estimate	Comparative Method
Vehicle Design Engineering:		
Structures & Mechanisms	Historical hours/lb. & sq. ft. area CER's	$/lb, engineering estimates, analogy
Reradiative Thermal Protection	NASA, Boeing Military Airplanes est. $/sq. ft.	$/lb, engineering estimates, analogy
Propulsion & Fluid Mgmt.	Historical hours/lb, vendor planning est.	$/lb, engineering estimates, analogy
Avionics & Primary Power	Historical hours/lb, vendor planning est.	$/lb, engineering estimates, analogy
Other	Historical $/lb, vendor planning est.	$/lb, engineering estimates, analogy
Software	Engr. estimates of Lines of Code (SLOC)	Shuttle, Apollo, airplane prog.'s analogy
Support Equipment	Analogy, historical factors, vendor est.'s	IUS, Shuttle, Apollo, Centaur analogies
Tooling	Labor to labor hours CER'S	Analogy to other space programs (i.e. IUS)
System Test	Task manload estimates & labor CER'S	Analogy, engineering estimates
Facilities	$/Sq. ft., prov. lists, & studies SSF data	Analogy to KSC & Apollo/Skylab data
Production	Labor CER'S, vendor est.'s, and $ CER'S	$/lb., analogy, historical factors
Systems Engineering	Labor to labor hours CER'S	Task manloading, analogy
Program Management	Labor factors & labor hours CER'S	Manloading by year
ETO Costs	NASA-provided $/lb. of payload factors	Historical programs cost/flt. (STS/Saturn)
LEO Node Operations	Engr. estimate by task/SSF Program est.'s	GD STIS (Infrastructure Study)
Growth and Fee	NASA-supplied program support factors	N/A

Figure 1-1.8-1.

DEVELOPMENT

CATEGORY	QUANTITY P/SHIPSET	WEIGHT	ENGR. COMPLEXITY	OFF THE SHELF %	TECH MATURITY
STRUCTURES AND MECHANISMS					
FWD INTERFACE STRUCTURE					
FWD BULKHEAD - CAB INTERFACE	(1)	110	5	0	0.65
CARGO MODULE SUPT BEAM ASSYS	(4)	66	5	0	0.65
CARGO MODULE SUPT/DEPLOY STRUTS	(4)	39	5	0	0.65
UMBILICAL PLATE	(4)	15	5	0	0.65
EQUIPMENT SUPPORT STRUCTURE					
EQUIPMENT MOUNTING PANELS	(4)	42	5	0	0.65
MAIN BODY STRUCTURE					
BASIC THRUST LONGERONS	(4)	44	5	0	0.65
SHEAR PANELS	(12)	112	5	0	0.65
UPPER CLOSEOUT PANELS	(4)	67	5	0	0.65
LATERAL CLOSEOUT PANELS	(4)	84	5	0	0.65
SECONDARY STRUCTURES					
LANDING GEAR SWAY STRUTS	(8)	29	5	0	0.65
LANDING GEAR FTGS	(16)	11	5	0	0.65
CARGO MODULE SUPT FTGS	(8)	11	5	0	0.65
THRUST STRUCTURE					
THRUST RING	(1)	251	5	0	0.65
ENGINE INTERFACE FITTINGS	(4)	4	5	0	0.65
LANDING GEAR					
PRIMARY STRUTS	(16)	47	5	0	0.65
SUPPORT / DEPLOYMENT STRUTS	(8)	71	5	0	0.65
ATTENUATOR STRUTS	(4)	137	5	0	0.65
LANDING PADS	(4)	45	5	0	0.65
SEPARATION SYSTEMS					
TANK MODULE RETENTION FTGS	(0)		5	0	0.65
TANK MODULE PUSH-OFF SPRINGS	(0)		5	0	0.65
CARGO MODULE RETENTION FTGS	(4)	50	5	0	0.65
INT & TEST	(1)	0	5	0	0
TANKAGE - MAIN					
LH2 TANK					
FWD DOME	(4)	30	5	0	0.65
FWD RING	(4)	20	5	0	0.65
CYLINDER	(4)	113	5	0	0.65
AFT RING	(4)	20	5	0	0.65
AFT DOME	(4)	30	5	0	0.65
VORTEX BAFFLE, SCREEN	(4)	13	5	0	0.65
PARA / ORTHO STRUCTURE	(1)	0	5	0	0.65
PROPELLANT GAUGE	(4)	28	5	0	0.65
TANK SUPPORT STRUTS, FTGS	(24)	4	5	0	0.65
LO2 TANK					
FWD DOME	(1)	77	5	0	0.65
RING	(1)	19	5	0	0.65
CYLINDER	(1)	194	5	0	0.65
AFT RING	(1)	19	5	0	0.65
AFT DOME	(1)	77	5	0	0.65
VORTEX BAFFLE, SCREEN	(1)	13	5	0	0.65
PROPELLANT GAUGE	(1)	27	5	0	0.65
TANK SUPPORT STRUTS, FTGS	(6)	8	5	0	0.65
INT & TEST	(1)	0	5	0	0
THERMAL CONTROL					
EXTERNAL TPS	(1)	0	5	0	0.65
EXTERNAL TCS	(1)	0	5	0	0.65
LH2 TANK INSULATION, MLI	(2)	217	5	0	0.65
LO2 TANK INSULATION, MLI	(2)	38	5	0	0.65
MISC INSULATION	(1)	0	5	0	0.65
EQUIPMENT THERMAL PALLET	(1)	0	5	0	0.65
INT & TEST	(1)	0	5	0	0
PROPULSION - MAIN PROPULSION					
MAIN ENGINES	(4)	700000000	1	0	
2015					
ENGINE ANCILLARY EQUIP	(1)	0	5	0	0.65
TVC ACTUATORS	(8)	13	5	0	0.65
TVC ACTUATOR SUPT/ INSTL	(8)	8	5	0	0.65
LH2 FEED, FILL, DRAIN					
VALVES - TANKAGE	(4)	20	5	0	0.65
VALVES - ENGINE SHUTDOWN	(8)	7	5	0	0.65
DISCONNECTS	(1)	44	5	0	0.65
LINES, FTGS, ETC - 5.0 in	(1)	93	5	0	0.65
LINES, FTGS, ETC - 3.0 in	(4)	22	5	0	0.65
LH2 TANK VENT, RELIEF					
THERMODYNAMIC VENT VALVES	(4)	10	5	0	0.65

Figure 1-1.8-2. Reference Lander PCM Inputs Example (Sheet 1 of 4)

DISCONNECTS	(0)	0	5	0	0
LINES, FTGS, ETC	(1)	11	5	0	0.65
LH2 TANK PRESSURIZATION					
DISCONNECTS	(0)				
VALVES	(2)	4	5	0	0.65
LINES, FTGS, ETC	(2)	14	5	0	0.65
LO2 FEED, FILL, DRAIN					
VALVES - TANKAGE	(4)	20	5	0	0.65
VALVES - ENGINE SHUTDOWN	(8)	7	5	0	0.65
DISCONNECTS	(1)	44	5	0	0.65
LINES, FTGS, ETC - 5.0 in	(2)	46	5	0	0.65
LINES, FTGS, ETC - 3.0 in	(4)	22	5	0	0.65
LO2 TANK VENT, RELIEF					
THERMODYNAMIC VENT VALVES	(4)	10	5	0	0.65
DISCONNECTS	(0)				
LINES, FTGS, ETC	(1)	11	5	0	0.65
LO2 TANK PRESSURIZATION					
DISCONNECTS	(0)				
VALVES	(2)	4	5	0	0.65
LINES, FTGS, ETC	(2)	13	5	0	0.65
FEEDLINE, PRESS LINE SUPT / INSTL	(1)	52	5	0	0.65
INT & TEST	(1)	0	5	0	
PROPULSION - REACTION CONTROL					
RCS SYSTEM	(16)	17500000	1	0	
180					
INT & TEST	(1)	0	5	0	0
POWER SOURCE					
POWER SUPPLY					
FUEL CELLS	(0)	0	5	0	0.65
REACTANT TANKAGE	(0)	0	5	0	0.65
ACCUMULATORS	(0)	0	5	0	0.65
REACTANT PLUMBING	(0)	0	5	0	0.65
COOLANT PLUMBING	(0)	0	5	0	0.65
SOLAR ARRAY	(2)	0	5	0	0.65
TVC BATTERY	(1)	320	5	0	0.65
POWER SUPPLY SUPT/INSTL	(1)	50	5	0	0.65
INT & TEST	(1)	0	5	0	0
WIRING & ELECT INTERFACE EQUIP	(0)	0	5	0	0.65
POWER DIST EQUIP					
LOAD DISTRIBUTION/CNTRL ASSY	(3)	29	5	0	0.65
INVERTERS	(3)	210000	1	0	
45					
WIRING	(0)	0	5	0	0.65
ELECTRICAL POWER SUPT/INSTL	(0)	0	5	0	0.65
INT & TEST	(1)	0	5	0	0
GUIDANCE, NAVIGATION, AND CONTROL	(0)				
GUIDANCE, NAVIGATION AND CONTROL	(1)	12000000	1	0	
150					
RENDEVOUS AND DOCK	(0)	0	5	0	
0					
STRUCTURES & MECHS CONTROLLER	(1)	10300000	1	0	
75					
AVIONICS SUPT/INSTL	(1)	21	1	0	0.65
COMMUNICATION AND DATA HANDLING					
COMMUNICATIONS AND TRACKING	(1)	0	1	0	
0					
HEALTH MONITORING / INSTRUMENTATION	(1)	6600000	1	0	
85					
DATA HANDLING	(1)	9300000	1	0	
150					
AVIONICS SUPT/INSTL	(1)	23	1	0	0.65
WEIGHT GROWTH MARGIN	(1)	2023	5	0	0.65
INT & TEST	(1)	0	5	0	0

MANUFACTURING

	QUANTITY P/SHIPSET	WEIGHT	MFG. COMPLEXITY	OFF THE SHELF %	QUANTITY	LEARNING CURVE
STRUCTURES AND MECHANISMS						
FWD INTERFACE STRUCTURE						
FWD BULKHEAD - CAB INTERFACE	(1)	110	5	0	10	100
CARGO MODULE SUPT BEAM ASSYS	(4)	66	5	0	40	100
CARGO MODULE SUPT/DEPLOY STRUTS	(4)	39	5	0	40	100
UMBILICAL PLATE	(4)	15	5	0	40	100
EQUIPMENT SUPPORT STRUCTURE						
EQUIPMENT MOUNTING PANELS	(4)	42	5	0	40	100
MAIN BODY STRUCTURE						

Figure 1-1.8-2. Reference Lander PCM Inputs Example (Sheet 2 of 4)

BASIC THRUST LONGERONS	(4)	44	5	0	40	100
SHEAR PANELS	(12)	112	5	0	120	100
UPPER CLOSEOUT PANELS	(4)	67	5	0	40	100
LATERAL CLOSEOUT PANELS	(4)	84	5	0	40	100
SECONDARY STRUCTURES						
LANDING GEAR SWAY STRUTS	(8)	29	5	0	80	100
LANDING GEAR FTGS	(16)	11	5	0	160	100
CARGO MODULE SUPT FTGS	(8)	11	5	0	80	100
THRUST STRUCTURE						
THRUST RING	(1)	251	5	0	10	100
ENGINE INTERFACE FITTINGS	(4)	4	5	0	40	100
LANDING GEAR						
PRIMARY STRUTS	(16)	47	5	0	160	100
SUPPORT / DEPLOYMENT STRUTS	(8)	71	5	0	80	100
ATTENUATOR STRUTS	(4)	137	5	0	40	100
LANDING PADS	(4)	45	5	0	40	100
SEPARATION SYSTEMS						
TANK MODULE RETENTION FTGS	(0)		5	0	10	100
TANK MODULE PUSH-OFF SPRINGS	(0)		5	0	10	100
CARGO MODULE RETENTION FTGS	(4)	50	5	0	40	100
INT & TEST	(1)	0	5	0	10	100
TANKAGE - MAIN						
LH2 TANK						
FWD DOME	(4)	30	5	0	32	100
FWD RING	(4)	20	5	0	32	100
CYLINDER	(4)	113	5	0	32	100
AFT RING	(4)	20	5	0	32	100
AFT DOME	(4)	30	5	0	32	100
VORTEX BAFFLE, SCREEN	(4)	13	5	0	32	100
PARA / ORTHO STRUCTURE	(1)	0	5	0	8	100
PROPELLANT GAUGE	(4)	28	5	0	32	100
TANK SUPPORT STRUTS, FTGS	(24)	4	5	0	192	100
LO2 TANK						
FWD DOME	(1)	77	5	0	8	100
RING	(1)	19	5	0	8	100
CYLINDER	(1)	194	5	0	8	100
AFT RING	(1)	19	5	0	8	100
AFT DOME	(1)	77	5	0	8	100
VORTEX BAFFLE, SCREEN	(1)	13	5	0	8	100
PROPELLANT GAUGE	(1)	27	5	0	8	100
TANK SUPPORT STRUTS, FTGS	(6)	8	5	0	48	100
INT & TEST	(1)	0	5	0	8	100
THERMAL CONTROL						
EXTERNAL TPS	(1)	0	5	0	8	100
EXTERNAL TCS	(1)	0	5	0	8	100
LH2 TANK INSULATION, MLI	(2)	217	5	0	16	100
LO2 TANK INSULATION, MLI	(2)	38	5	0	16	100
MISC INSULATION	(1)	0	5	0	8	100
EQUIPMENT THERMAL PALLET	(1)	0	5	0	8	100
INT & TEST	(1)	0	5	0	8	100
PROPULSION - MAIN PROPULSION						
MAIN ENGINES	(4)	12000000	1	0	32	100
2015						
ENGINE ANCILLARY EQUIP	(1)	0	5	0	8	100
TVC ACTUATORS	(8)	13	5	0	64	100
TVC ACTUATOR SUPT/ INSTL	(8)	8	5	0	64	100
LH2 FEED, FILL, DRAIN						
VALVES - TANKAGE	(4)	20	5	0	32	100
VALVES - ENGINE SHUTDOWN	(8)	7	5	0	64	100
DISCONNECTS	(1)	44	5	0	8	100
LINES, FTGS, ETC - 5.0 in	(1)	93	5	0	8	100
LINES, FTGS, ETC - 3.0 in	(4)	22	5	0	32	100
LH2 TANK VENT, RELIEF						
THERMODYNAMIC VENT VALVES	(4)	10	5	0	32	100
DISCONNECTS	(0)	0	5	0	8	100
LINES, FTGS, ETC	(1)	11	5	0	8	100
LH2 TANK PRESSURIZATION						
DISCONNECTS	(0)					
VALVES	(2)	4	5	0	16	100
LINES, FTGS, ETC	(2)	14	5	0	16	100
LO2 FEED, FILL, DRAIN						
VALVES - TANKAGE	(4)	20	5	0	32	100
VALVES - ENGINE SHUTDOWN	(8)	7	5	0	64	100
DISCONNECTS	(1)	44	5	0	8	100
LINES, FTGS, ETC - 5.0 in	(2)	46	5	0	16	100
LINES, FTGS, ETC - 3.0 in	(4)	22	5	0	32	100
LO2 TANK VENT, RELIEF						
THERMODYNAMIC VENT VALVES	(4)	10	5	0	32	100
DISCONNECTS	(0)					
LINES, FTGS, ETC	(1)	11	5	0	8	100
LO2 TANK PRESSURIZATION						

Figure 1-1.8-2. ·Reference Lander PCM Inputs Example (Sheet 3 of 4)

DISCONNECTS	(0)					
VALVES	(2)	4	5	0	16	100
LINES, FTGS, ETC	(2)	13	5	0	16	100
FEEDLINE, PRESS LINE SUPT / INSTL	(1)	52	5	0	8	100
INT & TEST	(1)	0	5	0	8	100
PROPULSION - REACTION CONTROL						
RCS SYSTEM	(1)	4062500	1	0	8	100
180						
INT & TEST	(1)	0	5	0	8	100
POWER SOURCE						
POWER SUPPLY						
FUEL CELLS	(0)	0	5	0	8	100
REACTANT TANKAGE	(0)	0	5	0	8	100
ACCUMULATORS	(0)	0	5	0	8	100
REACTANT PLUMBING	(0)	0	5	0	8	100
COOLANT PLUMBING	(0)	0	5	0	8	100
SOLAR ARRAY	(2)	0	5	0	16	100
TVC BATTERY	(1)	320	5	0	8	100
POWER SUPPLY SUPT/INSTL	(1)	50	5	0	8	100
INT & TEST	(1)	0	5	0	8	100
WIRING & ELECT INTERFACE EQUIP	(0)	0	5	0	8	100
POWER DIST EQUIP						
LOAD DISTRIBUTION/CNTRL ASSY	(3)	29	5	0	24	100
INVERTERS	(3)	21000	1	0	24	100
45						
WIRING	(0)	0	5	0	8	100
ELECTRICAL POWER SUPT/INSTL	(0)	0	5	0	8	100
INT & TEST	(1)	0	5	0	8	100
GUIDANCE, NAVIGATION, AND CONTROL	(0)					
GUIDANCE, NAVIGATION AND CONTROL	(1)	8800000	1	0	8	100
150						
RENDEVOUS AND DOCK	(1)	0	1	0	8	100
0						
STRUCTURES & MECHS CONTROLLER	(1)	7500000	1	0	8	100
75						
AVIONICS SUPT/INSTL	(1)	21	5	0	8	100
INT & TEST	(1)	0	5	0	8	100
COMMUNICATION AND DATA HANDLING						
COMMUNICATIONS AND TRACKING	(1)	0	5	0	8	100
0						
HEALTH MONITORING / INSTRUMENTATION	(1)	13000000	1	0	8	100
85						
DATA HANDLING	(1)	1600000	1	0	8	100
150						
AVIONICS SUPT/INSTL	(1)	23	5	0	8	100
WEIGHT GROWTH MARGIN	(1)	2023	5	0	8	100
INT & TEST	(1)	0	5	0	8	100

Figure 1-1.8-2. Reference Lander PCM Inputs Example (Sheet 4 of 4)

Space operations were estimated with special factors and parameters developed by Space Station Freedom project personnel. Figure 1-1.8-3 is a summary chart of the "in-space estimating parameters" presented at several STV interim reviews. The parameters have been updated to 1991 dollars for the final report. The parameters assume the use of the existing STS shuttle orbiter crew space suit. The costs of crew egress and ingress from the Space Station work modules are included in the extravehicular activity (EVA) cost parameter. The EVA cost includes two astronauts in the existing suit designs supported at all times by one intravehicular activity (IVA) individual crew member located in a Space Station module workstation area.

Work package estimates are developed for repair and maintenance tasks during the operations phase. These estimates are developed by specific subsystem labor-hours analogy to STS 31 and STS 51 mission data, adjusted for changes in hardware and EVA/IVA maintenance techniques, and calculated with actual KSC labor wraprates (ground operations) or the in-space estimating parameters. See section 1-3.4 for more explicit examples of the STV O&S estimating techniques and O&S estimates for space- and ground-based systems.

(Source of base dollar parameters is the MSFC/Boeing SSF contract)

SERVICE OR LABOR TASK, ON-ORBIT OR IN-SPACE	UNIT OF MEASURE	UNIT ESTIMATE (1991 DOLLARS)
Extravehicular Activity (EVA)	Crew (2) + IVA Obsvr. Hour	$ 135,500 /hr.
Intravehicular Activity (IVA)	Astronaut (1) Labor Hour	21,000 /hr.
SSF/Free Flyer Services:		
SSF Service Facility (+Equip.)	30x30m Hanger Cost *	$ 550 M
SSF Operations Module/Equip.	6.8x4.5m Maint. Shop*	200 M
Unpressurized Logistics Pallet	2.5x4.6m Carrier Assy.(Rec)	30 M ea.
SSF Logistics Pallet Service	Per Pound of Cargo	4,000 /lb.
SSF Logistics Module Use	Per Pound of Equip.	6,000 /lb.
SSF Airlock Services	Per Egress & Ingress Event	150,000 /ea.
Manipulator Arm Service	Per Operations Hour	46,000 /hr.
Electric Power from SSF	Per Kilowatt Hour	250 /hr.
Propulsion (On-orbit moves)	Sq. Ft. Cross Sec. Area/Day	5 /unit
Data Management Services	Per Channel Ops. Hour	7,300 /hr.
Software Support Services	Per Line of Code (HOL)	350 /line
Communication Services	Per Channel Ops. Hour	2,800 /hr.
Space Tug Refurbishment	Per STS Delivery (14 Flts./Yr.)	58 M

(Note: * These estimates include development & one production unit costs.)

Figure 1-1.8-3.

1-1.9 TRADE STUDIES - COST ANALYSIS SUMMARY

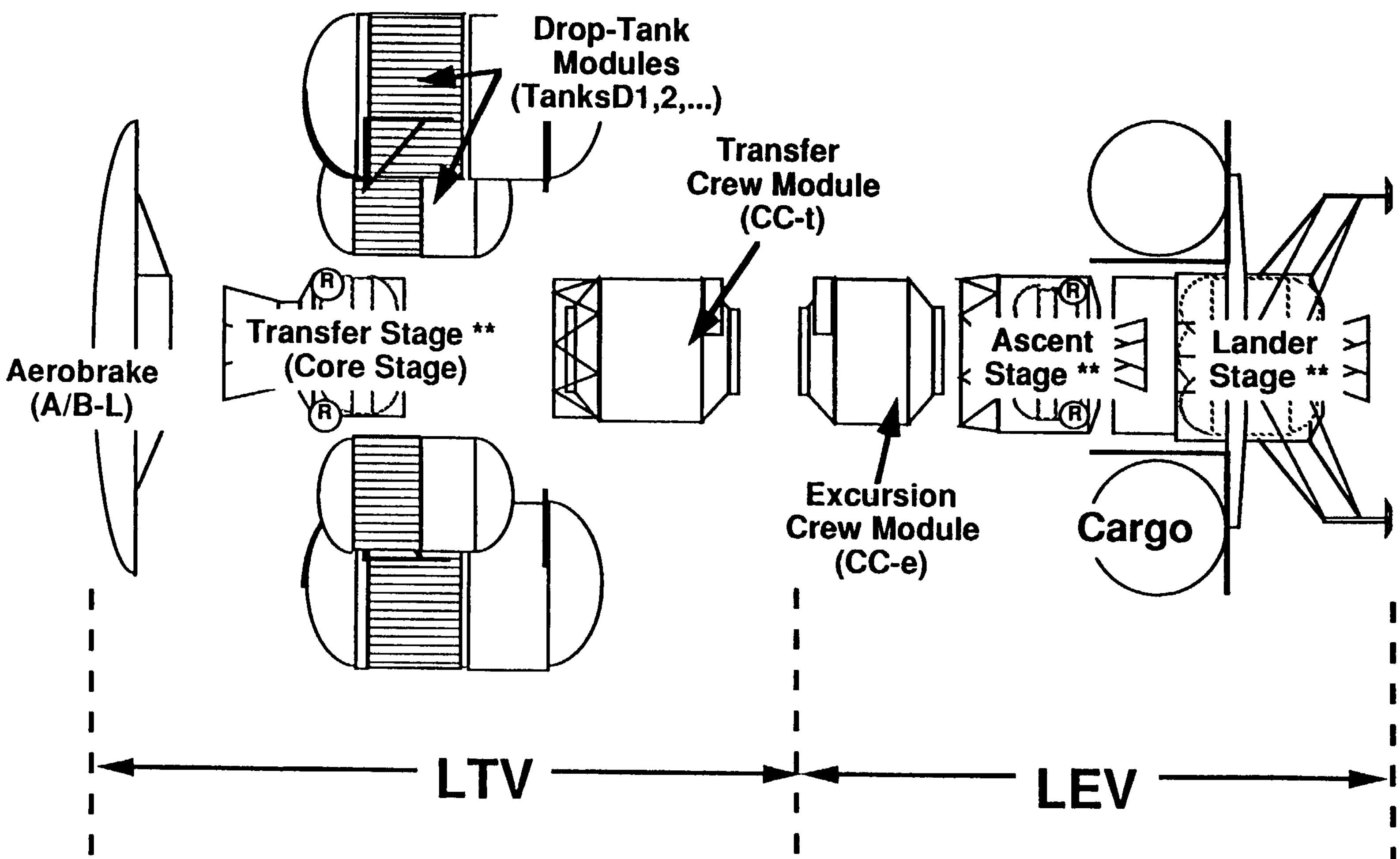
The Boeing approach to the STV architecture trade study involved many different LTS vehicle designs. The conceptual designs varied from single-stage vehicles to multistage vehicles (up to four stages, with droptanks). Figure 1-1.9-1 shows the general categories of flight elements that were estimated for development and unit production cost using the Boeing parametric cost model. The vehicle illustrated is a space-based, 3.5-stage (droptanks are considered a half stage) candidate vehicle with dual crew modules that uses lunar orbit for LEV storage.

The many different vehicle designs were estimated using a modular design integration and estimating approach. Flight elements of varying size and performance capability were estimated from over 40 weight statement and hardware description spreadsheets. The PCM global factors were held constant at a space platform level. Nominal parameters for design and manufacturing complexity, off-the-shelf factor, design technology maturity (new items only), and material factors are used for the trade study runs commensurate with the hardware description inputs. Outputs from the PCM were reviewed with each subsystem designer before the inputs were released to the LCC model analyst.

After the reference, minimum, and maximum size/performance flight element descriptions were estimated for DDT&E and first production unit costs, the results (in 1989 dollars) are input into an MS Excel© spreadsheet LCC model.

The STV LCC model was specially built for the STV contract and a copy was delivered to the study COR (Mr. Don Saxton). Figure 1-1.9-2 illustrates the architecture cost trade studies support process. The weighting given to system hardware LCC as an evaluation criteria (50%) is shown in in Figure 1-1.9-3.

A least squares projection is developed from the PCM cost data in the STV LCC model to estimate variants of the design configurations for trade. Approximately 102 PCM runs of candidate STV hardware were produced in 30 days to feed the LCC model. After the initial 102 PCM runs, a second group of 10 PCM runs was estimated for several new aerobrake, core stage (lander), and crew module flight elements not estimated in the first set.



** Includes Core Tanks (TanksC1,2,...) and Propulsion Unit (Prop1,2,..)

Figure 1-1.9-1. Flight Element Definition

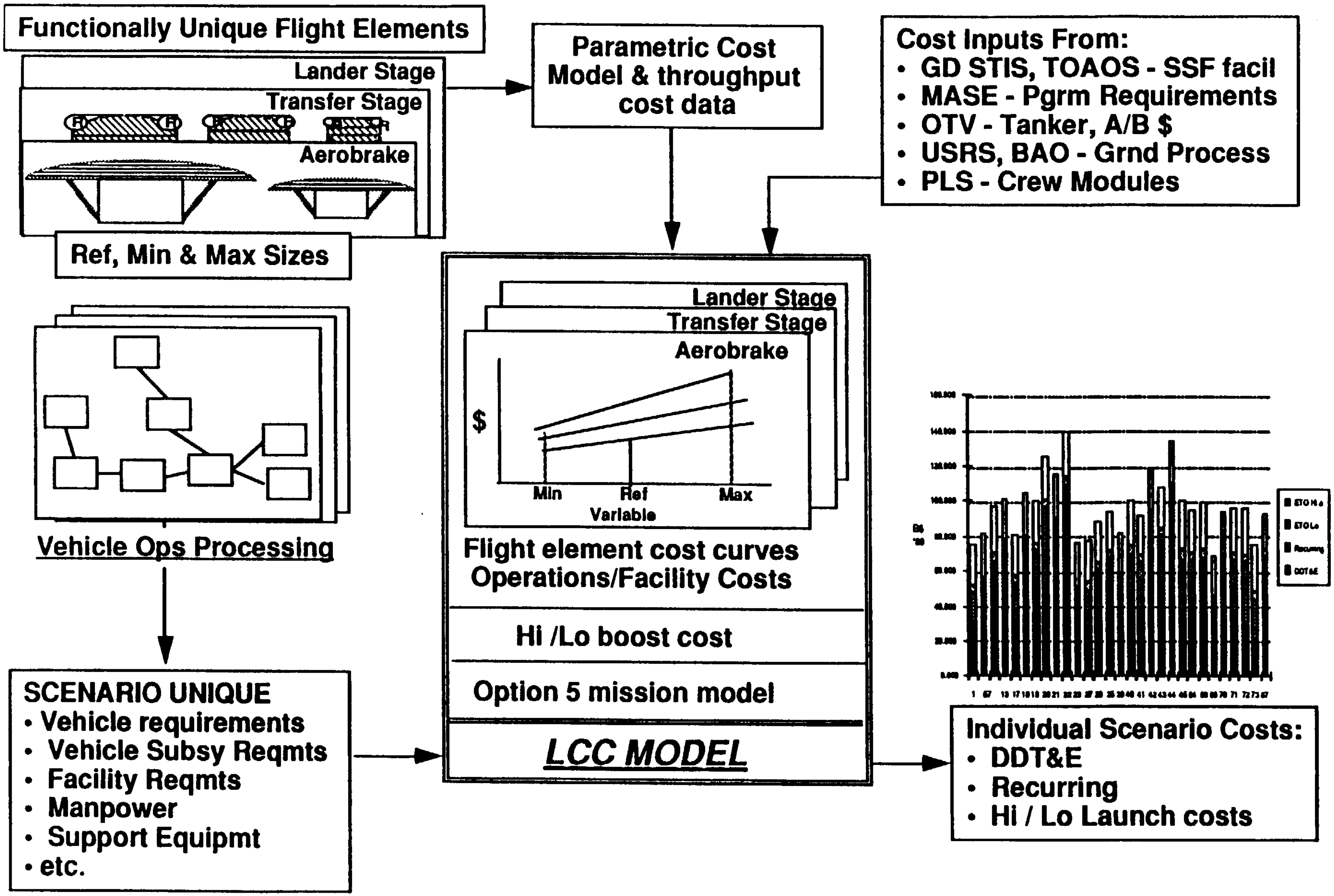

Functionally Unique Flight Elements
Lander Stage
Transfer Stage
Aerobrake
Ref, Min & Max Sizes
Parametric Cost Model & throughput cost data
Cost Inputs From:
• GD STIS, TOAOS - SSF facil
• MASE - Pgrm Requirements
• OTV - Tanker, A/B $
• USRS, BAO - Grnd Process
• PLS - Crew Modules
Vehicle Ops Processing
Lander Stage
Transfer Stage
Aerobrake
$
Min
Ref
Max
Variable
Flight element cost curves
Operations/Facility Costs
Hi /Lo boost cost
Option 5 mission model
LCC MODEL
SCENARIO UNIQUE
• Vehicle requirements
• Vehicle Subsy Reqmts
• Facility Reqmts
• Manpower
• Support Equipmt
• etc.
Individual Scenario Costs:
• DDT&E
• Recurring
• Hi / Lo Launch costs

Figure 1-1.9-2.

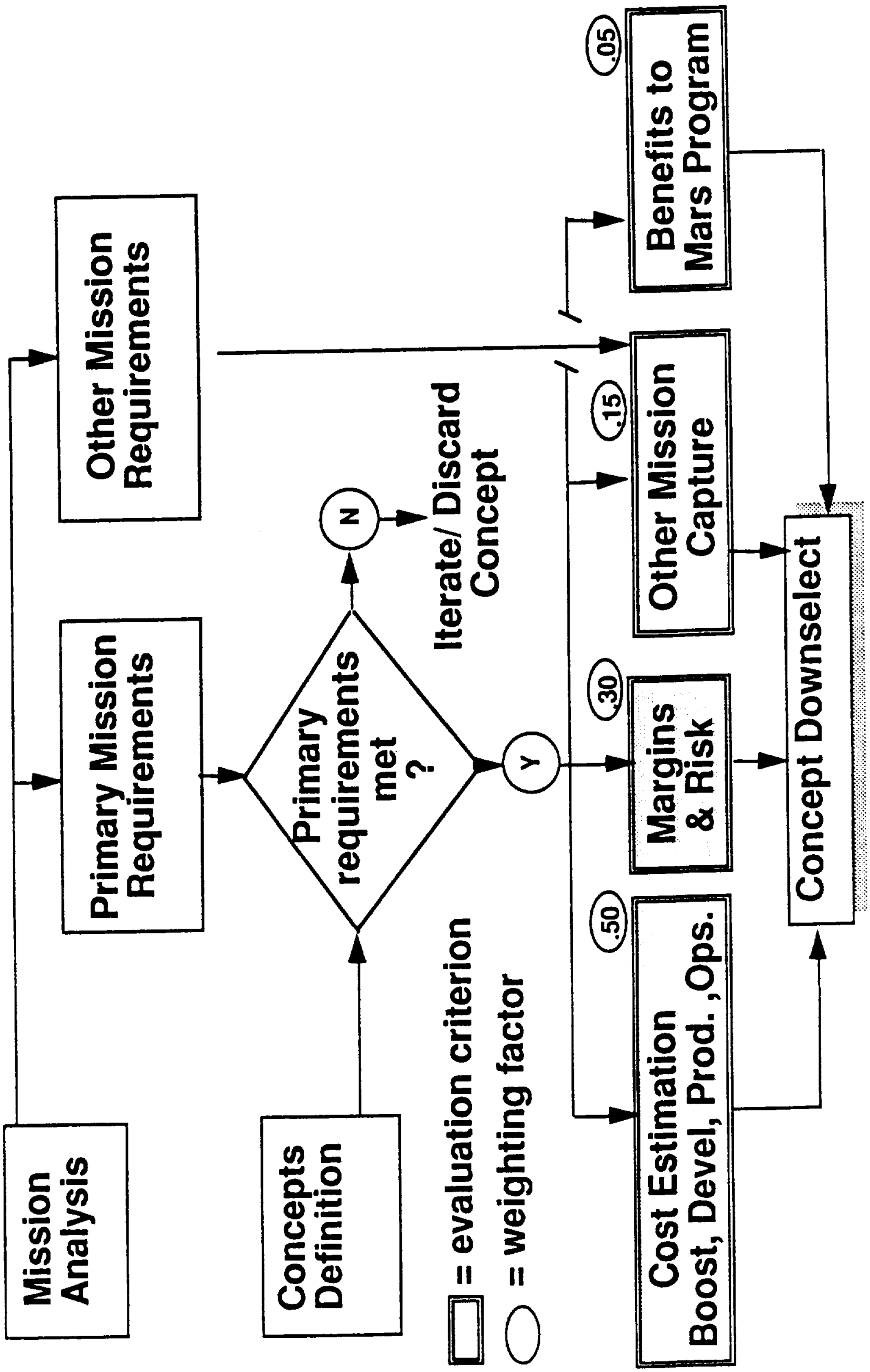

Mission Analysis
Concepts Definition
Primary Mission Requirements
Other Mission Requirements
Primary requirements met ?
N
Iterate/ Discard Concept
Y
= evaluation criterion
= weighting factor
.50
Cost Estimation Boost, Devel, Prod. ,Ops.
.30
Margins & Risk
.15
Other Mission Capture
.05
Benefits to Mars Program
Concept Downselect

Figure 1-1.9-3.

Operations cost estimates were developed from MacProject II© design reference scenario flow diagrams. The diagrams were evaluated for launch, in-space preparation (if required), flight, and equipment refurbishment (at Earth return or at the LEO node) descriptions. Estimates were developed for each flow item box and subelement using Boeing Aerospace Operations data, STS shuttle processing data (e.g., external tank task flows at KSC), IUS data, Centaur processing descriptions, and many other sources (prior NASA study contract reports). In total, 43 different operation and support cost estimates were developed to feed the LCC model. Figure 1-1.9-4 is an example of a O&S cost estimate summary used to create inputs for the STV LCC model.

A set of 43 out of 92 LTS mission configuration candidates were estimated using the STV LCC model. The model actually is quite flexible and the has capability to estimate over 400 candidate configurations. The final results, in constant year 1989 dollars, for the final 43 estimates out of the STV LCC spreadsheet model are shown in Figure 1-1.9-5.

After the evaluation process was completed for the 43 representative candidates, three vehicle configurations were selected as the most cost effective for the lunar mission requirements. The three systems appearing to be the most desirable were all single-stage configurations with one crew module and droptanks (called 1.5-stage configurations). Three basing concepts (space, ground-orbital assembly, and single launch ground) were selected, based on cost and margins and risks criteria (margins and risk influenced the selection between configurations that were close in LCC value). The three final configurations comparison is shown in Figure 1-1.9-6. The next phase of estimating requires a more detailed analysis of the three configurations selected.

The 1.5-stage, space-based LTV was carried forward as a design reference vehicle after Interim Review number 2 (the 90-Day Study two-stage reference vehicle was also carried forward until Interim Review number 4). The space-based candidate has two advantages for evaluation: (1) it became the NASA inhouse reference for comparison discussions and (2) it was within the estimating accuracy range of the LCC model output in relation to the other two lowest cost configurations.

Boeing LTS Configuration: SB2-1.5HP Operations Estimate Summary			
	(1989 Dollars in Millions)		
Date of Estimate: 7-11-90	Cargo	Manned 1st	Refurb &
LTS Operations & Support Task	Mission	Time Mission	Repeat Mission
Ground Operations:			
KSC Aerobrake Processing	N/A	N/A	N/A
KSC Core/Module Processing	3.900	10.495	N/A
KSC Launch Escape Sys. Proc.	N/A	N/A	N/A
KSC TLI Expendable Stage Proc.	N/A	N/A	N/A
KSC TLI Tanksets Processing	1.870	1.870	1.870
KSC TEI Tanksets Processing	1.870	1.870	1.870
Space Assembly Operations:			
Space Tug Use ($70M refurb.amort.)	38.889	38.889	31.111
LEO Core/Crew Module Proc.	1.093	2.924	N/A
LEO Aerobrake C/O & Mate	N/A	N/A	N/A
LEO TLI Stage C/O & Mate	N/A	N/A	N/A
LEO TLI/TEI Tanksets I&C/O	7.500	7.500	7.500
LEO Crew/Cargo Processing	2.743	12.476	12.476
Outbound Flight Operations:			
Flight Crew Pay (IVA)	N/A	7.868	7.868
Lunar Surface Operations	(Expended)	(Not Priced)	(Not Priced)
Inbound Flight Operations:			
Flight Crew Pay (IVA)	N/A	6.005	6.005
LTS Refurbishment Operations:			
Ground Refurbishment (KSC)	N/A	N/A	N/A
In-space (LEO) Refurbishment	N/A	N/A	129.031
Subtotal LTS Operations-	**$ 57.865**	**$ 89.897**	**$ 197.731**
Other Mission Control Ops.	**183.400**	**183.400**	**183.400**
Total LTS O&S Estimate($M)-	**$ 241.265**	**$ 273.297**	**$ 381.131**

Figure 1-1.9-4. Boeing LTS Configuration

Configuration Option		Costs Ops ($B)					
Number	Name	DDT&E	Recurring	ETO Lo	ETO Hi Δ	TOTAL (lo)	TOTAL (hi)
1	GB1-1.5S	28.292	21.384	5.691	28.455	55.367	83.822
3	GB1-2.5S	37.992	37.193	5.868	29.342	81.053	110.395
5	GB2-1.5S	28.941	24.650	5.399	26.994	58.990	85.984
7	GB2-2.5S	39.555	28.006	5.425	27.126	72.987	100.112
13	GB2-2.5D	45.310	31.288	4.806	24.031	81.404	105.434
17	GB2-1.5H	31.281	23.371	4.941	24.707	59.593	84.300
18	GB2-2H	43.700	32.822	5.188	25.940	81.710	107.650
19	GB2-2.5H	43.694	30.817	4.953	24.763	79.463	104.226
20	GB2-3H	45.670	45.054	5.068	25.338	95.791	121.129
21	GB2-3.5H	49.733	37.411	5.186	25.929	92.330	118.259
22	GB2-4H	51.743	51.833	5.301	26.504	108.876	135.380
23	SB1-1.5S	25.729	21.248	6.129	30.646	53.106	83.752
25	SB1-2.5S	35.561	37.528	6.050	30.252	79.140	109.392
27	SB2-1.5S	27.560	22.201	4.889	24.443	54.650	79.092
29	SB2-2.5S	36.338	24.735	4.743	23.717	65.816	89.532
35	SB2-2.5D	41.096	26.683	4.552	22.760	72.331	95.091
39	SB2-1.5H	30.808	23.571	4.743	23.713	59.122	82.835
40	SB2-2H	41.276	28.095	5.219	26.096	74.590	100.686
41	SB2-2.5H	39.582	26.234	4.604	23.020	70.420	93.440
42	SB2-3H	49.591	40.379	4.722	23.611	94.692	118.303
43	SB2-3.5H	46.439	33.689	4.864	24.319	84.991	109.310
44	SB2-4H	56.441	48.074	4.980	24.900	109.495	134.395
45	SB2-1.5SP	25.242	26.161	5.923	29.614	57.325	86.939
46	SB2-1.5HP	28.217	22.891	5.812	29.058	56.920	85.978
47	SB2-2.5HP	38.523	28.645	5.809	29.047	72.978	102.025
48	SG1-1.5S	30.133	26.341	7.719	38.594	64.193	102.786
52	SG2-1.5S	29.363	24.262	5.722	28.611	59.347	87.958
64	SG2-1.5H	31.101	24.622	5.201	26.007	60.925	86.932
65	SG2-2H	42.829	29.826	5.579	27.895	78.234	106.129
66	SG2-2.5H	41.095	27.468	4.991	24.955	73.554	98.509
67	SG2-3H	51.099	41.983	5.109	25.547	98.192	123.738
70	SG2-1.5SP	27.252	27.746	6.288	31.442	61.286	92.728
71	SG2-1.5HP	29.949	23.889	5.737	28.686	59.575	88.262
72	SG2-2.5HP	40.111	29.316	5.527	27.635	74.954	102.590
73	GO1-1.5S	21.312	22.130	5.734	28.669	49.176	77.845
74	GO1-2S	30.678	36.871	5.574	27.869	73.122	100.991
75	GO1-2.5S	30.998	38.121	5.647	28.234	74.765	102.999
76	GO1-3S	39.957	49.862	5.723	28.613	95.542	124.155
77	GO2-1.5S	21.950	24.812	5.434	27.171	52.196	79.367
79	GO2-2.5S	32.573	28.976	5.458	27.289	67.007	94.296
89	GO2-1.5H	24.289	23.987	4.965	24.824	53.241	78.065
91	GO2-2.5H	36.213	30.179	4.971	24.857	71.364	96.220

Figure 1-1.9-5. STV LCC Model Outputs

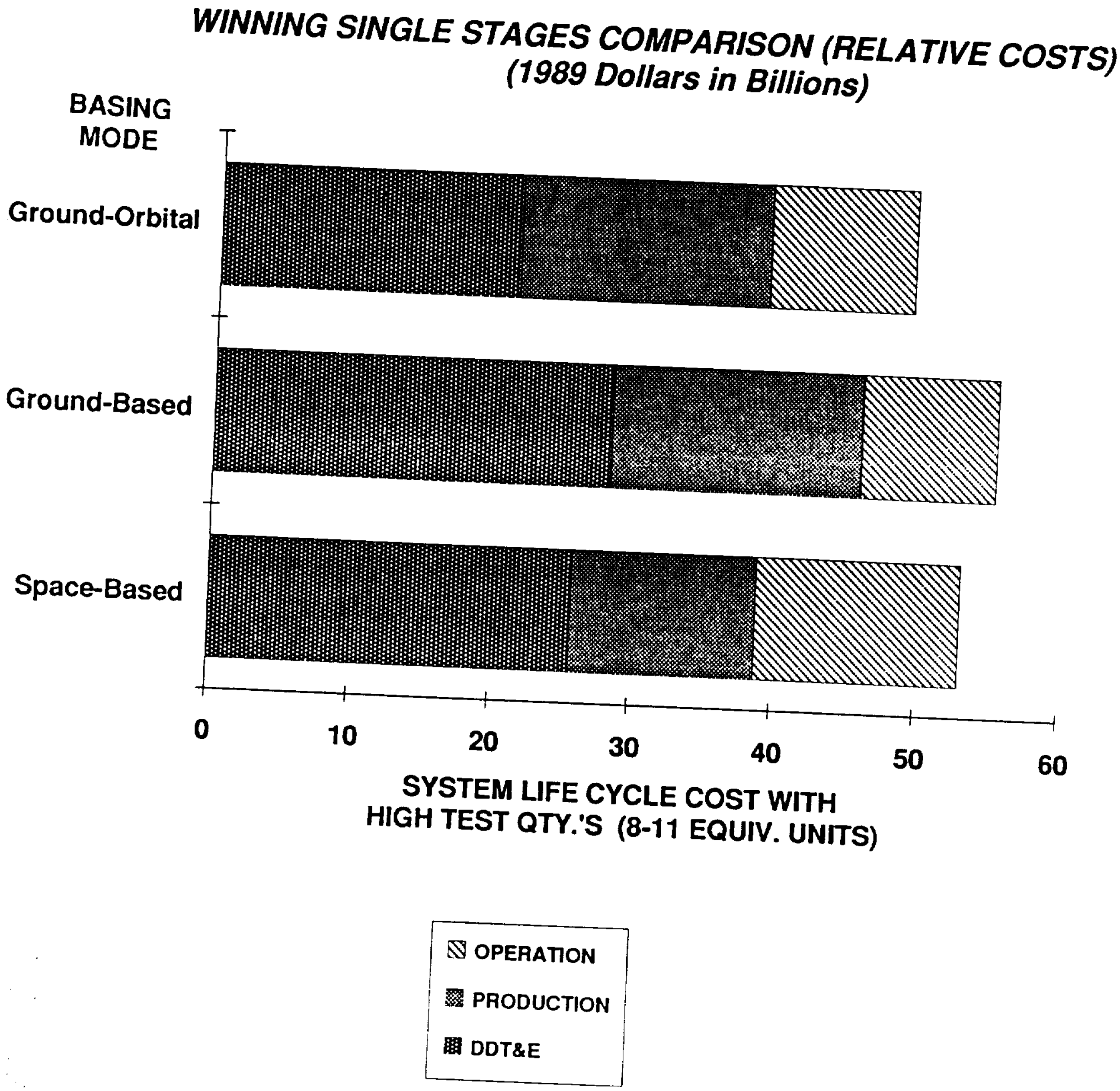


Figure 1-1.9-6. Winning Single Stages Comparison

1-2.0 SUMMARY COST PRESENTATIONS

Section 1-2.0 is a chronological record of the interim review material relating to cost analysis. These materials have been previously presented in Space Transportation Week main sessions or splinter meetings. The subsections include a brief summary of the study contract tasks accomplished during that period of review and the key conclusions or observations identified related to STV program cost estimates.

During the course of the study (June 1990), Boeing was directed by NASA to estimate in constant year 1991 dollars (the study statement of work designated that cost estimates would be done in 1989 dollars). Therefore, all trade studies done in the STV LCC model were conducted in 1989 for "relative dollars" comparison purposes. After Interim Review number 3, the final three configuration estimates were calculated in 1991 dollars, in accordance with NASA customer direction.

1-2.1 INTERIM REVIEW NUMBER 2 SUMMARY

Interim Review number 2 contained very little cost analysis information. The NASA 90-Day Study two-stage STV for the lunar mission was evaluated at a top level. The two-stage vehicle evaluation was necessary to set up the Boeing PCM and identify high-value subsystems of a the space transportation system. The avionics, propulsion, aerobrake, and structures subsystems constituted approximately 80% of the flight hardware development cost estimate.

The two-stage vehicle estimates and PCM inputs were checked against recent and past transfer vehicle hardware estimates by conducted by Boeing-Seattle (IUS actuals and prior OTV studies) and Eagle Engineering (LM/LEV only). The estimates were further evaluated using some actual NASA Apollo program cost data for the command service module (CSM) and lunar module obtained from NASA during recent architecture study contracts. All escalation table factors applied to the historical program data were obtained from the NASA cost analysis functional interface person at MSFC.

A selection of charts from the interim review general presentation is presented in Figures 1-2.1-1 through 1-2.1-3.

The top-level program schedule parameters were obtained from NASA and expanded to estimate a STV lunar mission development project for the two-stage reference vehicle. At this point in the study, phase C/D was planned for a start date of mid-1994. After Interim Review number 3, the phase C/D start date slips further due to unexpected NASA funding forecast shortfalls in the Space Exploration Initiative (SEI) 5-year operating plans submitted to Congress in 1990. All study participants did not change the first operational flight date, so the phase C/D plans are put into a compression situation from the original program planning.

STV MSFC-BOEING PRELIMINARY MASTER SCHEDULE

3-22-90

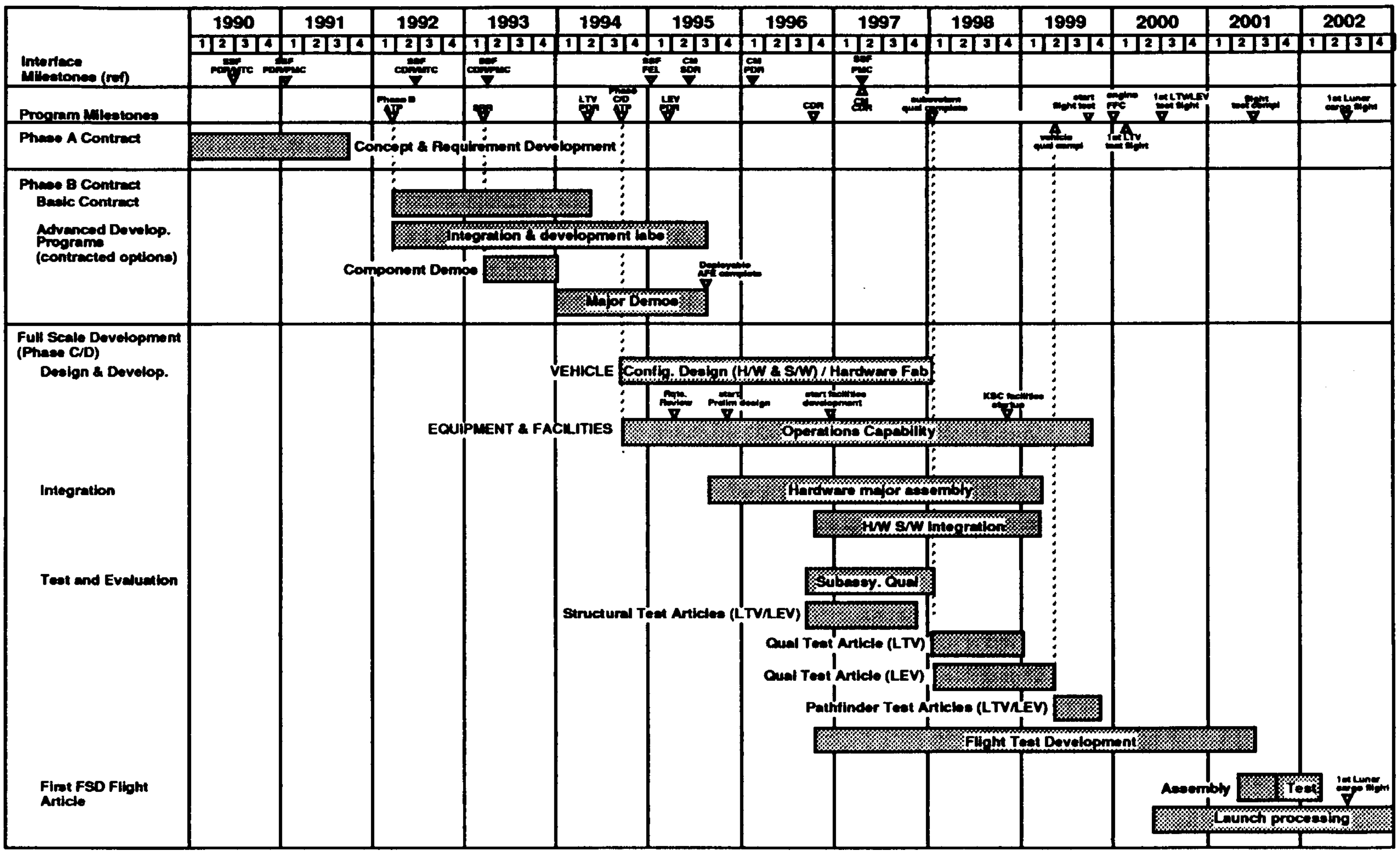


Figure 1-2.1-1. Preliminary Master Schedule

STV

MSFC- BOEING

STV DEVELOPMENT SCHEDULE

3-22-90

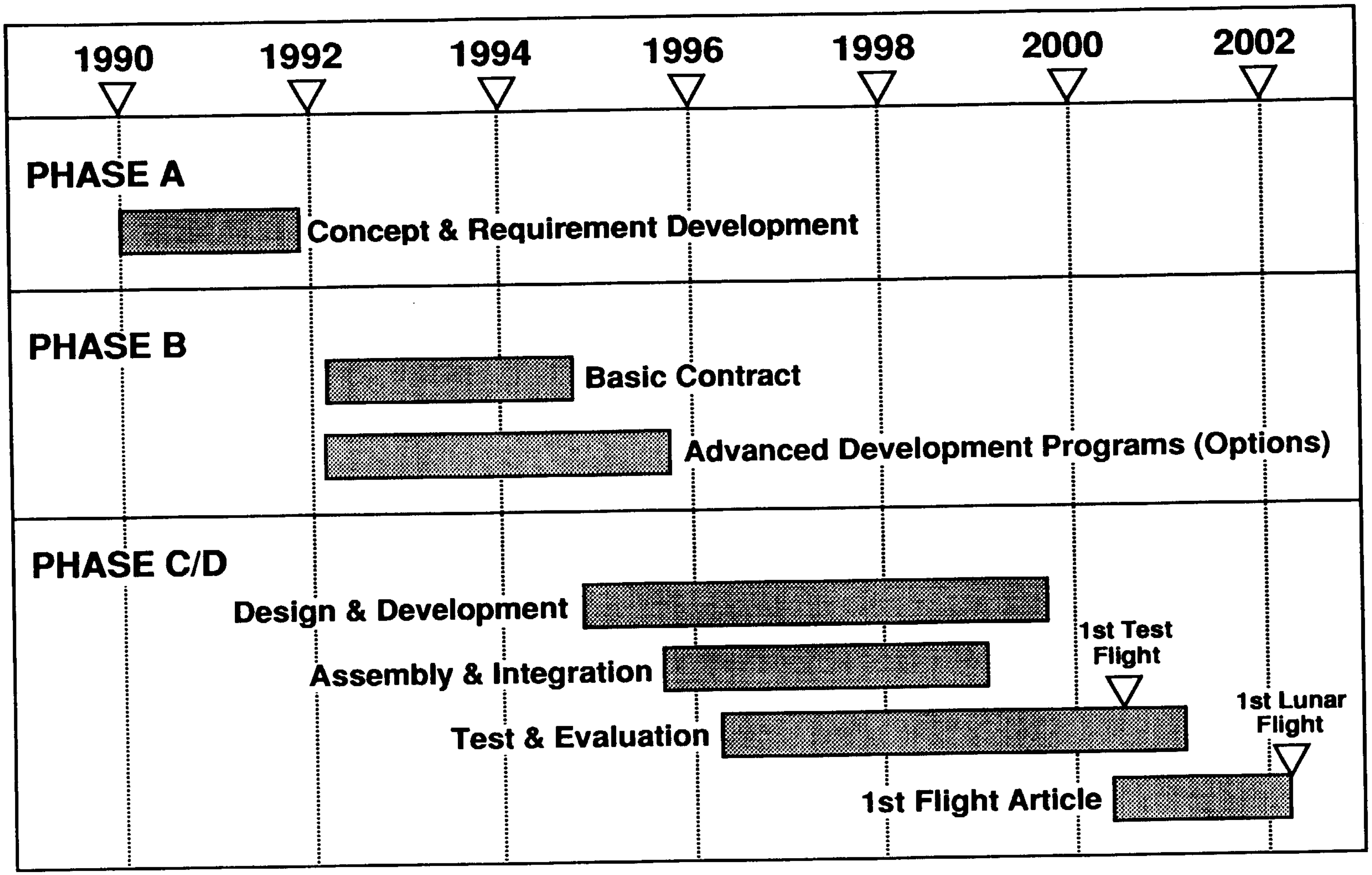


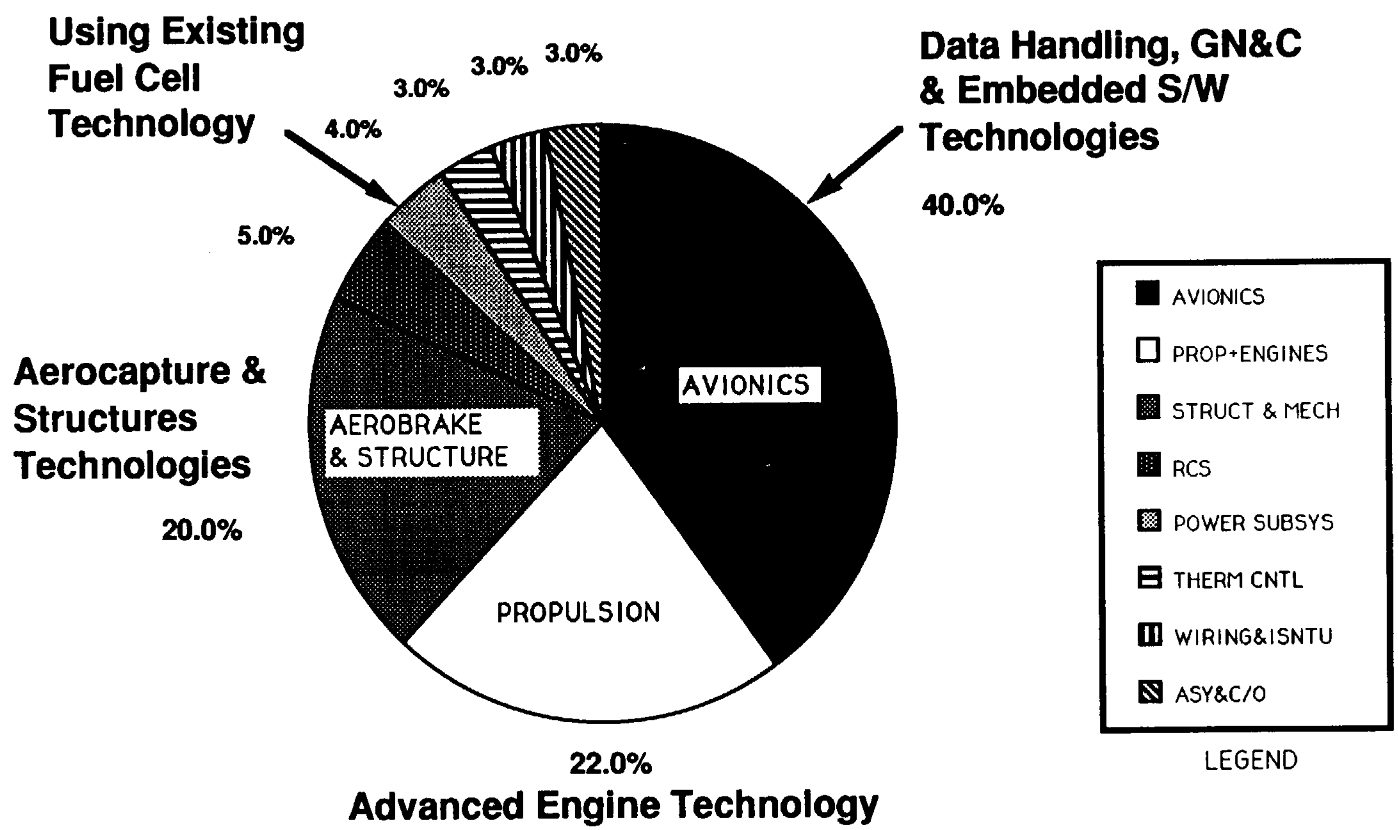
Figure 1-2.1-2. STV Development Schedule

STV MAJOR WORK PACKAGES (MISSION L2)

MSFC- BOEING

PRELIMINARY DATA 3-22-90

LTV/LEV DDT&E COST (FLIGHT HARDWARE)



The High Value Items are: Avionics, Propulsion, and Structures........

Figure 1-2.1-3. Major Work Packages

1-2.2 MIDTERM INTERIM REVIEW NUMBER 3 PRELIMINARY COST DATA

Interim Review number 3 data are the first time in the study that a full set of groundrules are presented with the cost estimate data. The master schedule is updated by NASA COTR direction. A WBS dictionary is drafted for use in cost analysis and programmatics definition. The WBS dictionary also helps to define flight hardware and software terminology, system flight elements, program support tasks, operation cost elements, and subsystems content (see Book 2, Volume III for the final WBS dictionary).

A lunar mission model operational scenario (DRS-1) is used to estimate operational vehicle quantities. The basis for this mission model is derived from NASA payload description documents and the civil needs database (CNDB) FY89 information. The reference vehicle design is now revised to a single-stage vehicle with droptanks (1.5-stage vehicle). The LTV uses low lunar orbit to park the aerobrake and tankage, while the lander core stage travels to the Moon's surface and back after a 6-month stay at the Moon base. This vehicle has no LEV and only one crew module to carry the four LTS passengers.

Two lunar mission types of trips are accomplished: an unmanned cargo-only sortie and a manned trip with a smaller cargo load. The vehicle estimated weighs (dry) 31,377 kg (69,174 lb). Six operational vehicles are required (with five reuses each) to perform 25 trips at one trip per year. A complete life cycle cost estimate is presented for this vehicle and the infrastructure needed to support the lunar mission. Other CNDB high-energy upper stage or in-space servicing mission estimates are not presented at this time.

Two of the cargo flights are proposed to be accomplished in the initial O&S phase. These flights are performed with two separate DDT&E units. (Later in the study, the schedule will be compressed to the point where only one DDT&E unit will be proposed as a cargo flight option.)

This is the first attempt at estimating modifications to Space Station Freedom (SSF) for facilities to assemble, service, refurbish, and provide flight crew services for the manned lunar missions. Facilities for launch preparation and mission control/training are estimated for sites at Kennedy Space Center (KSC) and Johnson Space Center (JSC). The launch booster costs estimated assume use of a 71 metric ton HLLV. The five replacement flights are cargo-only flights with the core stage hardware expended on the Moon's surface.

The technology maturity levels of the subsystems for this vehicle are presented for discussion. Some reviewers at the presentation believe that several of these maturity assessments may be too optimistic. The Boeing team promises to reevaluate the items in question for verification and adjustments.

The observations or disclosures at this point in the study are as follows:

1. Flight management functions must be located in many flight elements for long-term space storage.
2. Design descriptions for vehicles will be expanded (after architecture trade studies are completed) to do subsystem selection.
3. Cost should be treated equal to safety and mission success.
4. McDonnell Douglas, General Dynamics, and Boeing studies data were used to define SSF modifications.
5. The Boeing team created a spreadsheet method to download inputs to PCM for the upcoming vehicle basing and mission capture architecture trade studies.

The midterm review charts presented are depicted in Figures 1-2.2-1 through 1-2.2-8. At this time in the study, 28 architecture cost trade studies are supported with 85 parametric model cost runs and 28 individual O&S cost estimates. See section 1-1.9 for a more indepth explanation of the vehicle selection architecture trade studies support.

STV

MSFC- BOEING

PROGRAMMATICS OBJECTIVES

Task 4 Programmatics

6-20-90

Task 4 Programmatics Goals for this Period:	Accomplishments
• Estimate a point-of-departure design for DDT&E and theoretical first unit costs	Completed
• Refine program schedules & test plans	Completed
• System-level LCC trades support	28 DRS's
• Refine work breakdown structure dictionary	Completed
• Estimate ground and space operations cost using data from Boeing, GD, & MDSSC	Completed
• Develop & use STVLCC spreadsheet model	Completed
• Support configuration down-select process	In Process

Figure 1-2.2-1. Programmatics Objectives

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ESTIMATE GROUNDRULES

Task 4 Programmatics

6-20-90

Space-Based Reference Vehicle LCC Estimate:

- Point-of-departure configuration is similar to the NASA-MSFC LTV single stage option with a single crew module.
- Lunar mission model: 25 trips from 2002 to 2026.
- Constant-year 1989 dollar estimates; 35% rqmt. contingency, 10% contractor fee, & 5% NASA factors applied at top level.
- Nominal mission timeline for O&S requirements.
- Assumes 1994 technology application freeze point.
- Weight growth allowance is 15%; O&S contains 25% cost contingency factor application to resource estimates.
- 1 qualification, 1 pathfinder, 3 prototype & flight DT&E vehicles.
- Parametric, top level estimates & conceptual design description.

Figure 1-2.2-2. Estimate Groundrules

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PROGRAM SCHEDULES

Task 4 Programmatics

6-20-90

Program master & development schedule tasks:

- Update program schedule for: reference lunar missions; Acquisition phases and O&S phase definition (DRS-1).
- Assume need for six production vehicles, and use of 2 protoflight vehicles for first two cargo flights.
- Add more aerobrake development detail to Phase C/D schedule.
- Plan for supporting first C/D test flight (2000), first cargo mission (2002) or first piloted mission (2004) to Moon.
- Coordinate schedules with WBS development, technology development planning, & mission analysis tasks.
- Think about plan options for DDT&E schedule stretchout (to be included in final report development plan.)

Figure 1-2.2-3. Program Schedules

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LUNAR MISSION MODEL (DRS-1)

Task 4 Programmatics

6-20-90

Date	Flight #	Mission Type	LTV/LEV
2002	0	Cargo	Expended
2003	1	Cargo	Expended
2004	2	Piloted	Delivery
2005	3	Piloted	2
2006	4	Cargo	Expended
2007	5	Piloted	Replacement
2008	6	Piloted	2
2009	7	Piloted	3
2010	8	Cargo	Expended
2011	9	Piloted	Replacement
2012	10	Piloted	2
2013	11	Piloted	3
2014	12	Piloted	4
2015	13	Piloted	5
2016	14	Piloted	Replacement
2017	15	Piloted	2
2018	16	Piloted	3
2019	17	Piloted	4
2020	18	Piloted	5
2021	19	Piloted	Replacement
2022	20	Piloted	2
2023	21	Piloted	3
2024	22	Piloted	4
2025	23	Piloted	5
2026	24	Piloted	Replacement

Figure 1-2.2-4. Lunar Mission Model

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PROGRAM MASTER SCHEDULE

Task 4 Programmatics

Status as of: 06-05-90

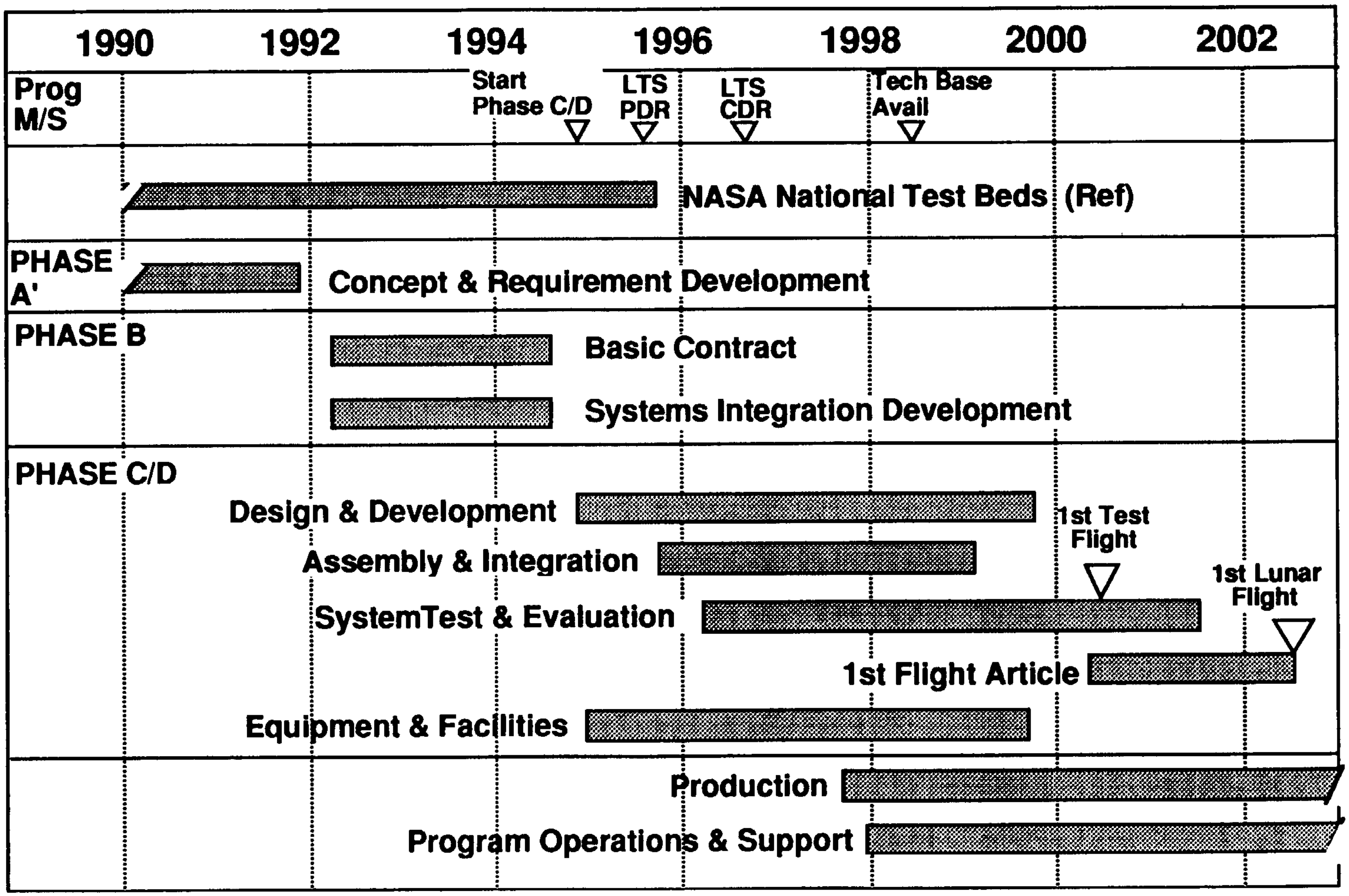


Figure 1-2.2-5. Program Master Schedule

STV SELECTED REFERENCE HARDWARE DESIGN

Task 4 Programmatics

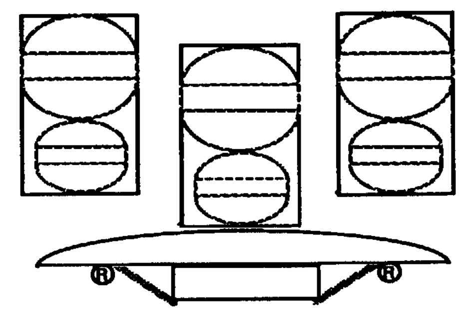
MSFC- BOEING

SB2-1.5S Vehicle 6-20-90

WBS Summary Items	Weight in Metric
LTV Core Vehicle Derivative:	
Structures, Mech., Landing Gear	2,677 Kg
Thermal Control (MLI, Active)	378
Aerobrake (incl.Thermal Shield)	3,578
Propulsion (Adv., 4 Engines)	2,181
Reaction Control (2 Types)	117
Power (Batteries/Solar)	173
Power Distribution	357
Guidance Nav. & Ctrl. Avionics	114
Comm. & Data Hdlg. (incl. VHS)	125
Drop Tank Modules (with Arrays)	13,036
Crew Module (Single, Complex)	4,550
Dry Mass (kilograms) Subtotal -	27,286
Weight Growth Margin (@ 15%)	4,091
Estimated Total Dry Weight	31,377 Kg (69,174 Lbs.)

Illustration

Tank Sets and Aerobrake



Crew Module and Single Stage

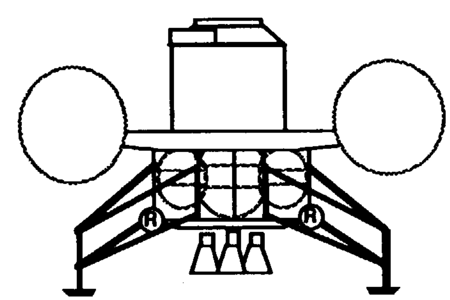


Figure 1-2.2-6. Selected Reference Hardware Design

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REFERENCE LCC SUMMARY

Task 4 - Programmatics

6-20-90

Reference SB2-1.5S Configuration: Lunar Mission (DRS-1)

(Constant Year, 1989 Dollars in Millions)

Concept Development & DT&E	$	22,333 M	FY 1992-2001
Facilities & Equip. at KSC/JSC/SSF		4,667	FY 1992-1999
Production (6 LTS Vehicle Sets)		14,063	FY 1997 (L/L) Thru 2022
Operations & Support (27 Yrs.)			
4 Cargo Flights		942	(2 in DT&E)
16 Steady State Flights		5,586	FY 1999 - 2026
5 Replacement Flights		1,610	
Launch Booster Costs		4,889	
*Total Life Cycle Estimate -	$	54,090 M	

Operational Scenario: Use of SSF Services, 25 Flights (1 Flight per Year)

Figure 1-2.2-7. Reference LCC Summary

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TECHNOLOGIES APPLICATION ASSUMPTIONS

Task 4 Programmatics 6-20-90

WBS Items	Technology Application Assumed	(NASA Maturity Scale) Technology Level
Hardware:		(Average)
Structures & Mech.	Aluminum; Honeycomb; Graphite Composites	Level 9
Thermal Control	MLI Blankets; Heat Exchangers; Heaters	Level 9
Aerobrake Systems	Adv. Rigid Tile; Gr. Ep. Honeycomb;Rigid Design	Level 3
Propulsion (LTV/LEV)	Advanced Engines - AETB Performance Goals	Level 2
Reaction Control	Integrated Cryogen Systems + N_2 Cold Gas	Level 9
Power Subsystems	Advanced GaAs (1995); Adv. STS Fuel Cells	Level 6
Guidance, Nav., Ctrl.	2nd Gen. Ring Laser Gyro's; Adv. SAR Radar	Level 7
Com. & Data Hdlg.	ATDRSS; Laser Comm.; VHMS; Adv. Processor	Level 3
Wiring & Instru.	Power - Superconductor Wire; Digital - Fiber Optics	Level 5
Software (Veh.)	Expert Systems; Ada Language ; LISP; 32-BIT	Level 4
Assy. & Checkout (Space)	Mech. Latch Assy.'s; Robotics; Telerobotics	Level 3
Support Equipment	Redundant, Fully-Automated Test Equip.; BIT	Level 6
System Test Operations	High Rel.; 2-Fault Tolerant (NASA STD-3000)	Level 8
Space Operations	Current EVA Suit; SSF Avail.; Telerobotics Maint.	Level 6

Figure 1-2.2-8. Technologies Application Assumptions

1-2.3 INTERIM REVIEW NUMBER 4 SELECTED VEHICLE COST ESTIMATES

Interim Review number 4 is the first review that includes an attempt to estimate all the missions identified in the CNDB FY89 missions description. The review also summarizes the results of the configuration architecture trade studies started just before Interim Review number 3.

The schedule definition was revised to include several NASA-directed changes that impacted the cost estimates. A new phase C/D (full-scale development) start date is incorporated into the master schedule. The master schedule was then used to develop a funding profile estimate based on the development, initial operating capability milestones from the President's SEI speech and mission model requirements. The space-based reference vehicle design is updated and redefined during this period with a more detailed mass properties description listing.

The new space-based vehicle estimate is estimated in constant year 1991 dollars. A factor of 10.1% inflation is used to increase operation and support estimate WBS items that did not change. The facilities and Space Station modifications estimates are updated to include maintenance crew quarters, new flight telerobotic servicer (FTS) 2 estimates from Martin, and more ground launch servicing facilities at KSC.

The NASA program-level factors are revised. The program requirements change factor decreases from 35% to 30%. The contractor fee allowance drops from 10% to 8%, by direction from the MSFC cost analysis technical interface person. The NASA program support factor stays at 15% for all flight system elements.

The configuration trade studies downselect activity yields two vehicle designs with three operational scenarios that can perform the LTS mission set; both designs are single-stage vehicles with droptanks. The new space-based unit, however, goes to the surface with the aerobrake attached (after a lunar orbit capture maneuver). The new space-based LTV does not store any hardware in lunar orbit (low lunar orbit rendezvous was deleted). Therefore, the aerobrake cost estimate is revised to eliminate reaction control and avionics equipment that were required for 6 months of stationkeeping.

The use of LTV equipment for the high-energy upper stage missions does not appear to be cost effective. The vehicle designed and produced to deliver very large lunar mission cargos and be refurbishable in space is overqualified to deliver 20,000-lb cargos to geosynchronous or high Earth orbits. More modular droptank configurations can be adapted to smaller stage conversions. If the space-based design allows for this modularity modification, it must not decrease reliability and increase LCC with a complex fluid supply system. The Boeing design is still optimized for the lunar missions.

The satellite servicing missions do look like a more promising application and more cost effective. The flight hardware is reused and not expended. These hardware cost and application issues are brought out in the presentation.

A LCC estimate for 10 years of operations of CNDB FY89 missions is developed to assess the impact of expending core stage hardware and address the option of higher production quantity requirements. The LCC estimate was prepared for the length of time covered by the CNDB FY89 document.

A development funding profile is developed in 1991 dollars. The development estimate funding profile includes the SSF modification and facilities estimates. The funding estimate excludes any HLLV development or setup costs. Multiprogram testbeds like the aeroassist flight experiment number 2 (to benefit the Mars system development also) are not included in the estimate, but assumed part of the total SEI development requirements and important to LTS success.

A facilities cost estimate breakdown for the space-based lunar transportation system LTS is included. The KSC facilities are increased to include more activity to prepare launching of STVs for the high-energy upper stage missions. The facilities estimates will be updated once more before Interim Review number 5 in January 1991.

The conclusions reached at the end of this Interim Review number 4 review are as follows:

1. The space-based configuration core stage used as an expendable upper stage is too large and not cost effective.
2. The STV LCC model is not adequate to build funding spreads; recommend separating lunar mission funding spreads only or extending CNDB (level load after 10 years of operations out to 25 years).
3. Development test quantities for hardware are the major cost driver, not weight.
4. Further cost analysis of the three selected configuration candidates will reveal which require more DDT&E funds up front and which capture more missions with less program risk.
5. The advanced engine and software developments are the schedule critical path items and high-cost risk areas of LTS full-scale development (phase C/D).
6. The qualification test vehicle can be used as the pathfinder to save money.
7. Three STV flight test vehicles are now proposed to demonstrate vehicle capability to perform all three CNDB mission categories (lunar, HEUS, and servicing).

The charts shown at the review are presented in Figures 1-2.3-1 through 1-2.3-11. At this time only the space-based operations costs were updated. One more update will be required to compare the space-based configuration with the ground-based vehicles.

STV

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PROGRAMMATICS ACTIVITIES STATUS

STV Programmatics Splinter

10-19-90

Task Goals for this Period:	Accomplishments
• Support configuration down-select process	Completed
• Update technology demonstrations plan	Completed
• Re-evaluate three STV Lunar mission designs for DDT&E and theoretical first unit estimates	50% Complete
• Update 3 ground and space operations cost estimates presented in June, 1990	33% Complete
• Develop preliminary LCC funding profiles	Space-based
• Support subsystems definition options	Space-based
• Develop & use spreadsheet funding profile model using lot buy assumptions	Excel with cum. values

Figure 1-2.3-1. Programmatics Activities Status

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DOWN-SELECT SUPPORT RESULTS

STV Programmatics Splinter

10-19-90

The down-selection to three vehicle configurations included:

- Calculation of life cycle costs for 13 additional configurations after the midterm review.
- All trades done in constant-year 1989 dollars (to be consistent with estimates for 29 options shown at midterm); future trades are in1991 dollars.
- Three estimates are close in total LCC magnitude, but require significant differences in booster and operational setup requirements.
- New Ground-Orbit system acquisition estimate is also very close in cost magnitude, except the biconic crew module is twice as expensive as the space-based module.

Figure 1-2.3-2. Downselect Support Results

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EARLY TRADES LCC COMPARISON

STV Programmatics Splinter

10-19-90

WINNING SINGLE STAGES COMPARISON (RELATIVE COSTS)
(1989 Dollars in Billions)

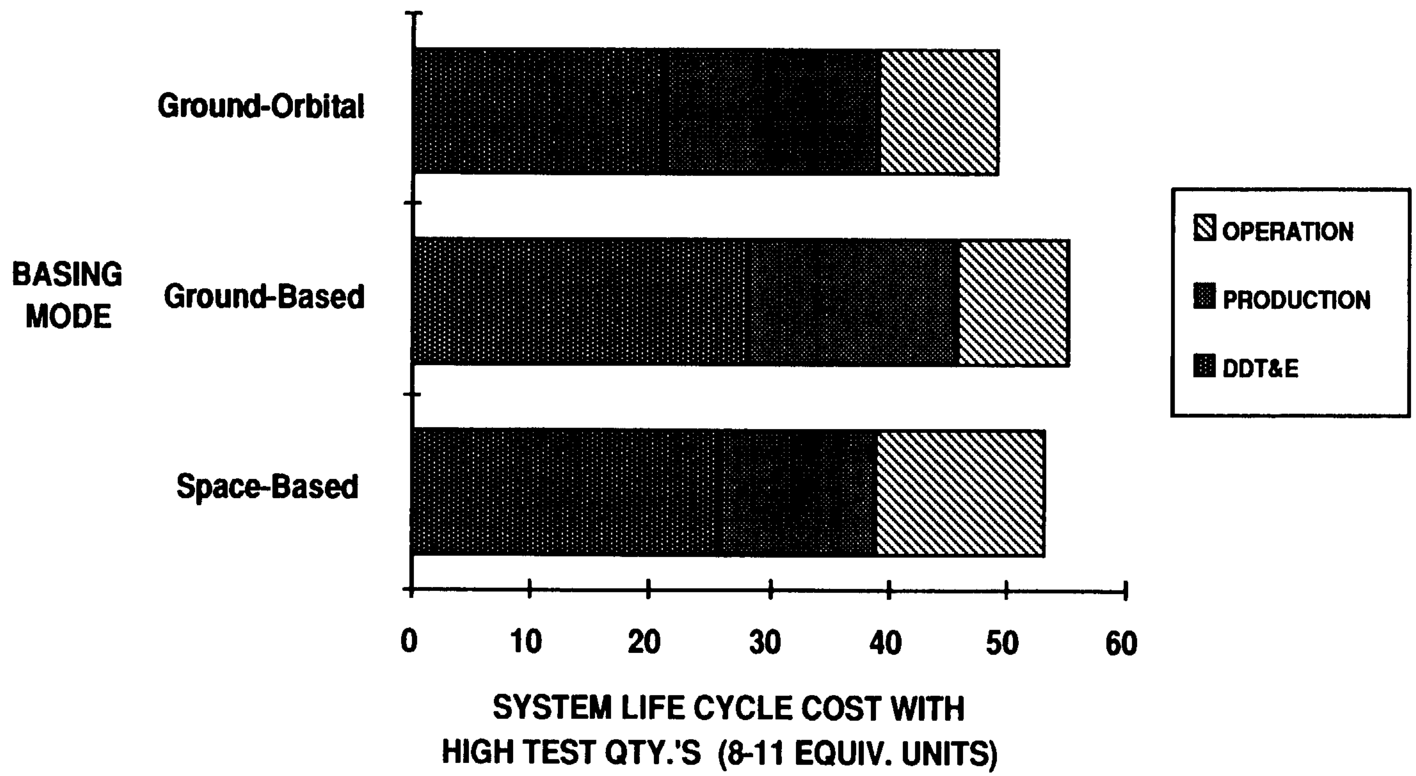

Figure 1-2.3-3. Early Trades LCC Comparison

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PROGRAM SCHEDULES OVERVIEW

STV Programmatics Splinter

10-19-90

Program master & development schedule status:

- Revised program schedules for funding analysis and new LCC estimates from data provided by COR.
- Assume need for six LTS production vehicles, and use of 3 protoflight vehicles for DoD, civil, and LTS.
- Developed more aerobrake development and demonstration detail for technology assessment.
- Plan for supporting first C/D test flight in 2001, first cargo mission in 2003 and first piloted mission in 2005 to Moon.
- Schedule changes for phase B and C/D based on 8-30-90 information which slides phase C/D start one year.
- Development of an expanded test hardware schedule and logic network for phase C/D is in progress.

Figure 1-2.3-4. Program Schedules Overview

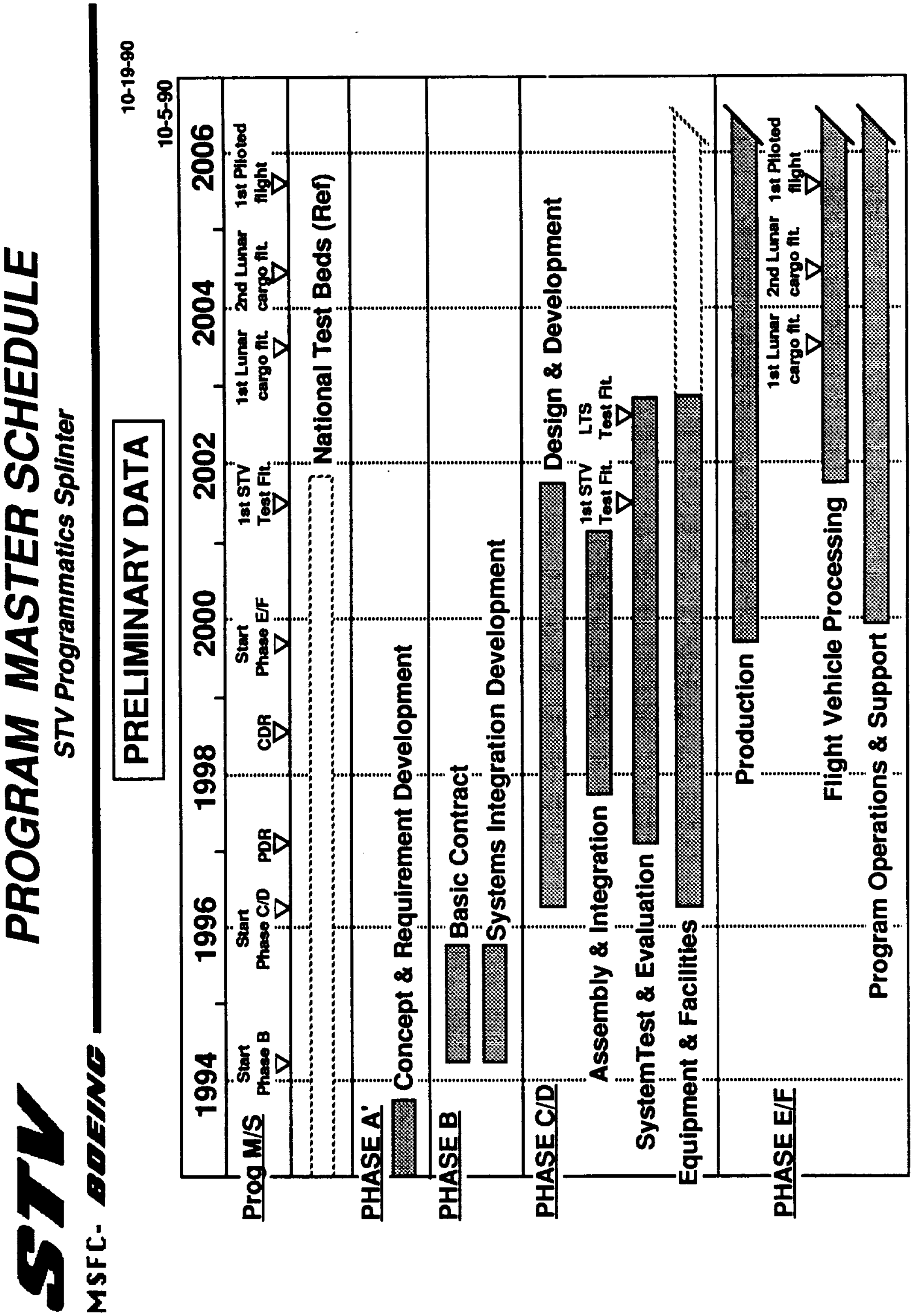

Figure 1-2.3-5. Program Master Schedule

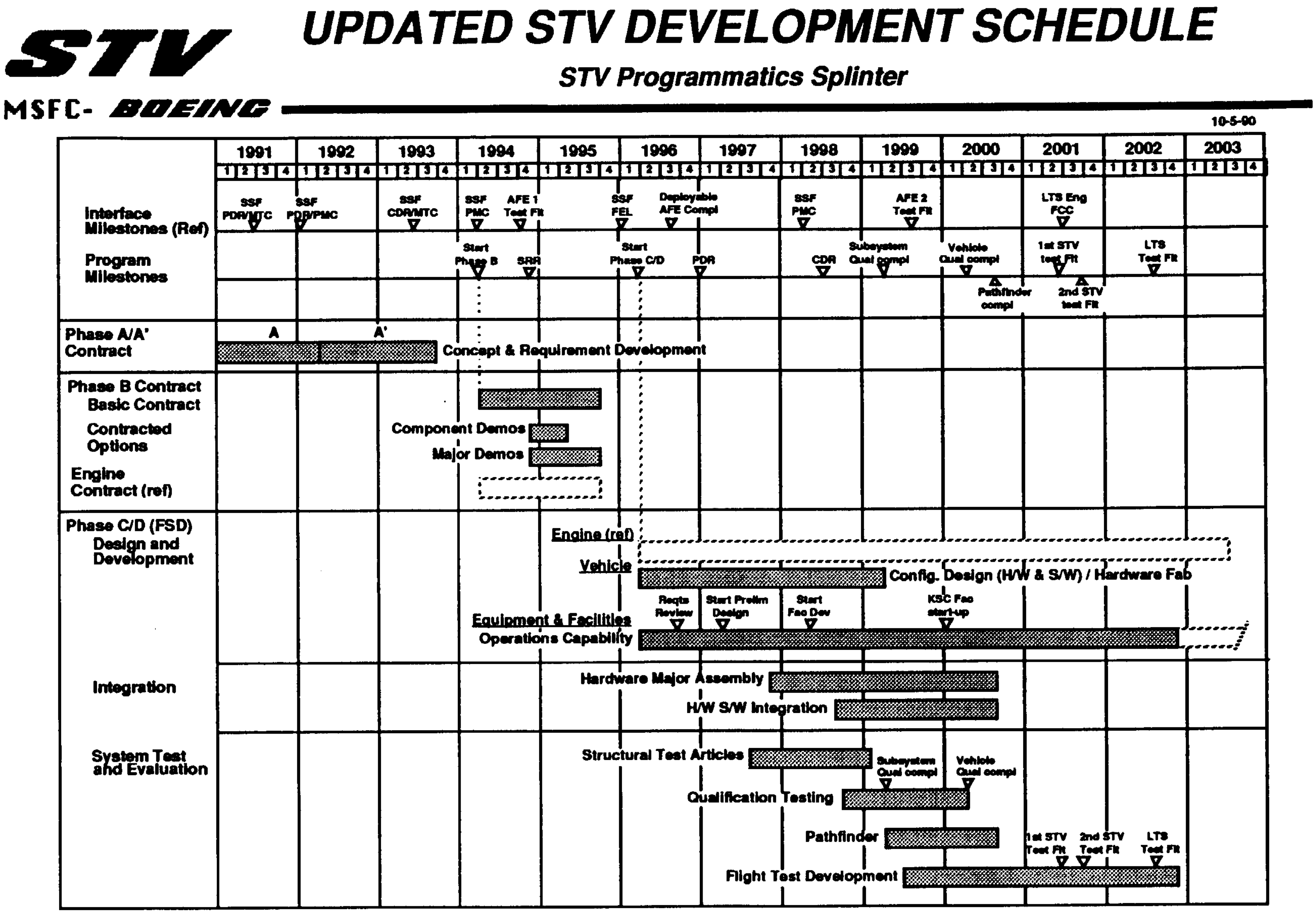

Figure 1-2.3-6. Updated STV Development Schedule

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REVISED ESTIMATING GROUNDRULES

STV Programmatics Splinter

10-19-90

Updated Vehicle LCC Estimates:

- Space-based configuration is similar to the NASA-MSFC LTV single stage option with a single crew module.
- (Rev) Lunar mission model: 25 trips from 2003 to 2027.
- (Rev) Constant-year 1991 dollar estimates; 30% rqmt. contingency, 8% contractor fee, & 15% NASA factors applied at top level.
- Nominal mission timeline for O&S requirements.
- (Rev) Assumes 1995 & '97 technology application freeze points.
- Weight growth allowance is 15%; O&S contains 25% cost contingency factor application to resource estimates.
- (Rev) Combined qual./pathfinder; 2 ground & 3 flight test vehicles.
- Parametrically derived, preliminary planning estimates.

Figure 1-2.3-7. Revised Estimating Groundrules

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SPACE-BASED SYSTEM DESIGN

STV Programmatics Splinter

10-19-90

ESTIMATES ARE NOW BEING DONE AT THE "BOX" LEVEL...............

WBS Summary Items	Weight in Metric	
LTV Core Vehicle Derivative:	10,696	Kg
Structures, Mech., Landing Gear	1,949	
Thermal Control (MLI, Active)	437	
Aerobrake Subassembly	3,575	
Propulsion (6 Engines & Tanks)	2,709	
Reaction Control	347	
Electrical Power	374	
Power Distribution	433	
Guidance Nav. & Ctrl. Avionics	268	
Comm. & Data Hdlg. (incl. VHS)	604	
Drop Tank Module (trans-Lunar)	3,066	
Drop Tank Module (Lunar descent)	1,775	
Crew Module (single, capsule)	3,907	
Dry Mass (kilograms) Subtotal -	19,444	
Weight Growth Margin (@ 15%)	2,916	
Estimated Total Dry Weight	22,360	Kg
	(49,295 Lbs.)	

Illustration

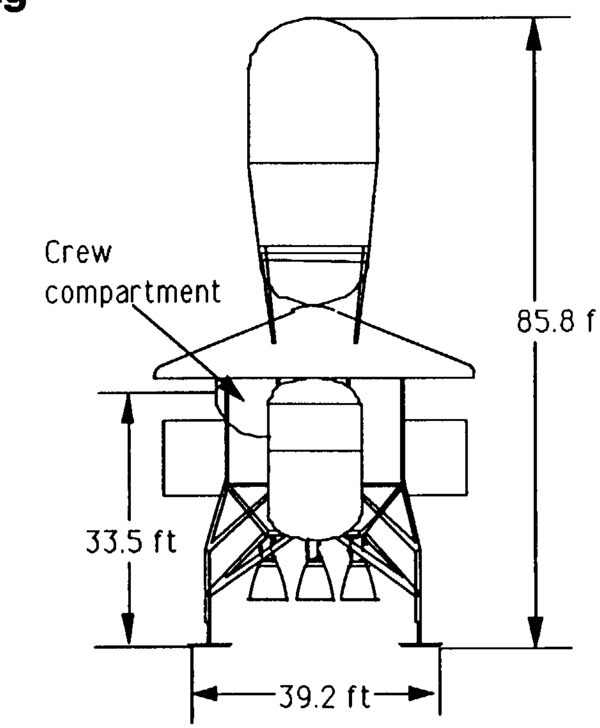

Figure 1-2.3-8. Space-Based System Design

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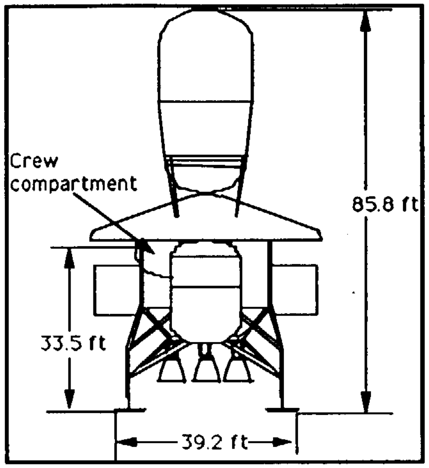
SPACE-BASED VEHICLE LCC SUMMARY

STV Programmatics Splinter

(Constant-Year 1991 Dollars in Millions) 10-19-90



- Single Stage Vehicle

Operations:
- SSF Lunar Node for LTS and Selected Missions
- ETR Launch Site; Some Other Mision Ground Launches
- 178 Expended stages for other missions
- 8 Lunar Sorties

Development:	
Core Stage & Aerobrake	$ 6,459 M
Drop Tanks	1,536
Crew Module	2,457
Software (Flt. & Ground)	1,500
Subtotal -	11,952 M
Requirements Factor (30%)	3,586
Contractors Fees (8%)	1,243
NASA Pog. Support (15%)	2,517
Subtotal -	$ 19,298 M
GFE Adv. Engine Program	1,525
Facilities Investments	5,900
Total DDT&E and Facilities -	$ 26,723 M
Operations for 10 Years:	
LTS Production (1/Yr.)	6,793
STV Other Production (19/Yr.)	66,076
LTS O&S (8 missions)	2,543
Other CNDB O&S (178 flt.'s)	9,369
SSF, KSC, MSFC, S/W Maint.	2,423
Total Production and O&S -	$ 87,204 M
Total Life Cycle Cost Estimate -	$ 113,927 M

Figure 1-2.3-9. Space-Based Vehicle LCC Summary

STV
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DEVELOPMENT FUNDING PROFILE

STV Programmatics Splinter

10-19-90

This preliminary development fiscal year funding profile for the Boeing Space-Based LTS mission candidate is based on the latest Phase C/D start date and cost estimates:

FY 1991 Constant-Year Dollars in Millions

Fiscal Years -	1994-5	1996	1997	1998	1999	2000	2001	2002	Total
Phase B Effort	40								40
Phase C/D:									
Basic Contracts		700	1,000	5,000	4,200	3,200	2,500	1,400	18,000
Advanced Engine	100	450	500	325	140	10			1,525
National Testbeds	20	38	500	500	200				1,258
Phase B & C/D -	160	1,188	2,000	5,825	4,540	3,210	2,500	1,400	20,823
Facilitization	—	250	750	1,800	1,500	1,000	—	—	5,900
Total by FY	160	1,438	2,750	7,625	6,040	4,210	2,500	1,400	26,723

Figure 1-2.3-10. Development Funding Profile

STV

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UPDATED FACILITIES ESTIMATES

STV Programmatics Splinter

10-19-90

<u>Design Reference Scenario Requirements</u>:

Ground Site - Process up to 21 vehicle sets per year
Space Station - Process and refurbish up to (TBD) vehicles per year.
Booster - 30 ft. shroud diam., 2 stage vehicle; HLLV facilities not addressed.
Special Missions Kits - Swapout tanks, advanced large FTS; other kits TBD.

INVESTMENT	PRIMARY GROUND OPERATIONS SITES	SPACE STATION LUNAR NODE*	AVIONICS, TRAINING & MISSION CTRL.	(91 $ MIL.) TOTALS
N/R Engr/SE&I	$ 28 Million	$ 755 Million		$ 783 M
Core Stage Fac.	93	550 (Hanger)		643
Crew Module Fac.	43	0 (Hanger)		43
Tanks Processing	30	100 (Equip.)		130
Support Equip.	314	265		579
Maint. Bldg./Module	6 (KSC)	400 (Modules)		406
Earth Landing Site	N/A	N/A		N/A
Alternate Landing	N/A	N/A		N/A
Engine Testing	65 (Stennis)	N/A		65
Spares Storage	4	330 (Pallets)		334
Office/Habitat	3 (KSC)	500 (Hab Module)		503
ETO-STS Services	N/A	2,100 (7 Launches)		2,100
SSF Fac. Setup	N/A	18		18
SUBTOTAL -	$ 586 M	$ 5,018 M		
Mission Control			$ 35 Million	35
Training Facility			251 (MSFC)	251
Recovery Equip.			N/A	0
AIL/SIL Facility			10	10
TOTAL -	$ 586 Million	$ 5,018 Million	$ 296 Million	$ 5,900 M

Note * : SSF estimate excludes truss, RCS, and power modif. costs that are required for node.

Figure 1-2.3-11. Updated Facilities Estimates

1-2.4 FINAL REVIEW (INTERIM REVIEW NUMBER 5) COST ESTIMATES

The ground-based vehicle designs are consolidated into one ground-based system that could be used for either ground-orbital (GO) assembly or launched as a whole system (GB). The ground-orbital vehicle requires a smaller HLLV booster (120 metric ton ETO payload capacity) than the single-launch configuration with a very large HLLV (250 metric ton ETO payload capacity). The ground-orbital system requires a liquid oxygen fuel tanker as an added cost. The ground-based version requires extensive HLLV delta development costs.

Both uses of the ground-based configuration require an HLLV larger than the current Advanced Launch System sizes planned for the initial fleet (by the year 2000). Figure 1-2.4-1 is a summary description of the ground-orbital and ground-based operational LTS flight vehicle. The vehicle has one engine mounted on each descent module tankset.

The mission model reference is changed, by NASA COR direction, from the civil needs database (CNDB) FY89 document to the CNDB FY90 plan. The FY90 plan eliminates many servicing missions for the STV derivatives. Figure 1-2.4-2 is the new hardware quantities schedule used for STV LCC estimating.

The descent tankset advanced space engine is replaced by a Pratt & Whitney RL10-A4 derivative for small stage applications (high-energy upper stage missions in the CNDB FY90 mission model). The small stage uses the descent tanks as they are with a replacement engine fluid supply manifold/valving kit and a thrust structure mounting kit. An avionics kit is also required to make a complete small stage. A summary description of the small stage derivative is contained in Figure 1-2.4-3.

The space-based vehicle design estimate was updated to include new droptank descriptions. The life cycle cost was recalculated to include new HLLV cost per flight factors agreed on by NASA and the contractors (Boeing, General Dynamics, and Martin) at the last interim review (#4). The LCC estimate was also updated to include the rest of the lunar mission flights out to the year 2026.

Ground-Based STV Mass Summary - Lunar Piloted

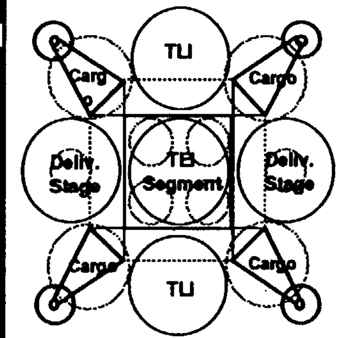
Cost & Programmatic Splinter Session

1-17-91

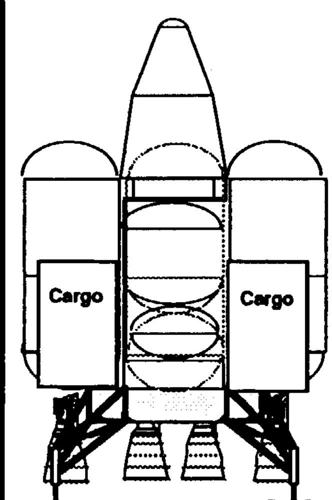
STV Mass Summary | **All mass in kg**

Ground-based Vehicle | **Lunar Piloted Mission**

	Core Vehicle							Drop-tanks		
	TEI Segment				Delivery Segment			TLI Tnkst	TLI Tnkst	Delivered
	Crew Mod	Av. Pallet	Tankset	Prop Mod	Lander	D Stg #1	D Stg #2	#1	#2	Cargo
Structure and Mechanisms	3341	155	505	483	1206	502	502	433	433	
Structures & Mechs - Landing gear	281	-	-	-	741	-	-	-	-	
Tankage - Main	-	-	385	-	-	659	659	659	659	
Protection	1315	116	378	-	82	570	570	570	570	
Propulsion - Main	-	-	376	917	828	545	545	380	380	
Propulsion - Reaction Control	162	-	-	-	-	190	190	-	-	
Power Source	-	374	-	-	-	-	-	-	-	
Wiring & Electrical Interface	272	265	28	56	78	39	39	28	28	
Guidance, Navigation & Control	130	464	-	-	-	-	-	-	-	
Communication & Data Handling	189	391	37	21	19	37	37	37	37	
Displays & Controls	108	-	-	-	-	-	-	-	-	
Environmental Control	813	-	-	-	-	-	-	-	-	
Personnel Provisions	635	-	-	-	-	-	-	-	-	
Weight Growth Margin	1087	265	256	222	443	381	381	316	316	0
Total Dry Mass	**8333**	**2030**	**1965**	**1699**	**3397**	**2923**	**2923**	**2423**	**2423**	**11630**
Crew, with Suits	800	-	-	-	-	-	-			
Non-Propellant Consumables	308	-	-	-	-	-	-			
Non-Cargo Items - Residuals	15	-	275	92	435	542	542	527	527	
Inert Mass	**9456**	**2030**	**2240**	**1791**	**3832**	**3465**	**3465**	**2950**	**2950**	**11630**
MPS Usable Propellants	-	-	17294	-	-	44592	44592	44676	44676	
RCS Usable Propellants	44	-	97	-	-	153	153	100	100	
EPS Usable Reactants	2	-	151	-	-	396	396	149	149	
Other - losses, etc	1800	-	75	-	-	296	296	515	515	
Total LEO-Assembled Mass	11302	2030	19857	1791	3832	48902	48902	48390	48390	
	34980				101637			96780		11630
	245026									



Top View



Side View

Figure 1-2.4-1. Ground-Based STV Mass Summary - Lunar Piloted

STV DESIGN REFERENCE SCENARIO HARDWARE QUANTITIES
(SELECTED CNDB '90 MISSION MODEL FOR ANALYSIS)

Jan. 5, 1991
Revision B
Page 1 of 3

Fiscal Years	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Prod. Qty. Subtotals
Lunar Missions:											
LTS (Lunar) Cargo		(Flight 0) (1)	1			1				1	3 Cargo LTV's
LTS (Lunar) Manned	(CM Test) (1)			1	1		1	1	1		5 Manned LTV's
LTV Core & Tanks	(1)	(1)	1	1	1	1	1	1	1	1	8 Prod. LTV's
LTV Crew Module (Legend: R = Reuse; D = Disposal after flight)	(1)	N/A		1	(R)	N/A	N/A	(R)	(D)	N/A	1 Prod. CM
Other Missions: Planetary Delivery	1		2	2			1				6
GEO Delivery	1	1	1		1		1		1		6
* GEO Servicing											0
* Leo Polar Servicing											0
* Nuclear Debris											0
* Capsule Recovery											0
DoD GEO	7	7	7	4	7	5	5	6	7	5	60
DoD HEO	5	5	5	4	5	6	5	4	4	6	49
Space-Based STV Tug	0	2	0	1	0	1	0	1	0	2	7 (reuseable)
Total RL-10X Model Flights	14	15	15	11	13	12	12	11	12	13	128 Deriv. Stages 8 LTV Stages 2 Adv.Buy Stages
Core Stage Systems Delivery Schedule	16	15	16	12	14	13	13	12	13	14	138 Hdw. Sets (incl. 2 Adv. Buy)
	(includes 2 advanced buy units carried forward in each lot)										

* (Note: all *Augmented Mission Set* sorties have been eliminated from the CNDB 90 mission model.)

Figure 1-2.4-2. STV Design Reference Scenario Hardware Quantities (Sheet 1 of 3)

STV DESIGN REFERENCE SCENARIO HARDWARE QUANTITIES
(SELECTED CNDB '90 MISSION MODEL FOR ANALYSIS)

Jan. 5, 1991
Revision B
Page 2 of 3

Fiscal Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Prod. Qty. Subtotals
Lunar Missions:											
LTS (Lunar) Cargo											3 Cargo Bal. Fwd.
Mars Mission (Ref.)					1		1				(2 Mars sorties)
LTS (Lunar) Manned	1	1	1	1	1	1	1	1	1	1	15 Manned (10+5)
LTV Core & Tanks	1	1	1	1	1	1	1	1	1	1	18 LTV's (8+10)
LTV Crew Module (Legend: R = Reuse; D = Disposal after flight)	1	(R)	(R)	(R)	(D)	1	(R)	(R)	(R)	(D)	3 CM's (2+1)
Other Missions: Planetary Delivery	1			2							9 (3+6 Bal. Fwd.)
GEO Delivery	0 →									0	6 (0+6)
GEO Servicing	*										0 (deleted)
Leo Polar Servicing	*										0 (deleted)
Nuclear Debris	*										0 (deleted)
Capsule Recovery	*										0 (deleted)
DoD GEO	5	5	5	5	5	5	5	5	5	5	110 (50+60)
DoD HEO	6	6	6	6	6	6	6	6	6	6	109 (60+49)
Space-Based STV Tug	0	1	0	1	1	1	0	1	0	2	14 (reuseable)
Total RL-10X Model Flight	12	12	11	14	12	12	11	12	11	13	248 Deriv. Stages 18 LTV Stages 2 Adv.Buy Stages
Core Stage Systems Delivery Schedule	13	13	12	15	13	13	12	13	12	14	268 STV's (Pg 1+2) (incl. 2 Adv. Buy)
	(includes 2 advanced buy units carried forward in each lot)										

* (Note: all *Augmented Mission Set* sorties have been eliminated from the CNDB 90 mission model.)

Figure 1-2.4-2. *STV Design Reference Scenario Hardware Quantities (Sheet 2 of 3)*

STV DESIGN REFERENCE SCENARIO HARDWARE QUANTITIES
(SELECTED CNDB '90 MISSION MODEL FOR ANALYSIS)

Fiscal Years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Prod. Qty./Flt. Totals
Lunar Missions:	(Mars missions from 2021-2026 are from 90-day study data)										
LTS (Lunar) Cargo											3 Cargo Flights
Mars Missions (Ref.)	1			1		1					(5 Mars sorties)
LTS (Lunar) Manned	1	1	1	1	1	1	0	0	0	0	21 Manned Flt.'s
LTV Core & Tanks	1	1	1	1	1	1	(undefined beyond 2026)				24 LTV's (6+18)
LTV Crew Module (Legend: R = Reuse; D = Disposal after flight)	1	(R)	(R)	(R)	(R)	(D)					4 CM's (1+3)
Other Missions: Planetary Delivery	1			2							12 (3+9 Bal. Fwd.)
GEO Delivery	0 →									0	6 (0+6)
GEO Servicing*											0 (deleted)
Leo Polar Servicing*											0 (deleted)
Nuclear Debris*											0 (deleted)
Capsule Recovery*											0 (deleted)
DoD GEO	5	5	5	5	5	5	0	0	0	0	140 (30+110)
DoD HEO	6	6	6	6	6	6	0	0	0	0	145 (36+109)
Space-Based STV Tug	0	1	0	1	1	1	0	0	0	0	18 (4+14)
Total RL-10X Model Flight	12	12	11	14	12	12	0	0	0	0	321 Deriv. Stages 24 LTV Stages
Core Stage Systems Delivery Schedule	13	13	12	15	13	11	0	0	0	0	345 STV's Total (excluding CM's)
	(adjustment for 2 advanced buy units in last lot buy)										

* (Note: all *Augmented Mission Set* sorties have been eliminated from the CNDB 90 mission model.)

Figure 1-2.4-2. STV Design Reference Scenario Hardware Quantities (Sheet 3 of 3)

STV Ground-based STV Small Stage Summary - GEO Delivery/Tug

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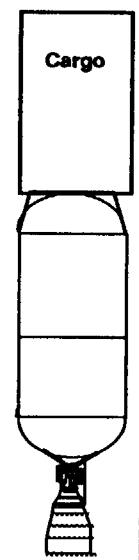
STV Mass Summary — All mass in kg
Ground-based Vehicle — Unmanned Delivery

	Core Vehicle Delivery Segment Av. Pallet	Core Vehicle Delivery Segment D Stg #1	Delivered Cargo
Structure and Mechanisms	134	502	
Structures & Mechs - Landing gear	-	-	
Tankage - Main	-	659	
Protection	116	570	
Propulsion - Main	-	545	
Propulsion - Reaction Control	-	190	
Power Source	381	-	
Wiring & Electrical Interface	211	39	
Guidance, Navigation & Control	192	-	
Communication & Data Handling	216	37	
Displays & Controls	-	-	
Environmental Control	-	-	
Personnel Provisions	-	-	
Weight Growth Margin	188	381	0
Total Dry Mass	**1438**	**2923**	**24000**
Crew, with Suits	-	-	
Non-Propellant Consumables	-	-	
Non-Cargo Items - Residuals	-	542	
Inert Mass	**1438**	**3465**	**24000**
MPS Usable Propellants	-	44592	
RCS Usable Propellants	-	153	
EPS Usable Reactants	-	396	
Other - losses, etc	-	296	
Total LEO-Assembled Mass	1438	48902	
		50340	24000
		74340	



Side View

The tug and small stage designs are simple & cost effective.

Theoretical First Unit (TFU) Estimate:

Basic Stage	$	31.2 M
Avionics Kit		18.1
RL10-A4+		2.9
Total (91$)	$	52.2 M

Figure 1-2.4-3. Ground-Based STVE Small Stage Summary - GEO Delivery and Tug

Other CNDB mission capture was not addressed because the vehicle had not been redesigned to facilitate making a small stage out of the existing droptanks. Figure 1-2.4-4 is a final summary description of the space-based vehicle candidate for the lunar missions. The "lander" flight element designation is equal to the core stage in the WBS dictionary (see book 2 for the final dictionary submittal).

The STV WBS dictionary is updated to include reaction control for the ground-based system crew cab, a new tanker element for the ground-orbital (GO) operation requirement, a "descent" stage element for the small stage provisions, and a launch escape system for the ground-based and GO vehicle crews that ride to low Earth orbit with the HLLV/LTV set.

The cost estimating groundrules are updated again. Figure 1-2.4-5 is the chart of new groundrules presented at the Interim Review number 5 splinter session. The program schedule for phase C/D start was slid another year. The 1-year slide forced the flight test program out another year and reduced the capability to absorb any engine or software development delays. The final program master schedule is shown in Figure 1-2.4-6. A phase C/D critical path schedule is shown in Figure 1-2.4-7. Figure 1-2.4-8 depicts an integrated flight test plan that verifies and validates each use of the STV derivative vehicles. The flight test plan demonstrates small stage capability on the first flight test, GO/GB biconic crew module reentry and LES integration capability (unmanned) on the second flight test, and autonomous lunar cargo flight capability on the third flight test. All three vehicles are estimated in the Boeing cost analyses.

Two ground test shipsets, for dynamic and static vehicle test, are included for all STV structural hardware items. Engine cost estimates include development firings, preflight readiness tests, and several cluster firings (all-up set of six advanced engines for the lunar mission). Facilities cost estimates include a new engine test stand facility for the cluster tests. All single-engine tests will use engine contractor, LeRC, or MSFC existing test facilities.

A final list of STV development plan system requirements is presented in the Figure 1-2.4-9 presentation chart. A summary list of STV cost drivers, by transfer vehicle configuration or basing type, is shown in Figure 1-2.4-10. The cost

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Space-Based STV Mass Summary - Lunar Piloted

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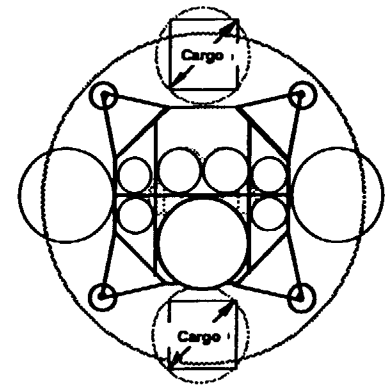
	Lunar Piloted Mission							
	Core Stage			TLI Drop-Tankset		LD Drop-Tankset		Lunar Surface Cargo
	Lander	Crew Module	Aero-Brake	Module #1	Module #2	Module #1	Module #2	
Structure and Mechanisms	1935	1496	1976	884	884	474	474	
Tankage - Main	583	-	-	1089	1089	597	597	
Protection	437	509	1583	642	642	385	385	
Propulsion - Main	2126	-	-	393	393	257	257	
Propulsion - Reaction Control	347	-	-	-	-	-	-	
Power Source	374	-	-	-	-	-	-	
Wiring & Electrical Interface	433	272	-	-	-	-	-	
Guidance, Navigation & Control	464	-	-	23	23	23	23	
Communication & Data Handling	422	124	15	35	35	39	39	
Displays & Controls	-	108	-	-	-	-	-	
Environmental Control	-	762	-	-	-	-	-	
Personnel Provisions	-	635	-	-	-	-	-	
Weight Growth Margin	1068	586	536	460	460	266	266	0
Total Dry Mass	**8189**	**4492**	**4110**	**3526**	**3526**	**2041**	**2041**	**9870**
Crew, with Suits	-	800	-	-	-			
Non-Propellant Consumables	-	291	-	-	-			
Non-Cargo Items - Residuals	332	-	-	781	781	374	374	
Inert Mass	**8521**	**5583**	**4110**	**4307**	**4307**	**2415**	**2415**	**9870**
MPS Usable Propellants	20967	-	-	63452	63452	27500	27500	
RCS Usable Propellants	137	-	-	102	102	152	152	
EPS Usable Reactants	242	-	-	5	5	391	391	
Other - losses, etc	107	1800	-	3168	3168	343	343	
Total LEO-Assembled Mass	29974	7383	4110	71034	71034	30801	30801	
	41467			142068		61603		9870
	255007							



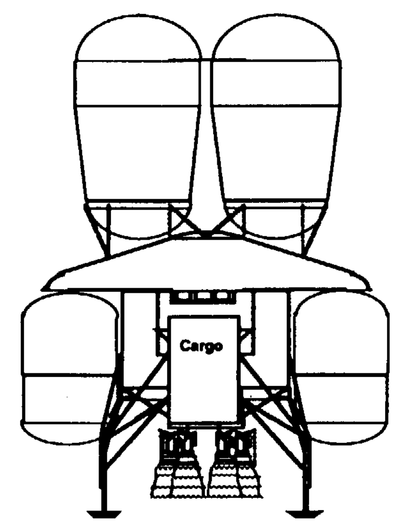


Figure 1-2.4-4. Space-Based STV Mass Summary - Lunar Piloted

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STV Program Schedules

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Program master & development schedule status:

- Revised program schedules for 1 year slide in C/D start.
- Change flight test #2 for biconic crew module proof test.
- Consider impacts of CNDB FY90 mission model needs.
- Plan for supporting first Lunar test flight in 2003; a cargo mission in 2004; 2nd CNDB Lunar flight can be manned.
- Change schedules based on 12-20-90 information from NASA (Ref. Norm Chaffee memo).

Development of an expanded test hardware schedule and STV logic network for phase C/D is in progress. Drafts will be available by month end for NASA review.

Figure 1-2.4-5. STV Program Schedules

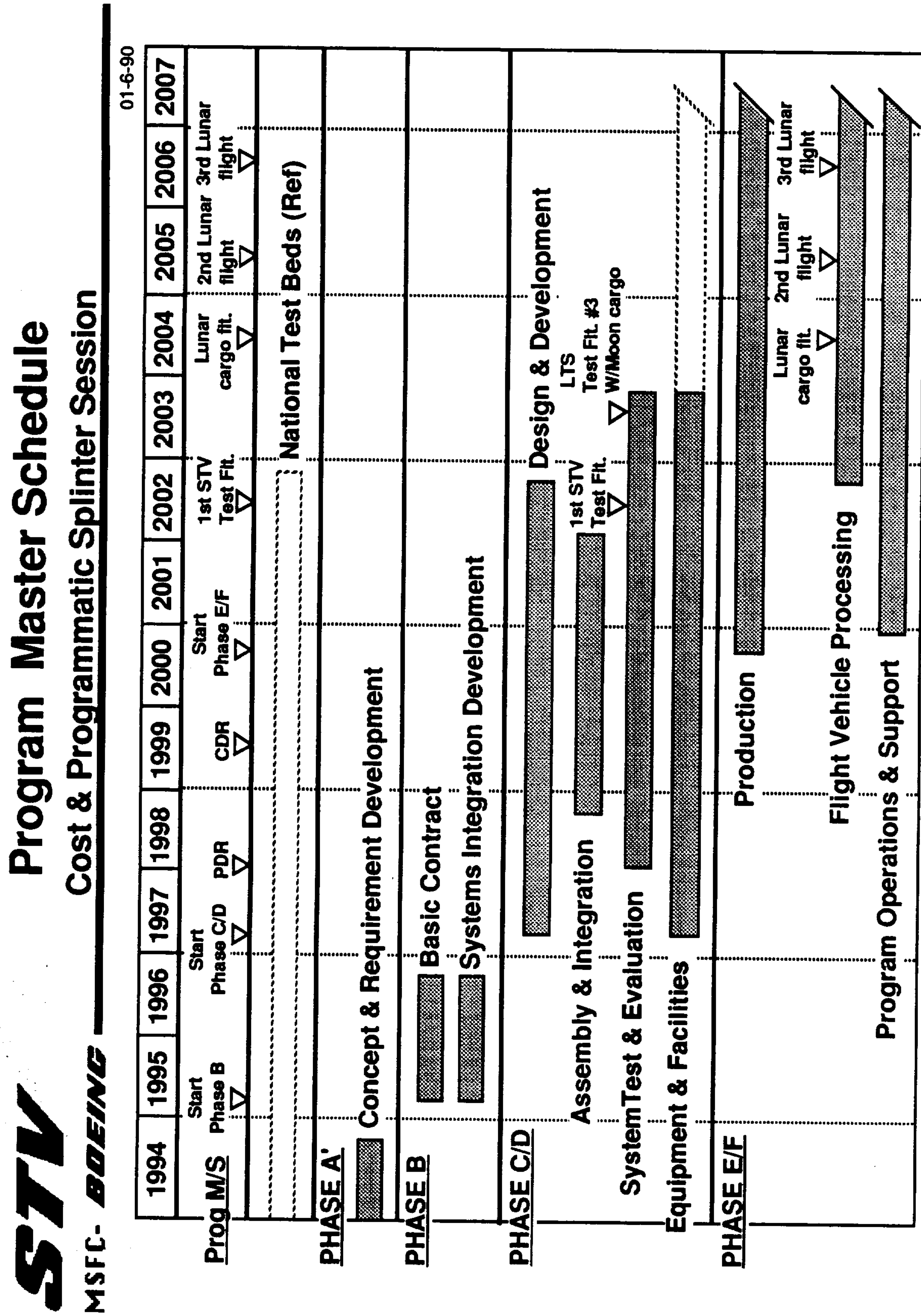

Figure 1-2.4-6. Program Master Schedule

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STV Critical Path Development Schedule

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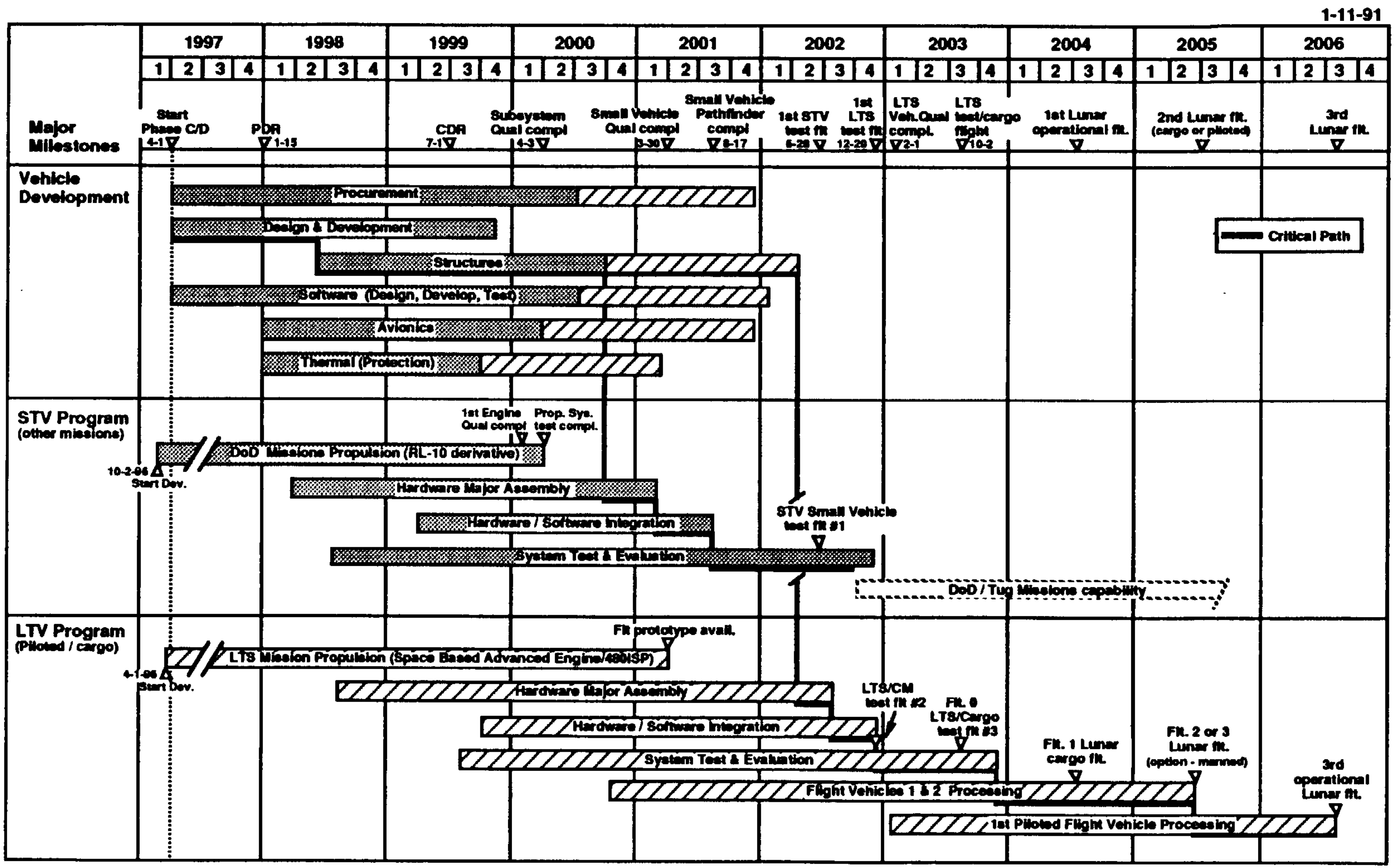

Figure 1-2.4-7. STV Critical Path Development Schedule

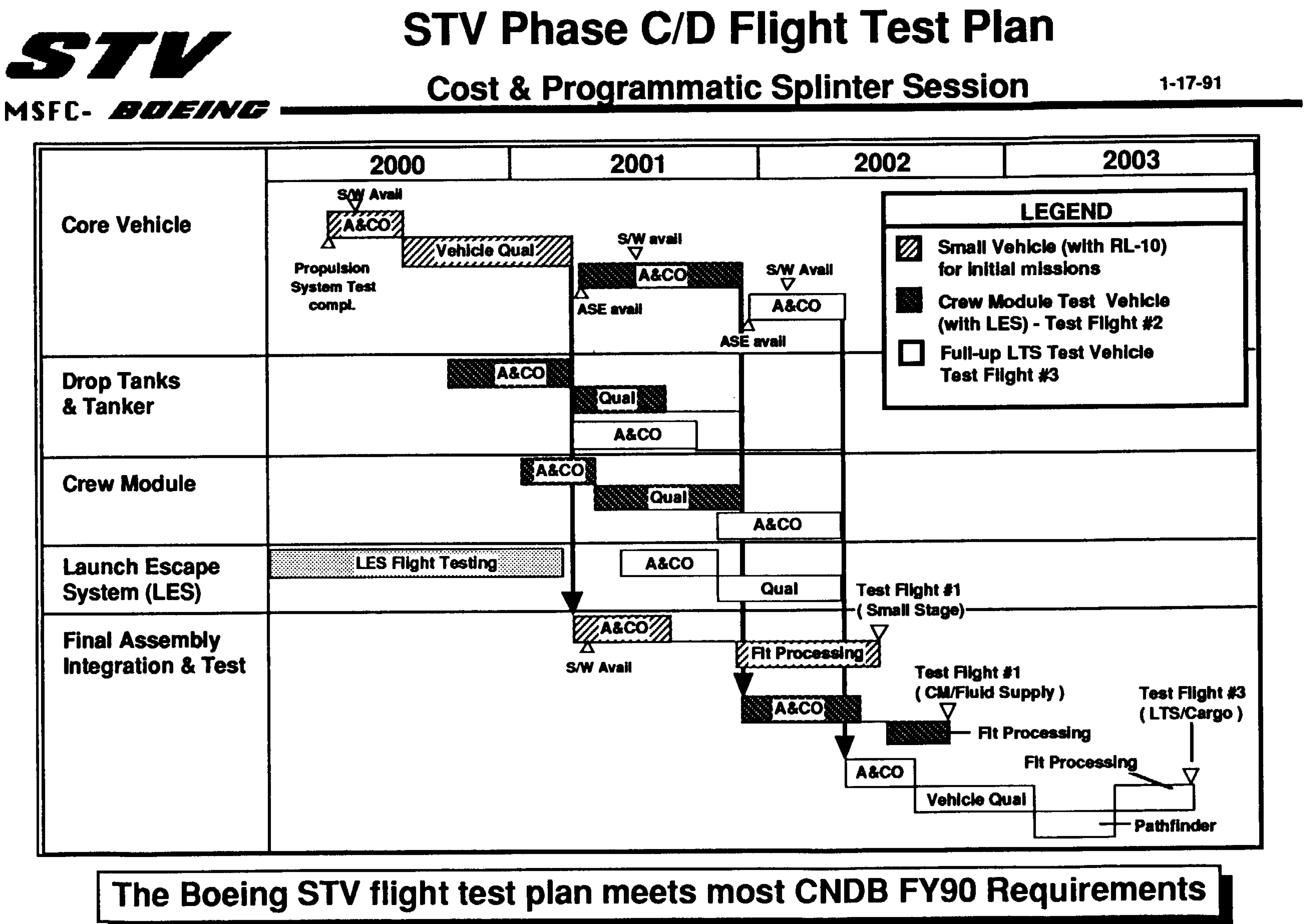

Figure 1-2.4-8. STV Phase C/D Flight Test Plan

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Updated Systems Requirements for Planning

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Point of Departure Requirements for the STV Development Plan:

- Radiation & advanced thermal protection are required.
- Autonomous vehicle control is desired for both manned & unmanned missions in the rendezvous, dock, & land modes.
- STV hardware & software must be highly reliable for safety, manned-rating, and extended Lunar mission timelines.
- LEO node, in-space assembly & maintenance of STV hardware are required for the space-based configuration.
- Modular assemblies & software are required for evolutionary growth and unscheduled on-orbit maintenance or abort.
- Ground-based (GO/GB) systems must have a "growth" (big) HLLV, with a launch escape system (LES) and landing site.
- Innovative technology applications must be incorporated by FY 1998 to meet Initial Operating Capability by FY 2001 to 2003.

Figure 1-2.4-9. Updated Systems Requirements for Planning

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Space Transfer Vehicle Cost Drivers

Cost & Programmatic Splinter Session

1-17-91

SD2-3634

Principle cost drivers	Transfer vehicles			
	Space-Based LTS	Ground-Based LTS/STV	Ground-Orbital LTS/STV	Current/Past Stages
1. Manned crew module and cargo only conversion requirement	Space module and aerobrake	Reentry module and launch escape	Reentry module and modularity	None
2. Safe and reliable with extended lunar surface stay	Yes	Yes	Yes	Apollo HDW only
3. Major staging/detach points (fuel, power, and mechanical)	Fuel, power and mech	Mechanical and Power	Mechanical and power	No drop tanks
4. GN&C aeroassist modeling and proof testing	Aerobrake subsystem	Biconic crew module	Biconic crew module	N/A–all expendable
5. 34 metric ton LTS cargo delivery capability	Yes	Yes	Yes	None
6. ETO delivery systems(s) (facilitization & GLOW capability)	71 Mt HLLV/STS *	250 Mt HLLV	125 Mt HLLV	18/110 STS/Saturn
7. In-space assembly complexity (including rendezvous and docking)	Highest (4-5 segments)	None (1 segment)	High (3 segments)	Apollo and STS (2 segments)
8. Reuse and refurbishment	Space logistics	CM and avionics	CM and avionics	None
9. Time of space operatons exposure (excluding lunar stay)	Highest (3 months)	High (6 days)	Higher (1 month)	Medium (1-2 days)

* Note: STS for crew and cargo on manned missions only

Figure 1-2.4-10. STV Cost Drivers

drivers list is compared to the previous Apollo system. The estimates for the Boeing configurations development cost are later compared with the Apollo actual development cost for similar function hardware at the end of the Interim Review number 5 presentation. As can be seen in the Figure, the new requirements and cost drivers are much more challenging than the Apollo program of 25 years ago.

The ETO cost estimates are revised for small (71 metric ton class) HLLVs and large (120 to 250 metric ton class) HLLVs. A new large HLLV ETO cost of $1,300 per payload pound is applied for all ground-based configurations. The small HLLV ETO cost is $2,500 per payload pound. NASA managers directed the contractors to use these numbers so that the factors were consistent in the STV studies.

The cost estimating groundrules are revised to include a new NASA program support factor of five percent. This 5% factor is applied to expendable flight hardware. Crew modules and other major reusable hardware still carry the 15% support factor (more testing and analysis is required). The technology application freeze point for development implementation moves out to 1996 for the small high-energy upper stage and large lunar cargo vehicle and 1998 for the manned lunar vehicle. The third test flight in phase C/D is proposed as an option to perform "Flight 0" of the lunar mission model (first unmanned cargo flight with the cargo unloader and other JSC manifest items).

The space-based LTS configuration LCC update is shown in Figure 1-2.4-11. Integrated logistics support (ILS) is included as part of the operation and support cost estimate. Following the LCC summary are Figures 1-2.4-12 and 1-2.4-13. These figures depict the charts for the aerobrake design illustration and the aerobrake estimate from the parametric cost model. The high-density refractory tiles on the aerobrake are one of several surface material options. The aerobrake theoretical first unit cost and development cost estimates shown exclude contract fee and other NASA program-level factors.

A LCC estimate summary for the ground-orbital-based vehicle is shown in Figure 1-2.4-14. The LES testing is comprised of 10 delta test flight launches with a crew module mass simulator and the LES hardware. The first launch of

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Space-Based Vehicle LCC Update

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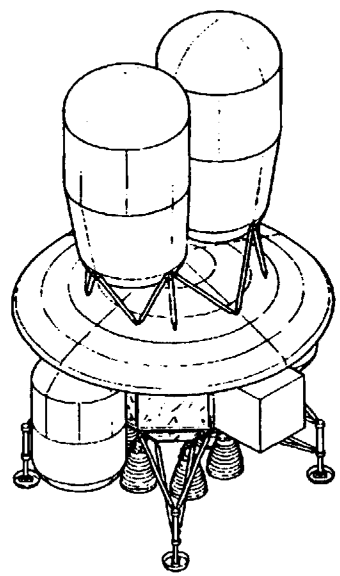

Space-Based Vehicle

Operations:
- SSF Lunar Node for LTS and Selected Missions
- ETR Launch Site; 71 Mt HLLV Carrier (Shuttle C size)
- Includes Tug Missions
- Other Missions Excluded

(Constant-Year 1991 Dollars in Millions)

Development:	
Core Stage & Aerobrake	$ 6,459 M
Drop Tanks (Revised)	1,087
Crew Module	2,457
Software (Flight & Dev. S/W)	1,500
Subtotal -	11,503 M
Requirements Factor (30%)	3,450
Contractors Fees (10%)	1,495
NASA Prog. Support (Rev. 5-15%)	1,174
Subtotal -	$ 17,622 M
GFE Adv. Engine Program	1,072
Facilities Investment	5,900
Total DDT&E and Facilities -	$ 24,594 M
LTS O&S for 27 Years (Incl. DT&E Flights):	
Full Production (1/Yr. + Tugs)	14,525
LTS and Tug Oper. & Support	4,404
ETO Launch (71 M t Booster @ $2,500/lb.)	52,434
SSF, Fac., & S/W Maint.; ILS	2,423
Total Production and O&S -	$ 73,786 M
LTS Life Cycle Cost Estimate -	$ 98,380 M

Note: Other CNDB missions were not addressed in this update.

Figure 1-2.4-11. Space-Based Vehicle LCC Update

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Boeing STV Aerobrake Preliminary Design

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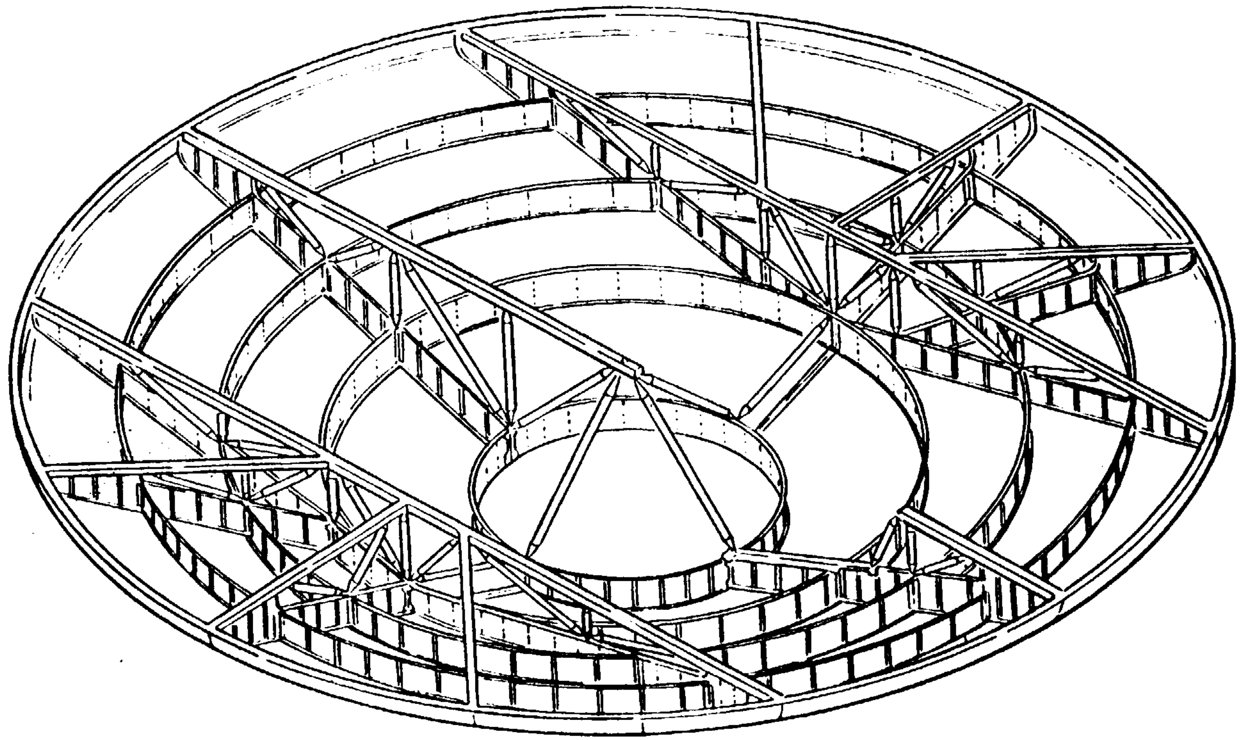

Boeing rigid brake design folds into 3 pieces for ETO delivery and uses advanced HDR thermal material tiles with mechanical attachment for easier replacement.

Figure 1-2.4-12. Boeing STV Aerobrake Preliminary Design

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Space-based Aerobrake DDT&E Estimate

(1991 Dollars in Millions)

1-17-91

TITLE: INPUT FILE: LTVABSB

	ENGR	MFG	TOTAL
AEROBRAKE STRUCTURES AND M	99.266	302.152	401.418
AEROBRAKE PROTECTION	88.878	84.998	173.876
AEROBRAKE COMMUNICATION &	3.864	344.974	348.838
AEROBRAKE WEIGHT GROWTH M	4.847	11.288	16.135
HARDWARE FINAL ASSY & C/O	-	82.857	82.857
SPARES	-	66.907	66.907
HARDWARE TOTALS (FROM ABOVE) ($M)	196.856	893.176	1090.031
0			
SUPPORT COST ($M):	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	36.055	-	36.055
SOFTWARE ENGINEERING	0.0	-	0.0
SYSTEMS GROUND TEST CONDUCT	66.546	-	66.546
SYSTEMS FLIGHT TEST CONDUCT	50.985	-	50.985
PECULIAR SUPPORT EQUIPMENT	24.498	41.631	66.129
TOOLING & SPECIAL TEST EQUIPMENT	-	561.441	561.441
TASK DIRECT QUALITY ASSURANCE	-	58.546	58.546
LOGISTICS	29.157	-	29.157
LIAISON ENGINEERING	15.714	-	15.714
DATA	9.227	-	9.227
TRAINING	0.607	-	0.607
FACILITIES ENGINEERING	1.387	-	1.387
SAFETY	0.434	-	0.434
GRAPHICS	0.954	-	0.954
OUTPLANT	0.434	-	0.434
PROGRAM MANAGEMENT	0.0	0.0	0.0
SUPPORT EFFORT TOTAL ($M)	235.997	661.618	897.615
0			
TOTAL ESTIMATE ($M)	432.853	1554.794	1987.647
0			
SCHEDULE PENALTY ($M)	0.0	62.192	62.192
TOTAL ESTIMATE (THIS SCHEDULE) ($M)	432.853	1616.986	2049.839
1			

Theoretical First Unit Cost is $ 135 M (in 1991 dollars) ....

Figure 1-2.4-13. Space-Based Aerobrake DDT&E Estimate

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Ground/Orbital (GO) - Based Vehicle LCC

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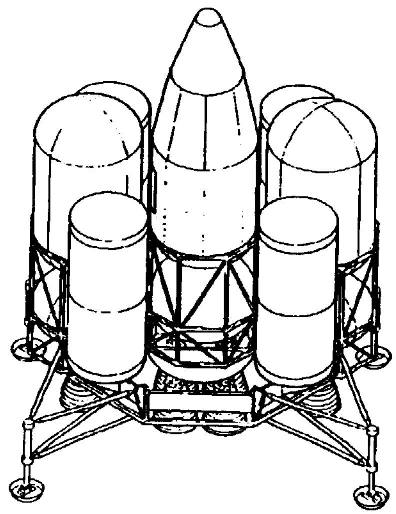

GO-Based Vehicle

Operations:
- Ground operations & refurb. at KSC
- ETR Launch Site; 125 Mt HLLV Carrier (Large ALS size)
- Includes Tug Missions (N/A to GO ops.)
- Other Missions Excluded

(Constant-Year 1991 Dollars in Millions)

Development:	
Core Stage & Small Stage	$ 3,897 M
Drop Tanks (TLI) & Tanker	1,312
Biconic Crew Module & LES	3,381
Software (Flight & Dev. S/W)	1,875
Subtotal -	$ 10,465 M
Requirements Factor (30%)	3,140
Contractors Fees (10%)	1,360
NASA Prog. Support (5-15%)	1,232
Subtotal -	$ 16,197 M
GFE Adv. Engine Program	1,137
Facilities & ALS Investment	3,425
Total DDT&E and Facilities -	$ 20,759 M
LTS O&S for 27 Years (Incl. DT&E Flights):	
Full Production (1/Yr. + Tugs)	22,179
LTS and Tug Oper. & Support	4,367
ETO Costs (125 Mt@ $1,300/lb.+ LES Tests)	25,282
Facilities & S/W Maint., ILS	4,233
Total Production and O&S -	$ 56,061M
LTS Life Cycle Cost Estimate -	$ 76,820 M

Note: Other CNDB missions were not addressed in this estimate.

Figure 1-2.4-14. GO-Based Vehicle LCC

the system is to orbit the liquid oxygen propellant tanker. The second launch of the HLLV delivers the vehicle and crew (if a manned lunar flight) to LEO. The LES is required for the second ETO launch and is part of the biconic crew module WBS for the LTV.

Results of a recent LES configurations (with similar escape requirements) cost trade study analysis are shown in Figure 1-2.4-15. The Apollo-type LES with a tractor function and solid rocket propulsion (also similar to the current LES Russian systems) appears to be the least cost alternative (cost data reference: NASA JSC, PLS contract NAS 9-18255, Boeing final report).

The LCC summary includes space tug missions (a NASA/Boeing forecast not included in the CNDB FY90 document). The other high-energy upper stage small stage missions were excluded (to make a more direct comparison of recurring costs between the space- and ground-based configuration LCC estimates). See section 1-4.0 for a funding breakout of other CNDB mission small stage estimates with the GO configuration.

The GO vehicle crew module and core avionics wafer returns to the Eastern Test Range (ETR) launch site for refurbishment. The rest of the core stage is expended on the trip back to Earth. The core lander legs and descent elements are left on the Moon's surface as expended hardware (could be salvaged for other purposes or used as lunar base spare parts because the ascent and descent engines and fluid supply components are identical).

The HLLV assumed for use here is a growth version of the ALS family. The dollars per pound allowance for this size vehicle is considered conservative if this vehicle is built concurrent with the other ALS family vehicles.

A development fiscal year funding profile chart for the GO configuration is contained in Figure 1-2.4-16. The impact to HLLV National Launch System funding may be significant in the FY 1994 through 1996 budget requests. However, this configuration seems more appealing considering the recent Space Station Freedom mission need changes and funding restrictions.

Launch Escape System Cost Trades

$ in Millions

STV — MSFC - BOEING

	LAUNCH ESCAPE SYSTEM TRADE SUMMARY					
	BY CONFIGURATION					
	1989 DOLLARS IN MILLIONS					
	Pointed End Forward			Pointed End Aft		
OPTION	Solid Tractor	Solid Pusher	Liquid Pusher	Solid Tractor(POD)	Solid Pusher	Liquid Pusher
DEVELOPMENT COST						
DESIGN & DEV. (+SUPPORT LABOR)	357.1	249.7	143.2	441.2	323	202.5
TOOLING	8.5	7.8	11.2	9.3	8.9	9
TEST HDWR (TFU x QTY) + INITIAL SPARES	300.3	277.2	385	325.6	312.4	316.8
(DEV QUAN=11 EQUIVALENT UNITS)						
TOTAL PHASE C/D (DDT&E)	665.9	534.7	539.4	776.1	644.3	528.3
PRODUCTION COST						
TFU HARDWARE	26.6	24.6	34.1	28.8	27.7	28.1
PSE ALLOTMENT (MFG. ONLY)	1.3	1.2	1.6	1.4	1.3	1.3
TASK DIRECT QA.	2.9	2.7	3.7	3.1	3	3.1
LIAISON ENGINEERING	16	10.1	4.9	20.8	14.1	7.7
SPARES (REPLENISHMENT)	0.7	0.6	0.9	0.8	0.7	0.7
DATA	7.7	5.3	3	9.6	7	4.3
TOTAL #1 COST ($M)	55.2	44.5	48.2	64.5	53.8	45.2

Figure 1-2.4-15. LES System Cost Trades

Ref: Boeing PLS Contract Cost Analysis Results

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GO-Based System Funding Profile

Cost & Programmatic Splinter Session 1-17-91

This preliminary development fiscal year funding profile for the Boeing Ground/Orbital -Based LTS mission candidate is based on a new FY 1997 Phase C/D start date:

FY 1991 Constant-Year Dollars in Millions

Fiscal Years -	1994-6	1997	1998	1999	2000	2001	2002	2003	Total
Phase A' & B	157								157
Phase C/D:									
Basic Contracts		610	2,400	3,500	3,400	2,600	2,000	990	15,500
Advanced Engine	160	290	300	195	150	42			1,137
National Testbeds	390	100	50						540
Phase B & C/D -	707	1,000	2,750	3,695	3,550	2,642	2,000	990	17,334
Facilities & HLLV	1,150	1,300	730	245					3,425
Total by FY	*1,857	2,300	3,480	3,940	3,550	2,642	2,000	990	20,759

*Note: Indicates significant impact to current HLLV/ALS funding requests between FY1994 and 1996.

Figure 1-2.4-16. GO-Based System Funding Profile

Facilities cost estimates are prepared for both ground- and space-based operational scenarios. The facilities estimate summaries presented are shown in Figures 1-2.4-17 and 1-2.4-18.

A summary of the principle cost drivers for the development and operations of each configuration, space or ground based, is summarized in Figure 1-2.4-19. The choice depends, for the most part, on other SEI program decisions and commitments outside the STV program. These outside decisions include the choice to expand the LEO facilities capability required for space basing or to invest more heavily in HLLV growth vehicles for lunar and Mars mission requirements in the next 6 years. Preliminary analysis indicates that LTS ground-based configurations may be easier to convert to other mission capture, but may not have as much technology transfer potential for future Mars transportation system evolution.

Summary of DDT&E Comparisons and Interim Review Number 5 Conclusions. Figure 1-2.4-20 provides an interesting development cost comparison (in constant-year 1991 dollars) of the equivalent Apollo mission hardware to the Boeing candidate LTS configurations. The Apollo equipment includes the Saturn IV-B upper stage (performed translunar injection function) and the command service module and lunar module set. (performed lunar transfer vehicle functions).

A time spread of these "front end" comparison development dollars, shown in Figure 1-2.4-21 (new data after Interim Review number 5), reveals that the schedule for Apollo was significantly shorter and represents the first time this mission was accomplished. The Boeing estimates for the LTS development are within the FY90 expenditures range of the current space transportation system portion of the NASA budget.

Based on development cost estimates of the STV-basing concepts alone, there is very little difference between the two configuration options. In a LCC comparison, a ground-orbital system might be more cost effective with a 125 metric ton HLLV. Design modularity on the GO system operation is appealing and feasible. Other CNDB missions (high-energy upper stage) are possible with the proper modular design considerations. Fewer missions in the CNDB FY90

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Space-Based System Facilities Estimate

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LTS Design Reference Scenario Requirements:

Ground Site - Process up to 3 vehicles (1 LTS, 2 tugs) per year
Space Station - Process and refurbish 1 LTS vehicle CM & Avionics Pallet per year.
Booster - 30 ft. shroud diam., 2 stage vehicle; HLLV facilities are not addressed.
Special Missions Kits - None

INVESTMENT	PRIMARY GROUND OPERATIONS SITES	SPACE STATION LUNAR NODE*	AVIONICS, TRAINING & MISSION CTRL.	(91 $ MIL.) TOTALS
N/R Engr/SE&I	$ 28 Million	$ 755 Million		$ 783 M
Core Stage Fac.	93	550 (Hanger)		643
Crew Module Fac.	43	0 (Hanger)		43
Tanks Processing	30	100 (Equip.)		130
Support Equip.	314	265		579
Maint. Bldg./Module	6 (KSC)	400 (Modules)		406
Earth Landing Site	N/A	N/A		N/A
Alternate Landing	N/A	N/A		N/A
Engine Testing	65 (Stennis)	N/A		65
Spares Storage	4	330 (Pallets)		334
Office/Habitat	3 (KSC)	500 (Hab Module)		503
ETO-STS Services	N/A	2,100 (7 Launches)		2,100
SSF Fac. Setup	N/A	18		18
SUBTOTAL -	$ 586 M	$ 5,018 M		
Mission Control			$ 35 Million	35
Training Facility			251 (MSFC)	251
Recovery Equip.			N/A	0
AIL/SIL Facility			10	10
TOTAL -	$ 586 Million	$ 5,018 Million	$ 296 Million	$ 5,900 M

Note * : SSF estimate excludes truss, RCS, and power modif. costs that are required for node.

Figure 1-2.4-17. Space-Based System Facilities Estimate

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GO-Based System Facilities Estimate

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<u>LTS Design Reference Scenario Requirements</u>:

Ground Site - Process up to 3 vehicles (1 LTS, 2 tugs) per year
Space Station - Process and refurbish 1 LTS vehicle CM & Avionics Pallet per year.
Booster - 45 ft. shroud diam., Growth 2 stage vehicle; HLLV DDT&E & Fac. delta added.
Special Missions Kits - None

INVESTMENT	PRIMARY GROUND OPERATIONS SITES	GROWTH BOOSTER ADDITIONAL COSTS*	AVIONICS, TRAINING & MISSION CTRL.	(91 $ MIL.) TOTALS
N/R Engr/SE&I	$ 32 Million	$ 1,000 Million		$ 1,032 M
Core Stage Fac.	93	N/A		93
Crew Module Fac.	48	N/A		48
Tank Processing	30	(in ELS estimate)		30
Support Equip.	43 (CM refurb.)	452 (ALS)		495
Maint. Bldg./Module	6 (KSC)	N/A		6
Earth Landing Site	10 (KSC)	504 (Facilities Delta)		514
Alternate Landing	24 (4 sites)	N/A		24
Engine Testing	65 (Stennis)	N/A		65
Spares Storage	4	(see ELS above)		4
Office Facilities	3 (KSC)	(see ELS above)		3
ETO-STS Services	N/A	N/A		N/A
Industrial Facilities	N/A	406 (ALS)		406
SUBTOTAL -	$ 358 M	$ 2,362 M		
Mission Control		409	$ 35 (JSC)	444
Training Facility		N/A	251 (MSFC)	251
Recovery Equip.		(see ELS above)	(Use ALS)	0
AIL/SIL Facility		(in N/R estimate)	10	10
TOTAL -	$ 358 Million	$ 2,771 Million	$ 296 Million	$ 3,425 M

Figure 1-2.4-18. GO-Based System Facilities Estimate

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Final Comparison of STV Systems

Cost & Programmatic Splinter Session

1-17-90

Principle cost drivers for the selected basing concept systems:

- ***Each vehicle has a manned crew module interface*, with requirements to be reliable in a Lunar surface environs for an extended stay time (major cost driver.)**
- ***Both space and ground-based designs have major assembly detach (staging) points*; these are an integration cost driver.**
- ***Both vehicles will require guidance & navigation modeling* tasks in development (biconic crew module versus aerobrake.)**
- ***Large booster launch facilities* (125 mt size), for ground-based, and *space node facilities*, for space-based, costs could be \$ 3 to \$ 6 billion; both require a significant investment for LTS mission accomplishment and reuse capability.**
- ***Ground-based vehicle descent stages are easier than the space-based concept to convert to other CNDB missions*; use relocatable avionics modules and new adapter kits.**

Figure 1-2.4-19. Final Comparison of STV Systems

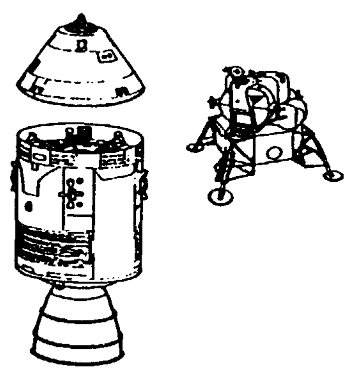
STV MSFC- BOEING

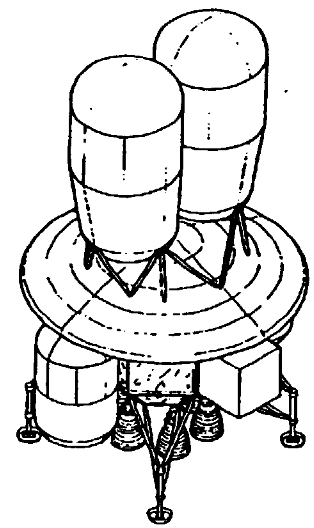
Space vs. Ground-Based DDT&E Comparison

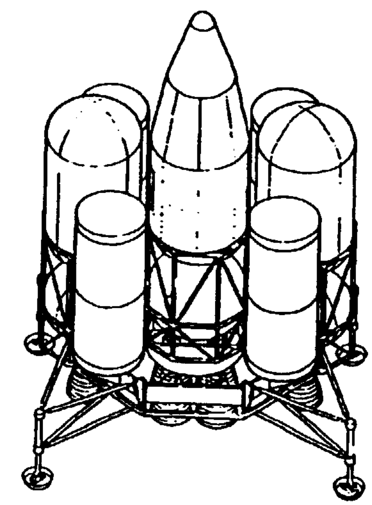
Cost & Programmatic Splinter Session

(All Cost Figures - 1991 dollars in billions)

Yesterday & Tomorrow ....







	Apollo Program	STV-SB Program	STV-GO Program
No. of Years in Development:	8 Years ('62-'69)	11 Years	11 Years ('97-'03)
Cost/Estimate:	$ 29.8 B	$ 17.6 B	$ 16.2 B
Hdw. Elements:	SIV-B, CSM, & LM	Core, CM, A/B, & Drop Tanks	Core, Biconic CM, Tanks, LES, Tanker

Note: All estimates and POP actuals (inflated with NASA factors) exclude engine DDT&E.

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Figure 1-2.4-20. Space-Based Versus Ground-Based DDT&E Comparison

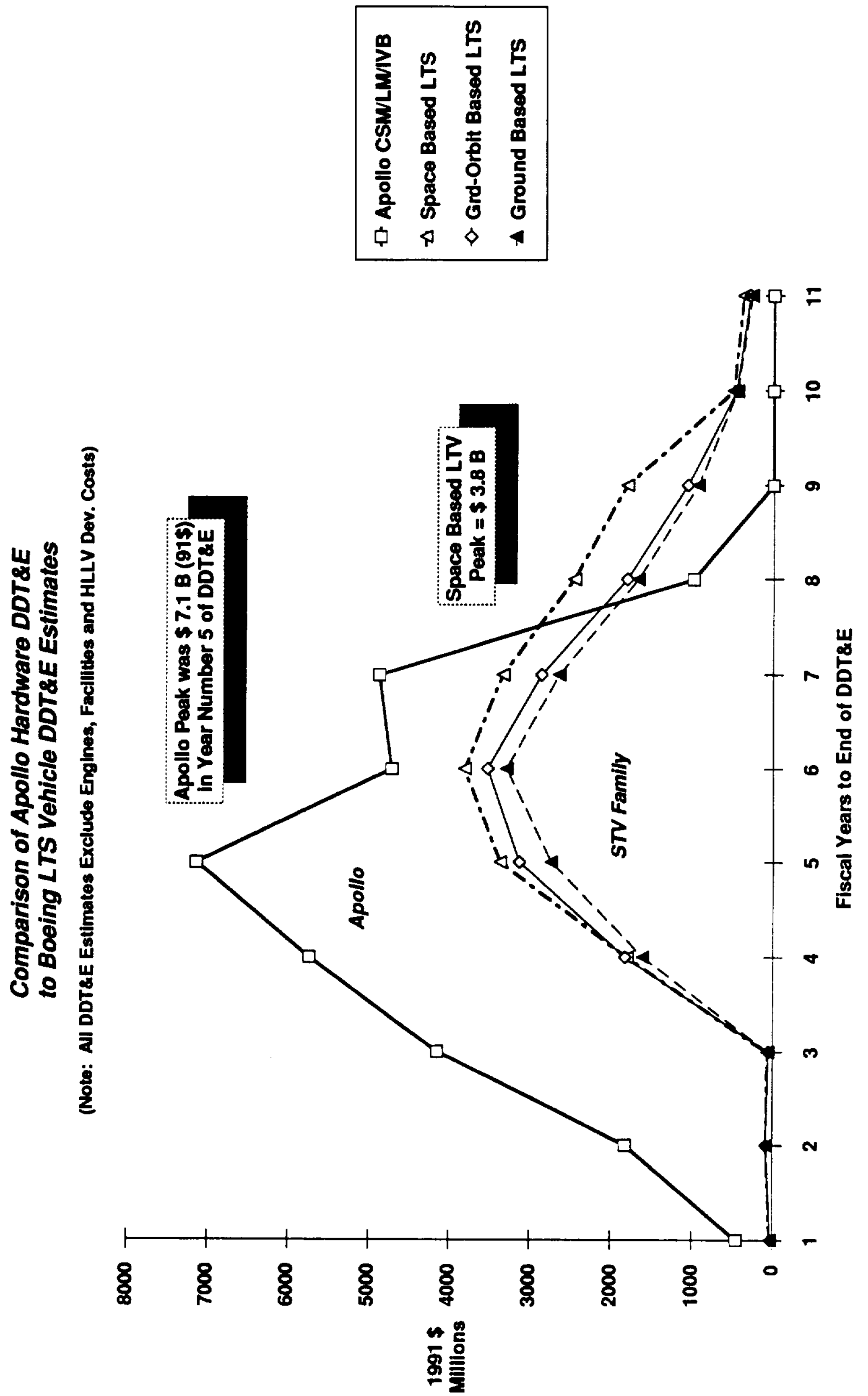

Figure 1-2.4-21. Apollo Hardware DDT&E Comparison

plan reduce the return on investment value of the advanced space engine development, but cost must not be the only factor in propulsion system selection (safety, maintainability, and performance advancement are important also).

The ground-based system, which is launched in one ETO trip, does not require a tanker; but it does require a significant HLLV capability (250 metric ton payload), which has no other known application except for the Mars missions. The extra development costs for a very large 250 metric ton HLLV appear to be in the $3 billion dollar range (in 1991 dollars) at the front of the HLLV program.

1-3.0 COST ESTIMATE BY WBS ELEMENT

1-3.1 LIFE CYCLE COSTS BY SUMMARY ITEM

The STV LCC estimates are estimated on the proprietary parametric cost model (PCM) at Boeing with inputs organized by a project WBS. The STV project WBS is documented in Book 2, Volume III. All elements are explained in the Book 2 STV WBS dictionary.

The WBS is formulated using the LTS as the STV program's primary mission, with other mission applications of the STV hardware and software handled as adjustments to the LTS project breakdown. For example, the small stage derivative of the ground-orbital operations configuration is created using a descent module tankset and structure with avionics, RL10-A4 engine, and fluid supply modification kits.

The summary containing the space-based and two ground-configuration systems is presented for comparison in Figure 1-3.1-1. The significant differences between the three systems are the aerobrake and Space Station Freedom refurbishment platform (or LEO node) requirements of the space-based LTV)versus the tanker, the "growth" size HLLV, and the biconic reentry crew module (with LES) requirements of the ground-based LTVs.

When compared at the total LCC estimate level, each system is close in system development cost. Each system development requires a national infrastructure commitment of support facilities and launch equipment, primarily outside the control of the STV project management. At the total LCC estimate level however, the Boeing ground-based (single-launch operation) configuration is lowest in total LCC estimate dollars (1991 dollars in millions).

The ground-based summary is estimated using the same conceptual design as the ground-orbital operation vehicle. The tanker is deleted and the HLLV development and setup costs are increased for this giant size booster requirement (250 metric ton payload capability for the LTS to fly in one launch). The ground-based single launch operation option is shown in the third column of Figure 1-3.1-1.

(1991 $ IN MILLIONS)

		SPACE BASED LTV CONFIGURATION			GROUND-ORBITAL LTV OPERATIONS CONFIGURATION			GROUND BASED LTV (SINGLE LAUNCH)		
		N/R	REC.	TOTAL	N/R	REC	TOTAL	N/R	REC.	TOTAL
7.0	LTS Project									
7.1	LTS Hdw. Integ. (NASA Prog. Supt.)	1,174	231	1,405	1,232	352	1,584	1,154	297	
7.2	LTS Dev./Production									
7.2.1	LTS Prog. Mgmt. (Req. Factor & Fees)	4,945	4,611	9,556	4,500	7,041	11,541	4,217	5,940	
7.2.2	LTS System Engr.	310	-	310	203	-	203	179	-	179
7.2.3	LTS Flight Hdw.									
7.2.3.1.1	LTV. Core Stage, Tug, ASE*	5,940	4,920	10,860	4,184	8,134	12,318	4,184	8,134	12,318
7.2.3.1.2	LTV Drop Tanks	938	3,907	4,845	345	1,872	2,217	345	1,872	2,217
7.2.3.1.3	LTS Tanker	-	-	-	823	2,312	3,135	-	-	-
7.2.3.1.4	LTV Crew Module	2,141	856	2,997	3,000	2,468	5.468	3,000	2,468	5,468
7.2.3.1.5	LTV FAIT	461	(in 7.3.1)	461	316	(in 7.3.1)	316	316	(in 7.3.1)	316
7.2.4	LTS Support Equip.	403	-	403	348	-	348	308	-	308
7.2.5	LTS Payload Accom.	(TBD)	(TBD)	-	(TBD)	(TBD)	-	(TBD)	(TBD)	-
7.2.6	LTS Software	1,500	-	1,500	1,875	-	1,875	1,775	-	1,775
7.2.7	System Test Ops.	882	-	882	508	-	508	473	-	473
7.2.8	Ground Ops. & Ctrl. N/R	586	-	586	358	-	358	358	-	358
7.2.9	LTS Mission Ops.	296	-	296	296	-	296	296	-	296
7.3	LTS Operations & Support									
7.3.1	LTS Hardware O&S Processing		1,439	1,439		977	977		873	873
7.3.2	LTS O&S Mission Support		(IN 7.3.1)	-		3,390	3,390		2,834	2,834
7.3.3	LTS Personnel Training		271	271		104	104		104	104
7.3.4	LTS Recovery Support		(N/A)	-		(TBD)	-		(TBD)	-
7.3.5	LTS Non-nom. Ops. Support		(TBD)	-		(TBD)	-		(TBD)	-
7.3.6	LTS O&S Logistics Services		2,235	2,235		2,224	2,224		2,153	2,153
7.3.7	LTS Consumables & Expendables		38	38		37	37		36	36
7.3.8	LTS Software Maint.		585	585		732	732		692	692
7.3.9	LTS Base Ops. Support		603	603		1,136	1,136		1,656	1,656
3.0	ETO O&S Services		52,434	52,434	2,771	25,282	28,053	4,528	18,919	23,447
4.0	Low Earth Orbit Support	5,018	1,656	6,674	-	-	-	-	-	-
LCC	Total with ETO/LEO -	24,594	73,786	98,380	20,759	56,061	76,820	21,133	45,978	67,111

*Note: Includes Management Factors from NASA; Engine is GFE to Prime Contractor

Figure 1-3.1-1. LCC Estimates by WBS Item

Figure 1-3.1-2 summarizes the small stage LCC estimate for the ground-orbital configuration. The cost estimate for a small stage derivative is based on the premise that this high-energy upper stage and space tug mission unit is developed simultaneously with the LTV hardware and software. All laboratories, test equipment, facilities, and processing equipment have their prime source of funding available as a result of the LTS requirements (past studies assumed evolution the other direction; from smaller stage to LTS).

(1991 Dollars in Millions)

Project Phase	Planning Estimate N/R	REC.	TOTAL	(REMARKS)
DEV./PRODUCTION				
Integ./ Mgmt. Factors	357	4,442	4,799	
Stage Flight Hardware	500	8,074	8,574	(92% Curve)
RL10 Derivative (A4+)	(LTS Tug Cost)	741	741	(2.6M AUPC)
Support Equipment	55	70	125	(2 Prod. Sets)
Software Dev & V/V	100	0	100	(Use LTS Fac.)
System Test Ops.	37	0	37	
Ground Ops. & Ctrl. N/R	20	0	20	
Mission Ops. N/R	(Use LTS Fac.)	0	0	
OPERATIONS & SUPPORT			0	
HEUS/CTV Oper. & Support	0	2,130	2,130	(26 Years)
ETO Services (@$600/lb.)	0	45	45	(285 Flt.s)
LCC Totals -	**$1,069**	**$15,502**	**$16,571**	

(Note: All cost estimates are predicated on the co-development of an LTS in parallel with the small stage derivative.)

Figure 1-3.1-2. STV Small Stage LCC Summary

1-3.2 NON-RECURRING DDT&E ESTIMATES

The design, development, test, and evaluation (DDT&E) phase estimates are developed by flight element of the STV system. The ground-based system design can be used in either ground-orbital or single-launch operation configurations, depending on which size HLLV is available and if a liquid oxygen orbiting tanker is required (only for the ground-orbital configuration with a growth HLLV of 125 metric ton capability).

Figures 1-3.2-1 through 1-3.2-9 contain the Boeing PCM outputs for DDT&E by LTS flight element for the space-based and ground-orbital operation STV systems. Each output estimate is shown in millions of constant-year 1991 dollars, excluding contract requirements change factor (30%), contractor fee (10%), and NASA program support factors (5% to 15%). The aerobrake is a subsystem of the space-based core vehicle (see the Book 2 WBS dictionary).

Each DDT&E estimate is based on the STV requirements document descriptions, an 11-year development schedule plan, and a 96-month advanced space engine development project for LTV main propulsion requirements.

1991 $ IN MILLIONS

	ENGR	MFG	TOTAL
FWD INTERFACE STRUCTURE	118.728	248.117	366.845
EXTERNAL TPS	3.459	14.795	18.255
CORE PROPULSION	128.946	441.47	570.416
CORE REACTION CONTROL SYS	28.349	44.951	73.3
CORE ELECTRICAL POWER	65.829	108.84	174.669
CORE STAGE AVIONICS	269.7	326.115	595.814
CORE WEIGHT GROWTH MARGIN	6.744	17.719	24.463
HARDWARE FINAL ASSY & C/O	-	169.584	169.584
SPARES	-	108.181	108.181
HARDWARE TOTALS (FROM ABOVE) ($M)	621.756	1479.77	2101.526
SUPPORT COST ($M)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	149.709	-	149.709
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	422.879	-	422.879
SYSTEMS FLIGHT TEST CONDUCT	152.956	-	152.956
PECULIAR SUPPORT EQUIPMENT	99.35	85.207	184.557
TOOLING & SPECIAL TEST EQUIPMENT	-	970.58	970.58
TASK DIRECT QUALITY ASSURANCE	-	96.091	96.091
LOGISTICS	116.621	-	116.621
LIAISON ENGINEERING	66.637	-	66.637
DATA	30.608	-	30.608
TRAINING	1.836	-	1.836
FACILITIES ENGINEERING	4.196	-	4.196
SAFETY	1.311	-	1.311
GRAPHICS	2.885	-	2.885
OUTPLANT	1.311	-	1.311
PROGRAM MANAGEMENT	0	0	0
SUPPORT EFFORT TOTAL ($M)	1050.299	1151.877	2202.176
TOTAL ESTIMATE ($M)	1672.055	2631.647	4303.699
SCHEDULE PENALTY	0	105.266	105.266
TOTAL ESTIMATE (THIS SCHEDULE)	1672.055	2736.913	4408.965

Figure 1-3.2-1. Space-Based LTV Core Stage

1991 DOLLARS IN MILLIONS

	ENGR	MFG	TOTAL
AEROBRAKE STRUCTURES AND MECH.	99.266	302.152	401.418
AEROBRAKE PROTECTION	88.878	84.998	173.876
AEROBRAKE COMMUNICATION &	3.864	344.974	348.838
AEROBRAKE WEIGHT GROWTH MARGIN	4.847	11.288	16.135
HARDWARE FINAL ASSY & C/O	-	82.857	82.857
SPARES	-	66.907	66.907
HARDWARE TOTALS (FROM ABOVE) ($M)	196.856	893.176	1090.031
SUPPORT COST ($M)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	36.055	-	36.055
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	66.546	-	66.546
SYSTEMS FLIGHT TEST CONDUCT	50.985	-	50.985
PECULIAR SUPPORT EQUIPMENT	24.498	41.631	66.129
TOOLING & SPECIAL TEST EQUIPMENT	-	561.441	561.441
TASK DIRECT QUALITY ASSURANCE	-	58.546	58.546
LOGISTICS	29.157	-	29.157
LIAISON ENGINEERING	15.714	-	15.714
DATA	9.227	-	9.227
TRAINING	0.607	-	0.607
FACILITIES ENGINEERING	1.387	-	1.387
SAFETY	0.434	-	0.434
GRAPHICS	0.954	-	0.954
OUTPLANT	0.434	-	0.434
PROGRAM MANAGEMENT	0	0	0
SUPPORT EFFORT TOTAL ($M)	235.997	661.618	897.615
TOTAL ESTIMATE ($M)	432.853	1554.794	1987.647
SCHEDULE PENALTY ($M)	0	62.192	62.192
TOTAL ESTIMATE (THIS SCHEDULE) ($M)	432.853	1616.986	2049.839

Figure 1-3.2-2. Space-Based LTV Aerobrake

1991$ IN MILLIONS

	ENGR	MFG	TOTAL
STRUCT AND MECHS - TLI TA	14.984	37.871	52.855
TANKAGE - TLI TANKSETS	10.796	29.196	39.992
PROTECTION - TLI TANKSETS	15.339	9.713	25.052
MAIN PROPULSION - TLI TAN	45.794	63.048	108.842
WIRING & ELECT I/F - TLI	4.186	2.134	6.32
COMM AND DATA	5.592	3.658	9.25
WEIGHT GROWTH MARGIN	0.547	3.217	3.763
HARDWARE FINAL ASSY & C/O	-	4.116	4.116
SPARES	-	4.465	4.465
HARDWARE TOTALS (FROM ABOVE) ($M)	97.239	157.418	254.657
SUPPORT COST ($M)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	14.309	-	14.309
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	13.229	-	13.229
SYSTEMS FLIGHT TEST CONDUCT	0.379	-	0.379
PECULIAR SUPPORT EQUIPMENT	9.375	8.112	17.487
TOOLING & SPECIAL TEST EQUIPMENT	-	64.482	64.482
TASK DIRECT QUALITY ASSURANCE	-	10.874	10.874
LOGISTICS	6.13	-	6.13
LIAISON ENGINEERING	4.143	-	4.143
DATA	2.512	-	2.512
TRAINING	0.299	-	0.299
FACILITIES ENGINEERING	0.682	-	0.682
SAFETY	0.213	-	0.213
GRAPHICS	0.469	-	0.469
OUTPLANT	0.213	-	0.213
PROGRAM MANAGEMENT	0	0	0
SUPPORT EFFORT TOTAL ($M)	51.953	83.468	135.422
TOTAL ESTIMATE ($M)	149.192	240.886	390.078

Figure 1-3.2-3. Space-Based LTV TLI Tanks

1991 $ IN MILLIONS

	ENGR	MFG	TOTAL
LIQUID HYDROGEN DROP TANK	7.203	18.653	25.856
LIQUID OXYGEN DROP TANK	5.623	14.277	19.9
DROP TANK STRUCTURES AND M	49.457	68.627	118.084
DROP TANK PROTECTION	16.63	15.079	31.708
DROP TANK - MAIN PROPULSIO	25.828	75.816	101.643
DROP TANK MODULE ATTITUDE	18.491	28.283	46.775
WEIGHT GROWTH MARGIN	5.572	7.45	13.023
HARDWARE FINAL ASSY & C/O	-	25.432	25.432
SPARES	-	6.846	6.846
HARDWARE TOTALS (FROM ABOVE) ($M)	128.804	260.463	389.267
SUPPORT COST ($M)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	33.321	-	33.321
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	29.918	-	29.918
SYSTEMS FLIGHT TEST CONDUCT	8.498	-	8.498
PECULIAR SUPPORT EQUIPMENT	18.973	12.778	31.751
TOOLING & SPECIAL TEST EQUIPMENT	-	136.011	136.011
TASK DIRECT QUALITY ASSURANCE	-	17.119	17.119
LOGISTICS	19.123	-	19.123
LIAISON ENGINEERING	7.781	-	7.781
DATA	4.933	-	4.933
TRAINING	0.393	-	0.393
FACILITIES ENGINEERING	0.899	-	0.899
SAFETY	0.281	-	0.281
GRAPHICS	0.618	-	0.618
OUTPLANT	0.281	-	0.281
PROGRAM MANAGEMENT	0	0	0
SUPPORT EFFORT TOTAL ($M)	125.019	165.908	290.927
TOTAL ESTIMATE ($M)	253.824	426.372	680.195
SCHEDULE PENALTY	0	17.055	17.055
TOTAL PENALTY (THIS SCHEDULE)	253.824	443.427	697.25

Figure 1-3.2-4. LTV Space-Based Lunar Descent Tanks

1991 $ IN MILLIONS

	ENGR	MFG	TOTAL
CREW MODULE STRUCT & MECH	145.389	265.369	410.757
CREW MODULE THERMAL PROTEC	22.201	65.928	88.129
CREW MODULE ELEC POWER	28.586	30.506	59.092
CREW MODULE AVIONICS	84.976	89.369	174.345
CREW MODULE ENVIRONMENTAL	31.37	94.645	126.015
CREW MODULE PERSONNEL PROV	55.264	211.91	267.174
CREW MODULE WEIGHT GROWHT	9.08	12.879	21.958
HARDWARE FINAL ASSY & C/O	-	85.887	85.887
SPARES	-	69.354	69.354
HARDWARE TOTALS (FROM ABOVE) ($M)	376.865	925.846	1302.711
SUPPORT COST($M)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	76.884	-	76.884
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	110.804	-	110.804
SYSTEMS FLIGHT TEST CONDUCT	25.493	-	25.493
PECULIAR SUPPORT EQUIPMENT	59.865	43.154	103.019
TOOLING & SPECIAL TEST EQUIPMENT	-	585.188	585.188
TASK DIRECT QUALITY ASSURANCE	-	60.687	60.687
LOGISTICS	66.158	-	66.158
LIAISON ENGINEERING	36.955	-	36.955
DATA	17.382	-	17.382
TRAINING	1.159	-	1.159
FACILITIES ENGINEERING	2.648	-	2.648
SAFETY	0.828	-	0.828
GRAPHICS	1.821	-	1.821
OUTPLANT	0.828	-	0.828
PROGRAM MANAGEMENT	0	0	0
SUPPORT EFFORT TOTAL ($M)	400.822	689.03	1089.85
TOTAL ESTIMATE ($M)	777.687	1614.876	2392.563
SCHEDULE PENALTY	0	64.595	64.595
TOTAL ESTIMATE (THIS SCHEDULE)	777.687	1679.471	2457.158

Figure 1-3.2-5. Space-Based LTV Crew Module

1991 DOLLARS IN MILLIONS

	ENGR	MFG	TOTAL
STRUCT AND MECHANISMS - L	47.29	136.163	183.452
STRUCT AND MECHS - ASCENT	34.655	40.991	75.646
STRUCT AND MECHS - ASCENT	24.844	51.977	76.821
THERMAL PROTECTION-CORE	6.58	11.412	17.992
PRIMARY ENGINES - CORE	33.86	5.342	39.202
CORE FLUID SUPPLY	60.136	307.17	367.305
TANKAGE - ASCENT TANKSET	8.143	27.141	35.284
POWER SOURCE - PALLET	25.669	32.517	58.186
POWER DIST - PALLET	23.48	27.221	50.702
STRUCT AND MECHS - PALLE	1.342	5.407	6.749
PROTECTION - PALLET	2.396	9.247	11.643
G,N,&C - PALLET	149.592	192.946	342.538
COMM AND DATA	70.051	70.931	140.982
VEHICLE HEALTH MAINTENA	23.176	55.366	78.542
VHMS - CORE	1.359	7.007	8.366
WIRING & ELECT I/F - COR	14.329	13.166	27.495
STRUCT AND MECHS - DESCE	34.101	171.306	205.407
PROTECTION - DESCENT STA	4.23	13.329	17.558
PROPULSION ENGINES - DES	28.424	15.86	44.284
DESCENT FLUID SUPPLY	11.153	138.267	149.421
TANKAGE - DESCENT STAGES	2.658	50.455	53.113
REACTION CONTROL - DESCE	25.446	41.012	66.458
VHMS	3.677	27.867	31.544
WEIGHT GROWTH MARGIN	12.235	22.523	34.757
HARDWARE FINAL ASSY & C/O	-	42.858	42.858
SPARES	-	44.239	44.239
HARDWARE TOTALS (FROM ABOVE) ($M)	648.824	1561.716	2210.539
SUPPORT COST (M$)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	98.765	-	98.765
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	254.297	-	254.297
SYSTEMS FLIGHT TEST CONDUCT	0.379	-	0.379
PECULIAR SUPPORT EQUIPMENT	94.938	84.465	179.403
TOOLING & SPECIAL TEST EQUIPMENT	-	913.956	913.956
TASK DIRECT QUALITY ASSURANCE	-	108.413	108.413
LOGISTICS	49.571	-	49.571
LIAISON ENGINEERING	48.239	-	48.239
DATA	20.499	-	20.499
TRAINING	1.994	-	1.994
FACILITIES ENGINEERING	4.557	-	4.557
SAFETY	1.424	-	1.424
GRAPHICS	3.133	-	3.133

Figure 1-3.2-6. Ground-Based LTV Core Stage (Sheet 1 of 2)

OUTPLANT	1.424	-	1.424
PROGRAM MANAGEMENT	0	0	0

SUPPORT EFFORT TOTAL ($M)	579.219	1106.833	1686.052

TOTAL ESTIMATE ($M)	1228.043	2668.549	3896.592

Figure 1-3.2-6. Ground-Based LTV Core Stage (Sheet 2 of 2)

1991 DOLLARS IN MILLIONS

	ENGR	MFG	TOTAL
STRUCT AND MECHS - TLI TA	15.0	37.9	52.9
TANKAGE - TLI TANKSETS	10.8	29.2	40.0
PROTECTION - TLI TANKSETS	15.3	9.7	25.1
MAIN PROPULSION - TLI TAN	45.8	63.0	108.8
WIRING & ELECT I/F - TLI	4.2	2.1	6.3
COMM AND DATA	5.6	3.7	9.3
WEIGHT GROWTH MARGIN	0.5	3.2	3.8
HARDWARE FINAL ASSY & C/O	-	4.1	4.1
SPARES	-	4.5	4.5
HARDWARE TOTALS (FROM ABOVE) ($M)	97.2	157.4	254.7

SUPPORT COST	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	14.3	-	14.3
SOFTWARE ENGINEERING	0.0	-	0.0
SYSTEMS GROUND TEST CONDUCT	13.2	-	13.2
SYSTEMS FLIGHT TEST CONDUCT	0.4	-	0.4
PECULIAR SUPPORT EQUIPMENT	9.4	8.1	17.5
TOOLING & SPECIAL TEST EQUIPMENT	-	64.5	64.5
TASK DIRECT QUALITY ASSURANCE	-	10.9	10.9
LOGISTICS	6.1	-	6.1
LIAISON ENGINEERING	4.1	-	4.1
DATA	2.5	-	2.5
TRAINING	0.3	-	0.3
FACILITIES ENGINEERING	0.7	-	0.7
SAFETY	0.2	-	0.2
GRAPHICS	0.5	-	0.5
OUTPLANT	0.2	-	0.2
PROGRAM MANAGEMENT	0.0	0.0	0.0
SUPPORT EFFORT TOTAL ($M)	52.0	83.5	135.4
TOTAL ESTIMATE ($M)	149.2	240.9	390.1

Figure 1-3.2-7. Ground-Based LTV TLI Tanks

1991 DOLLARS IN MILLIONS

	ENGR	MFG	TOTAL
STRUCTURES AND MECHANISMS	16.5	26.6	43.1
PROTECTION	8.9	12.2	21.1
FLUID SUPPLY - PROP	25.6	56.2	81.9
TANKAGE - MAIN	8.7	36.9	45.6
REACTION CTRL & INSTL	24.1	7.5	31.6
DEORBIT ROCKETS	9.5	1.3	10.8
POWER SOURCE	19.8	107.1	126.9
POWER DIST & WIRING	8.1	9.0	17.1
GUIDANCE, NAVIGATION, AN	21.6	65.8	87.4
COMM AND DATA HANDLING	34.6	44.9	79.5
WEIGHT GROWTH MARGIN	5.7	7.1	12.7
HARDWARE FINAL ASSY	-	10.4	10.4
SPARES	-	11.2	11.2
HARDWARE TOTALS (FROM ABOVE) ($M)	183.1	396.2	579.3
SUPPORT COST (M$)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	24.5	-	24.5
SOFTWARE ENGINEERING	0.0	-	0.0
SYSTEMS GROUND TEST CONDUCT	27.4	-	27.4
SYSTEMS FLIGHT TEST CONDUCT	7.6	-	7.6
PECULIAR SUPPORT EQUIPMENT	19.2	20.4	39.6
TOOLING & SPECIAL TEST EQUIPMENT	-	186.9	186.9
TASK DIRECT QUALITY ASSURANCE	-	27.4	27.4
LOGISTICS	11.0	-	11.0
LIAISON ENGINEERING	9.3	-	9.3
DATA	4.7	-	4.7
TRAINING	0.6	-	0.6
FACILITIES ENGINEERING	1.3	-	1.3
SAFETY	0.4	-	0.4
GRAPHICS	0.9	-	0.9
OUTPLANT	0.4	-	0.4
PROGRAM MANAGEMENT	0.0	0.0	0.0
SUPPORT EFFORT TOTAL ($M)	107.3	234.7	342.0
TOTAL ESTIMATE ($M)	290.4	630.9	921.3

Figure 1-3.2-8. Ground-Based LTV Tanker

1991 DOLLARS IN MILLIONS

	ENGR	MFG	TOTAL
CREW MODULE STRUCT & MECH	176.545	353.018	529.562
CREW MODULE RADIATION PRO	71.454	65.962	137.416
CREW MODULE REACTION CTRL	8.694	33.252	41.945
CREW MODULE ELEC POWER	28.343	21.415	49.758
CREW MODULE AVIONICS	80.865	125.448	206.313
CREW MODULE ENVIRONMENTAL	28.166	114.479	142.645
CREW MODULE WEIGHT GROWHT	56.237	138.897	195.134
CREW MODULE WEIGHT GROWHT	7.648	0	7.648
HARDWARE FINAL ASSY & C/O	-	129.581	129.581
SPARES		85.247	85.247
HARDWARE TOTALS (FROM ABOVE) ($M)	457.949	1067.299	1525.248

SUPPORT COST (M$)	ENGR	MFG	TOTAL
SYSTEM ENGINEERING & INTEGRATION	65.058	-	65.058
SOFTWARE ENGINEERING	0	-	0
SYSTEMS GROUND TEST CONDUCT	126.422	-	126.422
SYSTEMS FLIGHT TEST CONDUCT	78.328	-	78.328
PECULIAR SUPPORT EQUIPMENT	64.494	46.46	110.954
TOOLING & SPECIAL TEST EQUIPMENT	-	518.432	518.432
TASK DIRECT QUALITY ASSURANCE	-	67.139	67.139
LOGISTICS	31.555	-	31.555
LIAISON ENGINEERING	33.323	-	33.323
DATA	13.755	-	13.755
TRAINING	1.495	-	1.495
FACILITIES ENGINEERING	3.417	-	3.417
SAFETY	1.068	-	1.068
GRAPHICS	2.349	-	2.349
OUTPLANT	1.068	-	1.068
PROGRAM MANAGEMENT	0	0	0
SUPPORT EFFORT TOTAL ($M)	422.333	632.03	1054.362
0			
TOTAL ESTIMATE ($M)	880.282	1699.329	2579.612
0			
SCHEDULE PENALTY ($M)	0	67.973	67.973
TOTAL ESTIMATE (THIS SCHEDULE) ($M)	880.282	1767.302	2647.584

Figure 1-3.2-9. Ground-Based LTV Crew Module

1-3.3 RECURRING PRODUCTION ESTIMATES

The production theoretical first unit (TFU) estimates are developed using the PCM (Boeing cost model). These TFU estimates are extended for production lot estimates by the use of cumulative learning curve factors, when applicable.

Whenever LTS flight hardware order quantities are one every 2 or 3 years (like reusable crew modules with at least five reuses), the cost improvement curve is not applied. The cost improvement curve method used at Boeing is the modified Wright learning curve derivation method. No "B factors" have been applied on the current STV program production estimates.

The first TFU estimate to be presented at Interim Review number 4 is presented for inspection as Figure 1-3.3-1. Note, because of the small delivery quantities and single unit production lot size, the aerobrake, space-based crew module, and FTS-2 do not have learning curves applied to the production estimate.

Figure 1-3.3-2 is the final presentation (Interim Review number 5) calculation sheet for the space-based system production estimate. The RL10-A4(+) engine is for the space tug derivative core stage. No other CNDB mission derivatives (small stages) are estimated at this time.

Figure 1-3.3-3 contains a summary of final presentation (Interim Review number 5) calculations for the ground-orbital operation configuration of the ground-based system. A small stage derivative production estimate is also presented in Figure 1-3.3-3.

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IR #4 PRODUCTION ESTIMATE TFU TABLE

FY 1991 Constant-Year Dollars in Millions

10-19-90

HARDWARE ITEM	THEO. 1ST UNIT EST.		LEARNING CUM VALUE		PRODUCTION ESTIMATE	HDW. QTY.	COST ESTIMATE IMPROVE. CURVE
Core Stage	$ 638.2 M	x	96.866	=	$61,820	182	90% Curve
RL-10X Engine	4.4 M	x	246.062	=	1,083	352	95% Curve
Advanced Engine	22.2 M	x	20.308	=	451	24	95% Curve
Aerobrake	204.9 M	x	5.000	=	1,024	5	No Learning
TLI Drop Tank	148.3 M	x	12.040	=	1,786	16	90% Curve
LD Drop Tank	118.7 M	x	20.727	=	2,460	30	90% Curve
Crew Module	430.6 M	x	3.000	=	1,292	3	No Learning
33.3 Ton Tank	74.1 M	x	8.689	=	644	11	90% Curve
9.1 Ton Tank	29.7 M	x	62.578	=	1,859	109	90% Curve
FTS-2 Mission Kit	75.0 M	x	6.000	=	450	6	No Learning
Total Production Estimate (including factors) -					$72,869 M		

Space-Based System Candidate;
Operations Quantity thru FY 2010

PRELIMINARY DATA

Figure 1-3.3-1. IR#4 Production Estimate TFU

LTS SPACE BASED CONFIGURATION PRODUCTION ESTIMATE					
	(Constant-Year 1991 Dollars in Millions)				
Flight Element Hardware	Quantity	Learning Curve	1st Unit Cost (91$M)	Cumulative Learning Factor	Production Totals (LTS + Tug Only)
LTS Core Stage Hardware	8	90%	408.5	6.57373	$2,686
Aerobrake Subassembly	5	100%	135.3	5.00000	$677
Advanced Space Engine	54	95%	6.3	43.20769	$270
Trans-Lunar Drop Tanks	48	90%	47.5	31.03674	$1,474
Lunar Descent Drop Tanks	48	90%	78.4	31.03674	$2,433
Space Based Crew Module	3	100%	285.5	3.00000	$856
Total LTS Mission Hdw. -					$8,396
LTS Space Tug Derivative	18	90%	92.6	13.33436	$1,235
RL10-A4(+) Engine, Tug	18	100%	2.9	18.00000	$52
Total SEI Tug Hdw. -					$1,287
Subtotal Production -					$9,683
NASA Program Factors					$4,842
Grand Total, Estimate -					$14,525

Figure 1-3.3-2. LTS Space-Based Configuration Production Estimate

LTS GROUND-ORBITAL CONFIGURATION PRODUCTION ESTIMATE					
	(Constant-Year 1991 Dollars in Millions)				
		Learning	1st Unit Cost	Cumulative	Production Totals
Flight Element Hardware	Quantity	Curve	(91$M)	Learning Factor	(LTS + Tug Only)
LTS Core Stage Hardware	24	90%	373.8	17.10016	$6,392
Reusable Avionics Pallet	4	100%	80.4	4.00000	$322
Advanced Space Engine	144	95%	6.3	107.42655	$672
Trans-Lunar Drop Tanks	48	90%	60.3	31.03674	$1,872
Liquid Oxygen Tanker	24	90%	78.4	17.10016	$2,312
Biconic Crew Module	4	100%	324.8	4.00000	$1,299
CM Launch Escape Sys.	21	90%	66.7	15.23729	$1,017
CM Docking Adpt./Tower	21	90%	10.0	15.23729	$152
Total LTS Mission Hdw. -					$14,038
LTS Space Tug Derivative	18	90%	52.2	13.33436	$696
RL10-A4(+) Engine, Tug	18	100%	2.9	18.00000	$52
Total SEI Tug Hdw. -					$748
Subtotal Production -					$14,786
NASA Program Factors					$7,393
Grand Total, Estimate -					$22,179

Figure 1-3.3-3. LTS Ground-Orbital Configuration Production Estimate

1-3.4 RECURRING OPERATION AND SUPPORT ESTIMATES

The operation and support (O&S) phase, sometimes called the "ownership" phase, is estimated with a non-parametric process. The process involves analogies, scaling factors, task direct labor estimates, hardware unit cost inputs (from the parametric cost model), and Government/contractor labor pricing factors (in 1991 dollars).

The O&S estimating process starts with the operations analysis process used during the architecture evaluation period of the NASA-Boeing STV study. Figure 1-3.4-1 illustrates the front end of the definition process. Estimates are developed based on specific mission timelines assessment, DRS generation, operational flow analyses, functional operation breakdown block diagrams, and research data from previous NASA and USAF studies or current space transportation programs (STS, Apollo, Centaur, and IUS).

The DRS flows were documented on MacProject II© application software. Figures 1-3.4-2 and 1-3.4-3 are examples of a space- and ground-based operations flow diagram, respectively. O&S cost estimates were developed for each item on the flow chart and, in some cases, two functions below the blocks shown.

Figure 1-3.4-4 contains a pie chart of the operations cost estimates for a single-stage space-based LTV configuration with in-space refurbishment. The in-space estimating factors used for the space-based system O&S estimates are documented in section 1-1.8 of this book (see Figure 1-1.8-3). Booster launch costs are not included in the pie chart breakout.

An example of an O&S flight cost build-up (in 1989 dollars) from the third interim review is presented in Figure 1-3.4-5 to illustrate the method of developing space-based system estimates for both types of lunar mission flights, manned and unmanned cargo, with five reuses maximum for each reusable flight hardware set. An O&S estimate breakdown summary, again in 1989 dollars, for a space-based LTV system is presented in Figure 1-3.4-6. These estimates were later updated in 1991 dollars to include new space tug operations and new ETO booster cost estimates.

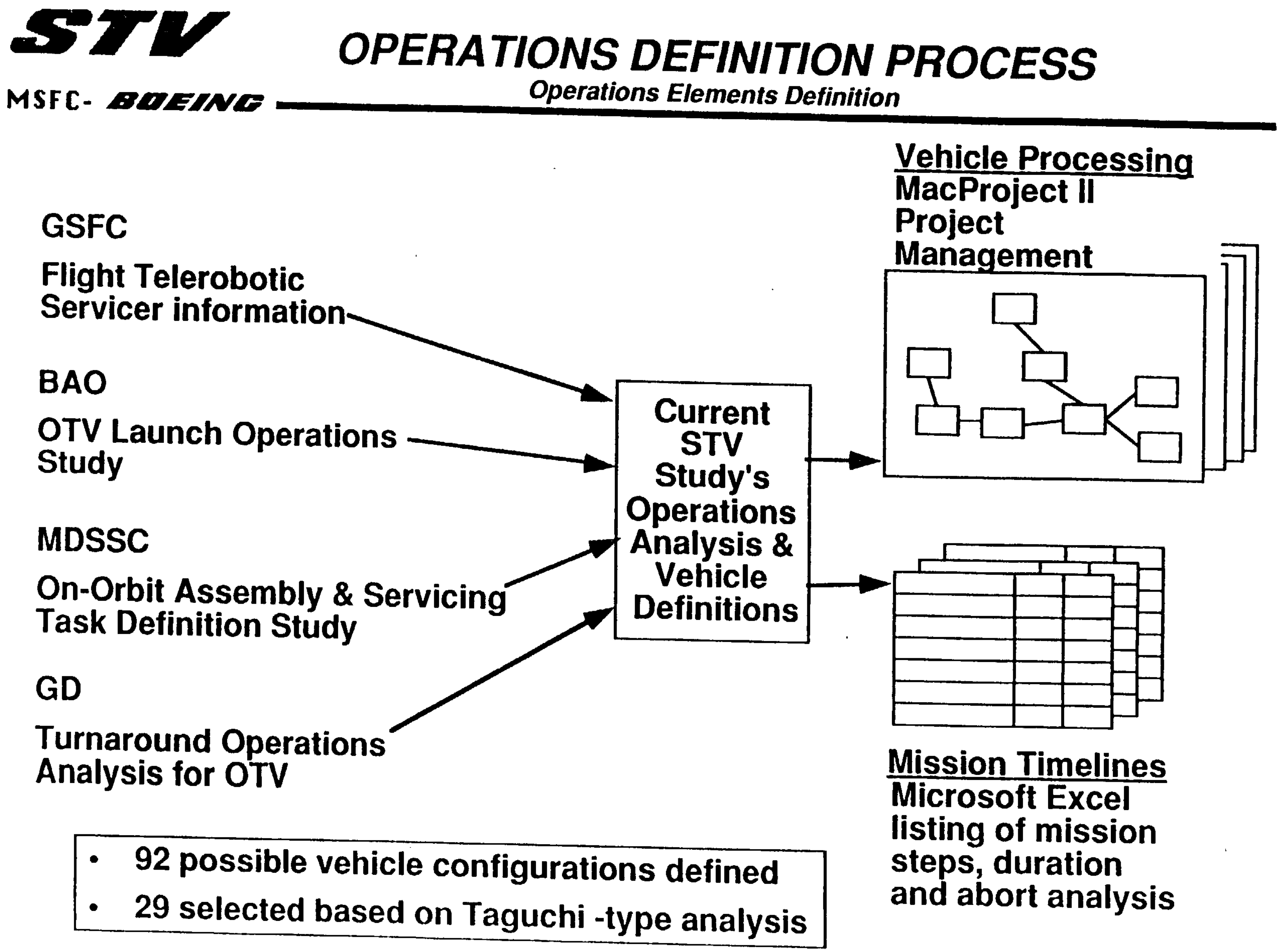

Figure 1-3.4-1. Operations Definition Process

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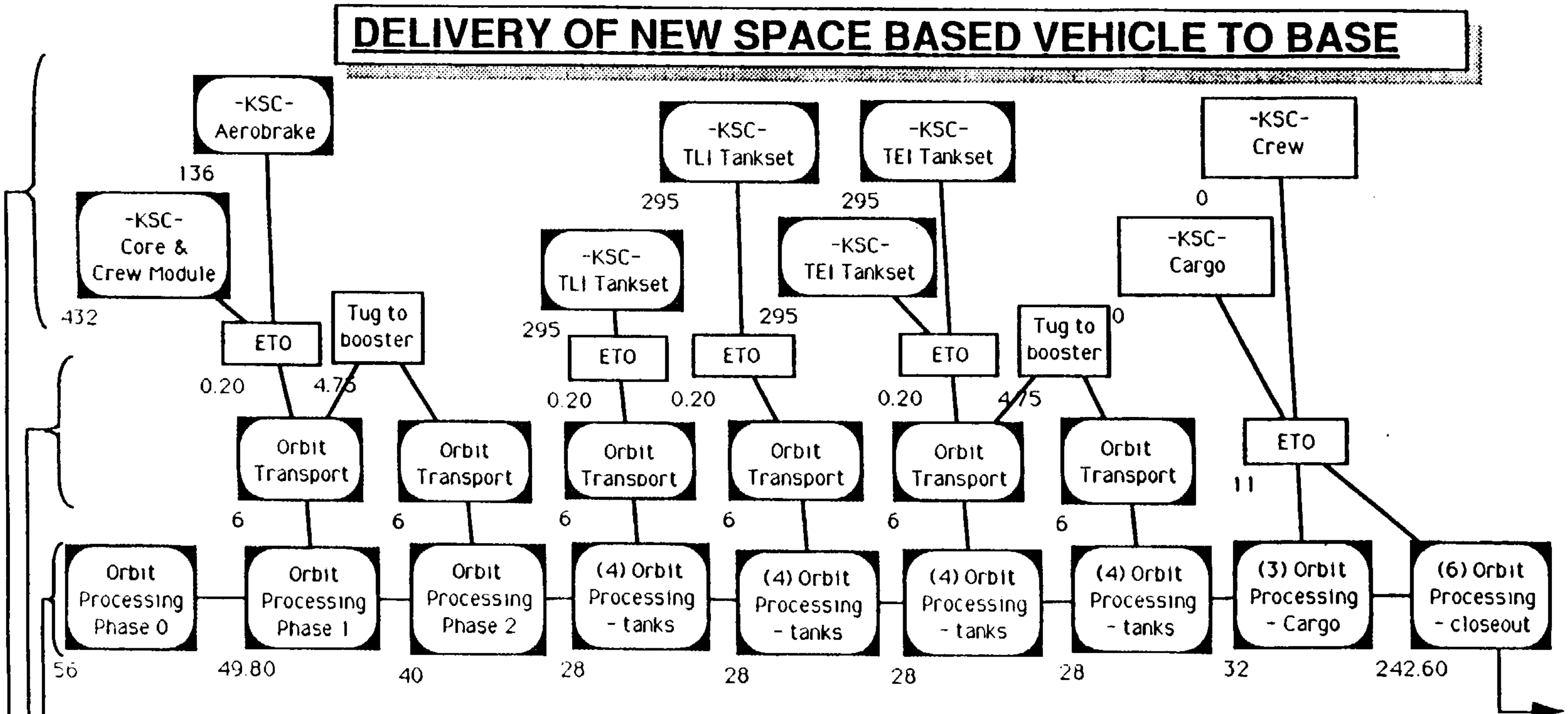
EXAMPLE OPS FLOW - SB2-1.5S

Operations Elements Definition



- Vehicle assembly at base (assumed to be SSF or equivalent)
- Vehicle element transport from KSC to base
- Vehicle element processing at KSC

Figure 1-3.4-2. Example Operations Flow - SB2-1.5S (Sheet 1 of 2)

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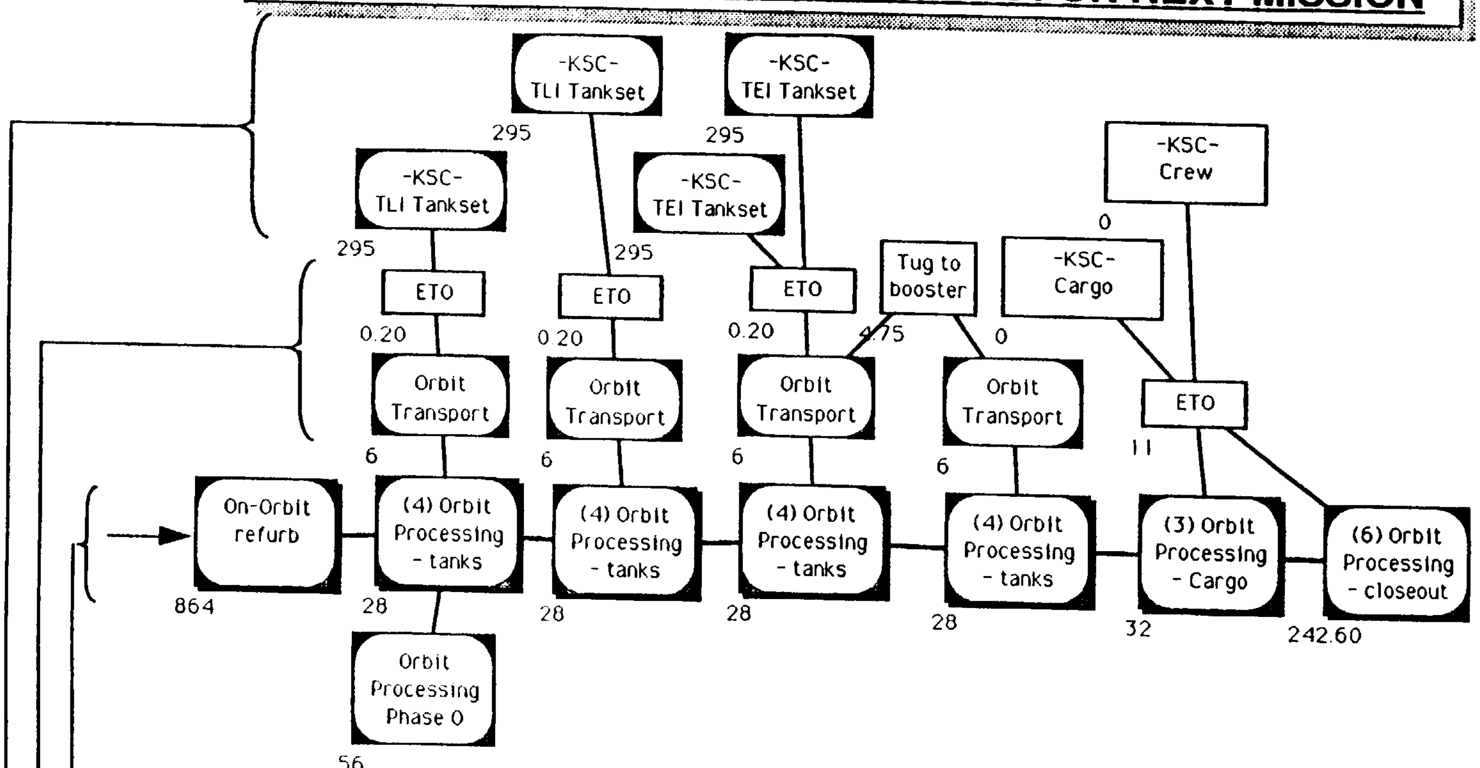
EXAMPLE OPS FLOW - SB2-1.5S (continued)

Operations Elements Definition

REFURBISHMENT OF LUNAR VEHICLE FOR NEXT MISSION



- Vehicle assembly at base
- Vehicle element transport from KSC to base
- Vehicle element processing at KSC

Figure 1-3.4-2. Example Operations Flow - SB2-1.5S (Sheet 2 of 2)

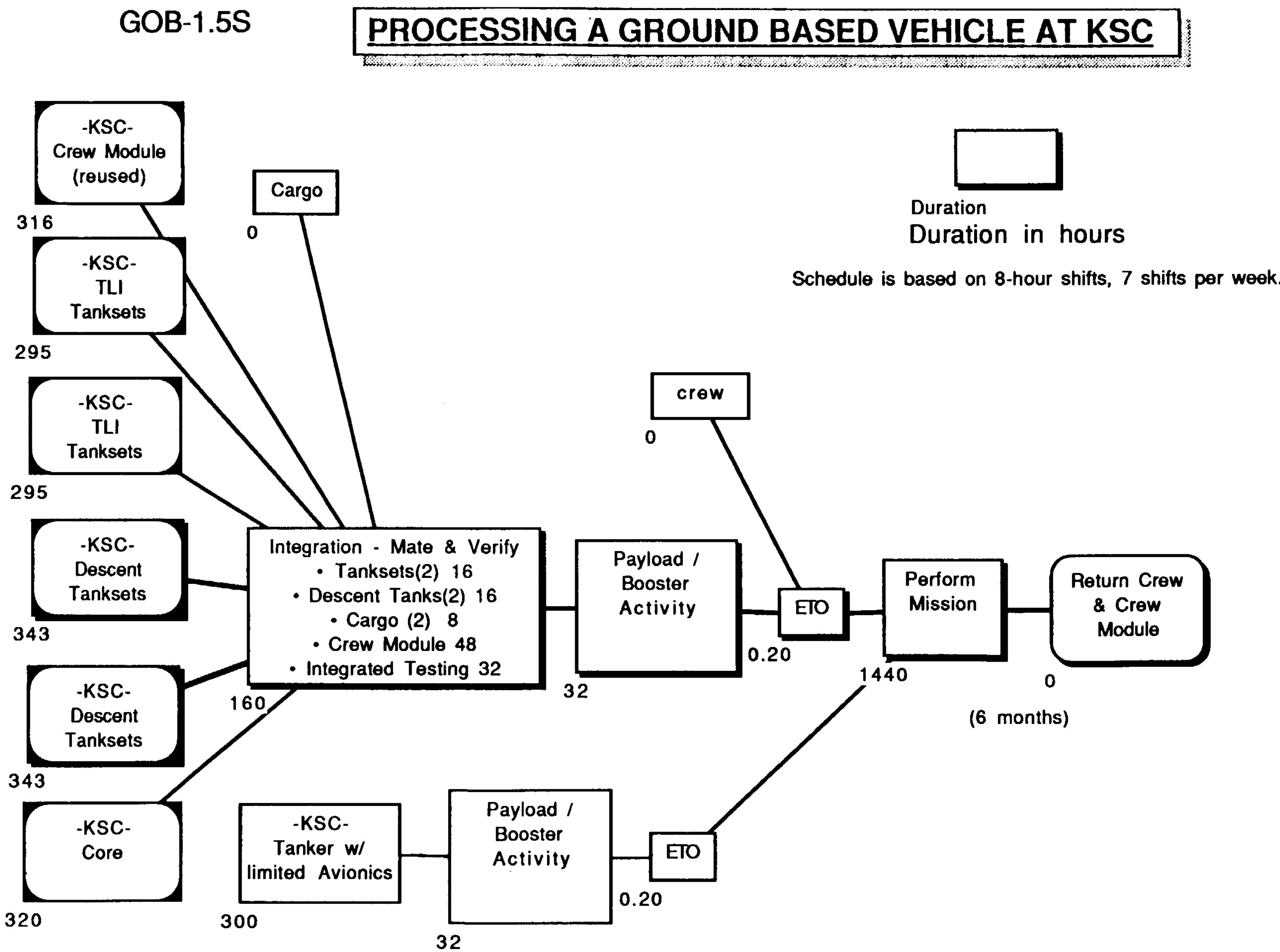


Figure 1-3.4-3. Processing a Ground-Based Vehicle at KSC

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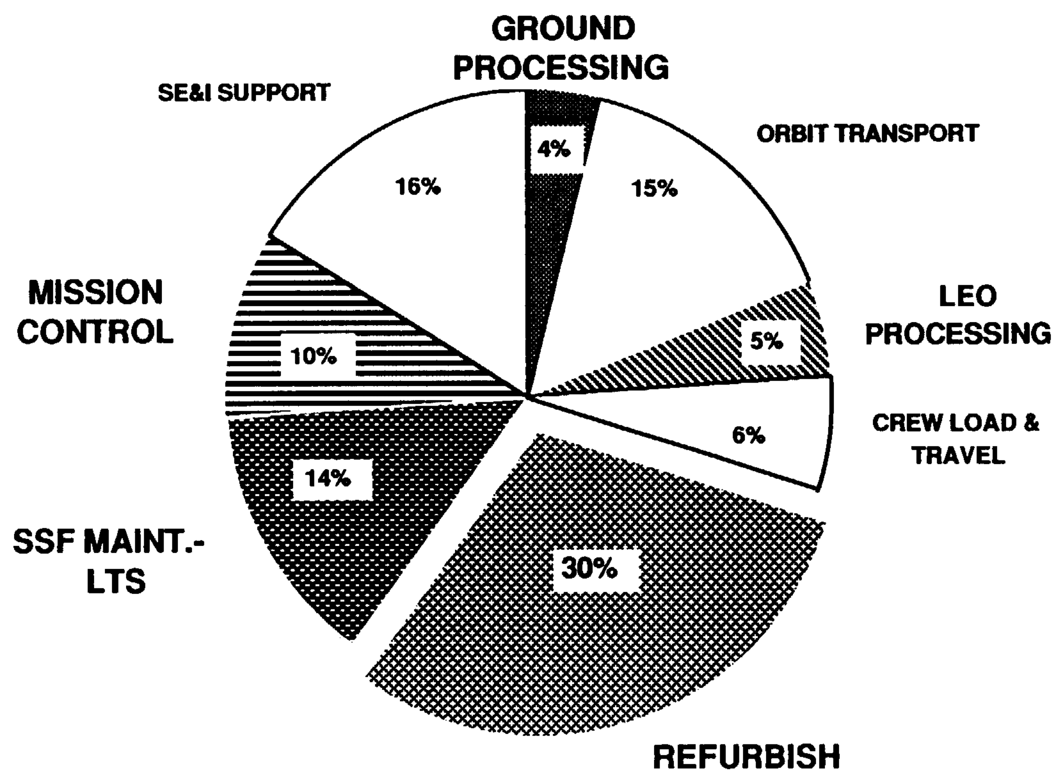
OPERATIONS COST LEVERAGE AREAS

High leverage areas in space operations are refurbishment, mission control, SSF operations, LEO processing & Ground Ops.........



Space-Based Single Stage Reference - Vehicle Cost/Round Trip

Figure 1-3.4-4. Operations Cost Leverage Areas

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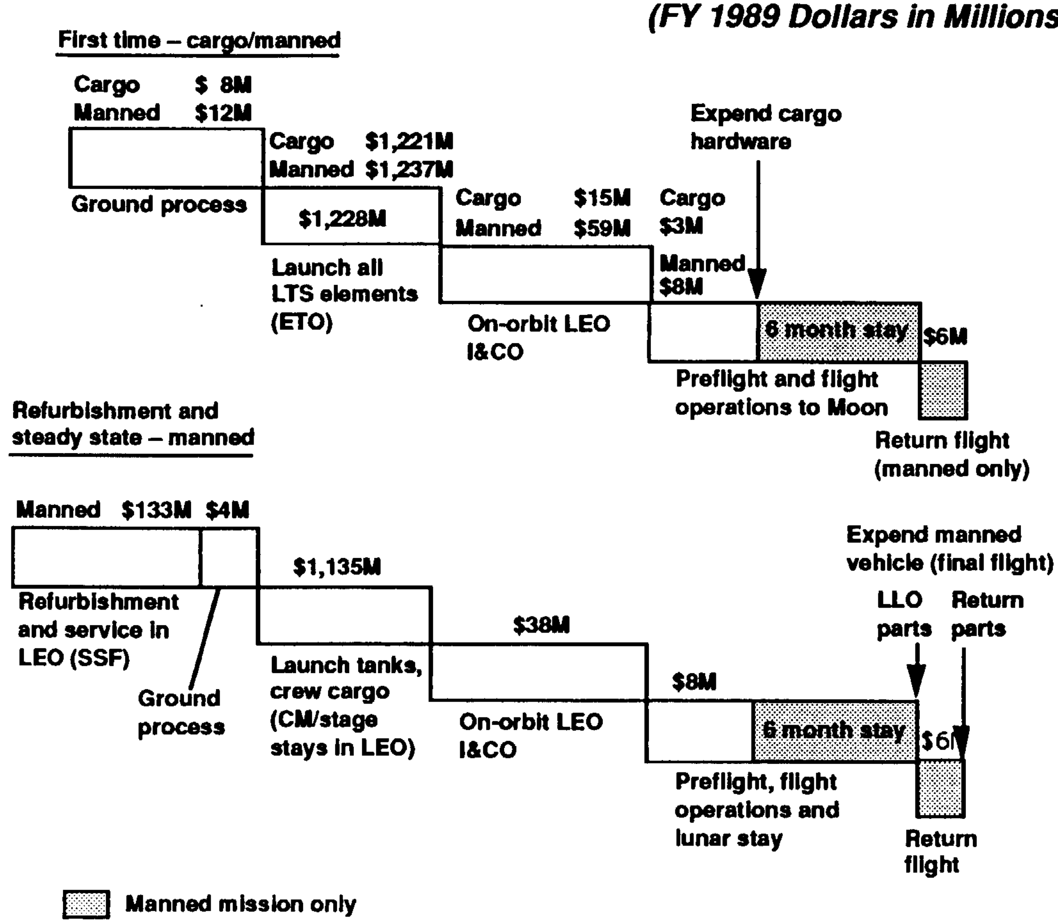
O&S FLIGHT COST BUILDUP - SB2-1.5S

6-20-90

(FY 1989 Dollars in Millions)



Summary (by mission type)

	Cargo	Manned
LTV	$ 26M	$ 27M
CM	0	58
Subtotal	$ 26	$ 85
ETO	1,221	1,237
Total*	$1,247M	$1,322M

	Manned only
LTV	$ 134M
CM	55
Subtotal	$ 189
ETO	1,135
Total*	$1,324M

* Note: Dollars exclude fee and NASA program support factors (at 10% and 5%) and mission control costs

Figure 1-3.4-5. O&S Flight Cost Buildup - SB2-1.5S

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O&S COST ESTIMATE ELEMENTS

6-20-90

(1989 DOLLARS IN MILLIONS)

	Estimated cost	Remarks
Space Station (SSF) setup costs:		
SSF accommodations	$4,500.0M	(Ref. – GD Infrastructure Study)
SSF verification and checkout	16.7	56 hours (7 days)
Total	$4,516.7M	
Functional flow (DRS) events:		
Ground processing – LTS	$ 7.8M	6 tug sorties – refurbishment plus consumables
Ground processing – Tanks	3.8	Aerobrake and stage/CM hardware
Orbit transport (STV tug)	42.0	Aerobreak and aero/stage I&CO
LEO processing phases 1 and 2	6.5	Drop tanks – 4 sets/launches
LEO processing and mate – tanks	7.5	4 TLI/TEI tank sets
LEO cargo/crew onload	2.6	Ground preparation not estimated
Outboard launch/flight	7.8	Preflight and launch/flight pay
Subtotal ①	$ 78.0M	
Inbound launch/flight	6.0	Moon to SSF and dock
Vehicle refurbish and service (LEO)	133.0	3 1/2 months; SSF crew = 6
Ground process – tanks	3.8	Repeat ground operations
Orbit transport (STV tug)	28.0	4 tug sorties
LEO processing and mate – tanks	7.5	Repeat orbit processing operations
LEO crew cargo onload	2.5	Repeat crew/cargo load
New mission launch preparation	7.8	
Subtotal ②	188.6M	
Flight operations cycle (①+②)	$ 266.6M	First manned flight plus refurbishment
SSF accommodations maintenance	$ 65.0	GD Infrastructure Study
MCC and launch sustaining	46.4	Boeing estimate
SE&I contract(s)	72.0	Boeing estimate

Figure 1-3.4-6. O&S Cost Estimate Elements

1-4.0 PROGRAM FUNDING SCHEDULES

Preliminary LCC)funding schedules have been developed for the development phases (DDT&E) only. These development projections stretch out for 11 years in duration. Figures 1-4.0-1 through 1-4.0-3 are fiscal year contractor and NASA expenditure spreads for the three LTS development projects: space based, ground orbital, and ground based, respectively (without other CNDB small stage mission impacts).

Figure 1-2.4-21 illustrated the comparison of the development of similar Apollo program hardware elements (command service module, lunar module, and Saturn IV-B upper stage) with the development profiles for each Boeing LTS candidate. In every case, the Boeing estimates (in 1991 dollars) fall within reasonable limits for the existing yearly budgets of the STS shuttle program. They also fall far below the equivalent 1991 dollars budget for the previous 8-year Apollo program (less engine development).

Figures 1-4.0-4 through 1-4.0-6 depict the estimated cost expenditures cash flow for each LTS system and an Apollo program summary cost flow in constant-year, 1991 dollars. These figures also include other development cost estimates such as the projected Boeing small stage and advanced space engine portions of the LTS project. Figure 1-4.0-4 (for the space-based system development) also includes a summary of the Apollo comparison data previously shown in Figure 1-2.4-21.

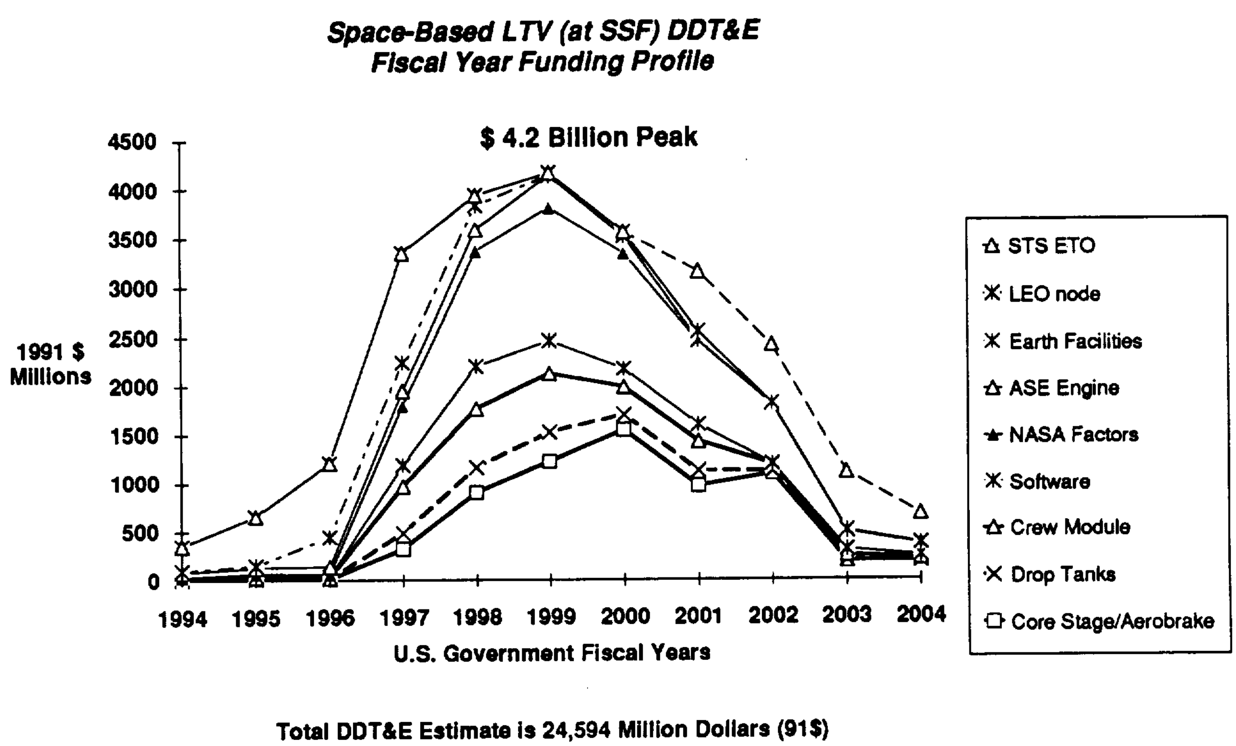

Figure 1-4.0-1. Space-Based LTV (at SSF) DDT&E

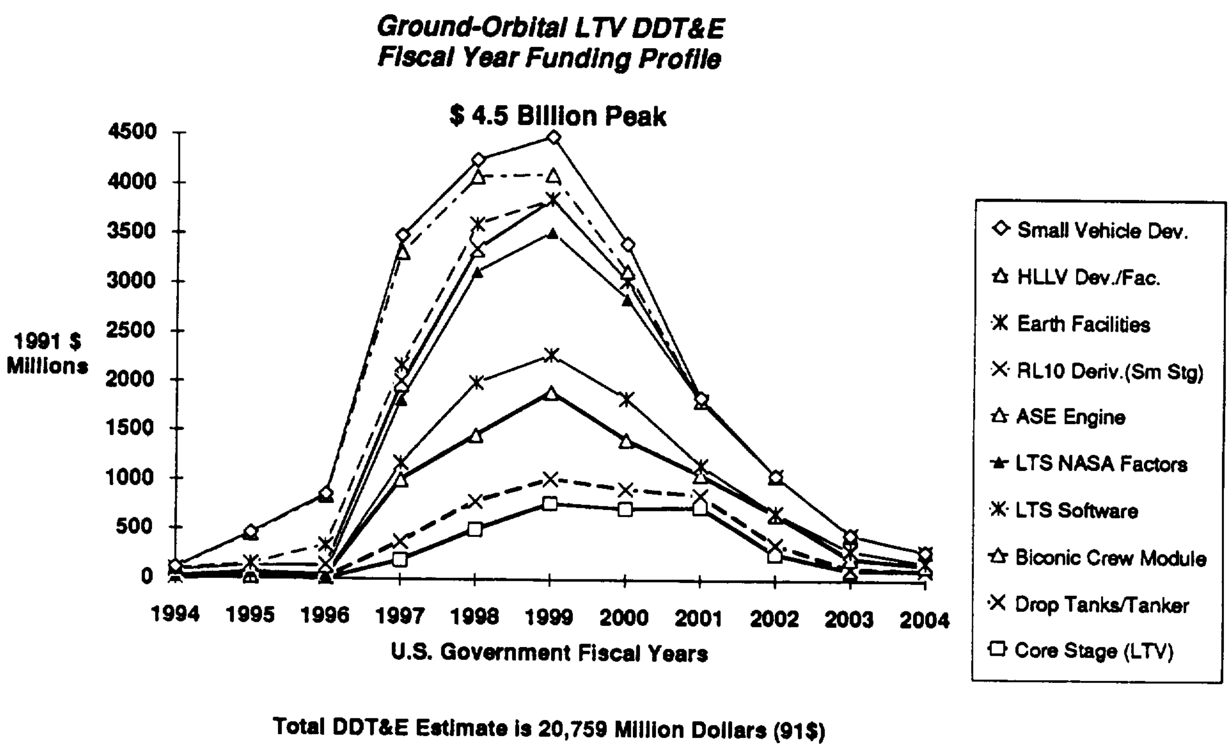

Figure 1-4.0-2. Ground-Orbital LTV DDT&E

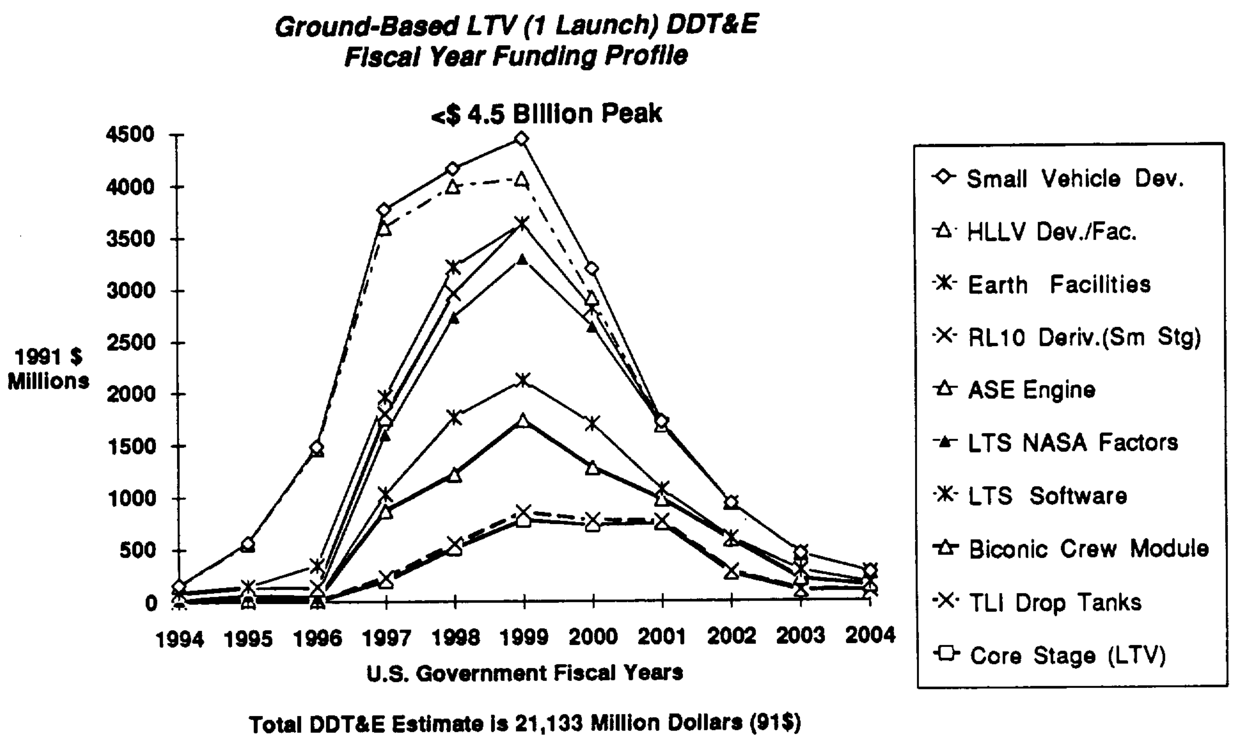

Figure 1-4.0-3. Ground-Based LTV (One Launch) DDT&E

(1991 Dollars in Millions)

YEARS	1	2	3	4	5	6	7	8	9	10	11	(91$ MILLIONS) TOTAL
(REF.) APOLLO SIVB+CSM+LM	448	1,820	4,148	5,730	7,133	4,715	4,865	985	985			29,844
(PERCENT BY YEAR)	1.5%	6.1%	6.1%	19.2%	23.9%	15.8 %	16.3 %	3.3%	3.3%			100
	A'	PHASE B-		PHASE C/D								
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
SPACE-BASED	.2%	.4%	.4%	10%	19%	22%	19 %	14%	10%	3%	2%	100%
STV (FINAL)												
CORE + AEROBRAKE	6	13	12	321	900	1,221	1,543	964	1,093	193	193	6,459
DROP TANKS	2	3	4	162	259	302	160	159	24	12		1,087
CREW MODULE	5	15	10	485	607	607	284	300	68	48	28	2,457
SOFTWARE	10	20	15	218	437	335	189	176	10	60	30	1,500
SUBTOTAL	23	51	41	1,186	2,203	2,465	2,176	1,599	1,195	313	251	11,503
NASA FACTORS	12	24	25	612	1,163	1,346	1,163	856	612	184	122	6,119
*SUBTOTAL	35	75	66	1,798	3,366	3,811	3,339	2,455	1,807	497	373	$17,622M
ASE ENGINE	50	60	80	150	217	330	175	10				1,072
FACILITIES												
EARTH	15	20	300	296	251							882
LEO NODE	255	500	765	1,100	100	28	50	90	15	10	5	2,918
STS ETO								600	600	600	300	2,100
SUBTOTAL -	320	580	1,145	1,546	568	358	225	700	615	610	305	$6,972M
TOTAL DDT&E	355	655	1,211	3,344	3,934	4,169	3,564	3,155	2,422	1,107	678	$24,594M

*COMPARISON LEVEL $ (LESS ENGINES & FACILITIES/OPS:)

Figure 1-4.0-4. Cost Spread for LTS Space-Based System

	1	2	3	4	5	6	7	8	9	10	11	
YEARS........................	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL
GROUND-BASED	.2%	.5%	.3%	.12%	.12%	.23%	.19%	.12%	.7%	.3%	.2%	.100 %
STV (FINAL)												
CORE VEHICLE (LTV)	3	6	5	195	505	775	720	736	263	96	96	3,400
DROP TANSK/TANKER	4	6	9	185	287	250	200	120	100	24	12	1,197
BICONIC MODULE	5	20	15	635	668	880	500	210	300	100	48	3,381
SOFTWARE	9	20	10	165	540	384	420	97	20	80	30	1,775
SUBTOTAL	21	52	39	1,180	2,000	2,289	1,840	1,163	683	300	186	9,753
NASA FACTORS	10	27	11	645	1,132	1,239	1,021	645	376	161	108	5,375
SUBTOTAL - $	31M	79	50	1,825	3,132	3,528	2,861	1,808	1,059	461	294	$ 15,128M
ASE ENGINE	50	60	80	150	217	330	175	10				1,072
RL-10 DERIV.	-	-	15	40	8	2	-	-				65
FACILITIES (LTS)	20	20	200	163	251							654
HLLV DEV. + FAC.	110	300	500	1,137	479	245						2,771
SUBTOTAL - $	180M	380	795	1,490	955	577	175	10				$ 4,562M
LTS DDT&E	211M	459	845	3,315	4,087	4,105	3,036	1,818	1,059	461	294	$ 19,690
DERIVATIVE												
SMALL STV	2	2	4	60	90	250	180	24				612
*SOFTWARE	1	5	10	55	20	4	5					100
SUBTOTAL - $	3	7	14	115	110	254	185	24				712
NASA FACTORS	2	3	7	58	55	127	93	12				357
SUBTOTAL- $	5M	10	21	173	165	381	278	36				$ 1,069M
GRAND TOTAL - $	216M	469	866	3,488	4,252	4,486	3,314	1,854	1,059	461	294	$ 20,759M
(GB Δ)	(+50)	(+100)	(+617)	(+500)	(+300)	(+190)						(1,757)

*ASSUME COMMON USE/SUPPORT FROM LTS/ALS/IUS EXISTING RESOURCES & FACILITIES

Figure 1-4.0-5. Cost Spread for Ground-Orbital System With Small Stage Definition

YEARS	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL
Core Stage (LTV)	3	6	5	195	505	775	720	736	263	96	96	3,400
TLI Drop Tanks	2	2	3	35	45	77	56	28	16	12	0	276
Biconic Crew Module	5	20	15	635	668	880	500	210	300	100	48	3,381
LTS Software	9	20	10	165	540	384	420	97	20	80	30	1,775
Subtotal	19	48	33	1,030	1,758	2,116	1,696	1,071	599	288	174	8,832
LTS NASA Factors	10	27	18	573	978	1,177	943	596	333	160	98	4,913
Subtotal	29	75	51	1,603	2,736	3,293	2,639	1,667	932	448	272	13,745
ASE Engine	50	60	80	150	217	330	175	10	0	0	0	1,072
Earth Facilities	20	20	200	163	251	0	0	0	0	0	0	654
HLLV Dev./Fac.	60	400	1,117	1,637	779	435	100	0	0	0	0	4,528
LTS Subtotal	159	555	1,448	3,553	3,983	4,058	2,914	1,677	932	448	272	19,999
Small Vehicle Dev.	5	10	21	173	165	381	278	36	0	0	0	1,069
RL10 Deriv.(Sm Stg)	0	0	15	40	8	2	0	0	0	0	0	65
Small Veh. Subtotal	5	10	36	213	173	383	278	36	0	0	0	1,134
Grand Total DDT&E	164	565	1,484	3,766	4,156	4,441	3,192	1,713	932	448	272	21,133

Figure 1-4.0-6. Cost Spread for LTS Ground-Based Single-Launch Case

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