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Contract NAS8-35614

Volume II

Final Report

June 1987

Cost and WBS/Dictionary

STS Propellant Scavenging Systems Study – Part II

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Volume II	Final Report	June 1987
Cost and WBS/Dictionary	STS PROPELLANT SCAVENGING SYSTEMS STUDY - PART II	

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FOREWORD

This document is part of the final report of the STS Propellant Scavenging Systems Study, Part II, performed under Contract NAS8-35614. It is a continuation of the propellant scavenging studies documented in a report dated February 1986. The final report was prepared in accordance with DR-6 by Martin Marietta Michoud Aerospace, New Orleans, Louisiana, for the NASA Marshall Space Flight Center. The report was prepared in two volumes:

Volume	Title
I	Executive Summary and Study Results
II	Cost and WBS/Dictionary

The MSFC Study Manager was Milton A. Page. The Martin Marietta Study Managers were Warren L. Gilmore and Walter P. Haese, and the Deputy Study Manager was Kevin Kelleher. The work was performed under the direction of Frank L. Williams, Director of Advanced Programs and Program Development.

CONTENTS

FIGURES

ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
ACS	altitude control system
Ae	nozzle exit area (sq in.)
AOTV	Aerobrake Orbital Transfer Vehicle
ASE	airborne support equipment
At	nozzle throat area (sq in.)
ATP	Authority to Proceed
B	billion
BRM	Baseline Reference Mission
Btu	British thermal unit
cg	center of gravity
CDR	Critical Design Review
CER	cost estimating relationship
CFMF	Cryogenic Fluid Management Facility
CP	Cherry Picker
CPF	cost per flight
CT&T	communications, telemetry and tracking (subsystem)
CTS	Canadian Technology Satellite
CY	calendar year
dB	decibel
delta-V	delta velocity
DFI	Development Flight Instrumentation
DMS	data management subsystem
DOD	Department of Defense
DOI	direct orbit insertion
EIU	engine interface unit
EPL	Engineering Propulsion Laboratory
EPS	electrical propulsion subsystem
ET	External Tank
FMEA	Failure Modes and Effects Analysis
FPR	flight performance reserve
fps	feet per second
FRF	Flight Readiness firing
FTA	Functional Test Article
Fty	tensile yield stress (lb/sq in.)
g	gravity
GEO	geosynchronous Earth orbit

ACRONYMS AND ABBREVIATIONS

GHe	gaseous helium
GH2	gaseous hydrogen
GN&C	guidance, navigation and control (subsystem)
GN2	gaseous nitrogen
GO2	gaseous oxygen
GSE	ground support equipment
GVTA	Ground Vibration Test Article
H2	hydrogen
He	helium
high-Q	high heat rate
I/F	interface
I/T	intertank
ICD	Interface Control Document
IIP	intact impact point
IMU	inertial measurement unit
IOC	initial operating capability
IR&D	Independent Research and Development
IR	infrared
Isp	specific impulse
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
K	thousand
klb	thousands of pounds
KSC	Kennedy Space Center
ksi	1000 lb/sq in.
lbf	pound-force
lbm	pound-mass
LCC	life cycle cost
LEO	low Earth orbit
LH2	liquid hydrogen
LO2	liquid oxygen
low-g	low gravity
LWACC	Lightweight ACC
LWT	Lightweight External Tank
M	million
MAF	Michoud Assembly Facility
MFSC	Marshall Space Flight Center

ACRONYMS AND ABBREVIATIONS

misc	miscellaneous
mlb	millions of pounds
MLI	multilayer insulation
MMH	monomethyl hydrazine
MPS	main propulsion system
MRMS	mobile remote manipulator system
NASA	National Aeronautics and Space Administration
N2O4	nitrogen tetroxide
NCFI	North Carolina Foam Industries
nm	nautical mile
O2	oxygen
OMS	orbital maneuvering system
OMV	Orbital Maneuvering Vehicle
Ops	Operations
OTV	Orbital Transfer Vehicle
OV	Orbital Vehicle
P/A	propulsion/avionics
P/S	Propellant Scavenging System
PAM-D	Payload Assist Module, Delta Class Spacecraft
PCM	pressure control monitor
PDR	Preliminary Design Review
PMD	propellant management device
PMF	Payload Mate Facility
POST	Program to Optimize Simulated Trajectories
PPS	primary propulsion system
prop.	propellant
PS	propellant scavenging
psia	pounds per square inch (absolute)
PSS	payload support structure
PSV	Propellant Scavenging Vehicle
R&M	reliability and maintainability
RCS	reaction control system
RF	radio frequency
RI	Rockwell International
RMS	remote manipulator system
rqd	required
RSS	range safety system

ACRONYMS AND ABBREVIATIONS

RTLS	return to launch site
RUD	rematable umbilical disconnect
RX	return-to-zero
RZ	rendezvous
S/W	software
SDV	Shuttle Derived Vehicle
SE&I	systems engineering and integration
sec	second
SOFI	spray-on foam insulation
SOW	Statement of Work
SRB	solid rocket booster
SRM	solid rocket motor
SS	Space Station
SSME	Space Shuttle main engine
STA	Scavenge Tank Assembly
	Structural Test Article
TALA	Transatlantic Abort Landing Avoidance
TBD	to be determined
TPS	thermal protection system
TRASYS	Thermal Radiation Analysis System (Computer Program)
TV	television
TVS	thermodynamic vent system
Veh	vehicle
WBS	Work Breakdown Structure
xfer	transfer
zero-g	zero gravity

1.0 INTRODUCTION

This document presents the results of the cost analysis performed to update and refine the program Phase C/D cost estimates for a Shuttle Derived Vehicle (SDV) tanker. The SDV tanker concept is an unmanned cargo vehicle (UCV) which incorporates a set of propellant tanks in the vehicle's payload module. The SDV tanker will be used to meet the demand for a cryogenic propellant supply in orbit. The propellant tanks are delivered to a low Earth orbit (LEO) or to an orbit in the proximity of the Space Station (SS).

The intent of the economic analysis is to provide the National Aeronautics and Space Administration (NASA) with economic justification for the propellant scavenging (PS) concept that minimizes the total Space Transportation System (STS) life cycle cost (LCC). The detailed costs supporting the concept selection process are presented with descriptive text to aid NASA in forecasting the Phase C/D project and program planning.

The scope of this document includes all PS program costs as well as all SDV, STS and Orbital Maneuvering Vehicle (OMV) charges to deliver the propellants to the SS. The detailed cost estimates are presented by a Work Breakdown Structure (WBS) to assure that all elements of cost are considered in the economic analysis and subsystem trades.

Sections 2 through 7 are formatted according to the outline given in DR-5. The WBS and WBS dictionary (see appendixes) are organized according to DR-4.

2.0 COSTING APPROACH

2.1 Methodology

The approach for the cost analysis was to adapt the WBS used in Part II for propellant scavenging to SDV tankers. With NASA approval, the WBS and WBS dictionary were developed to ensure that all program cost impacts would be identified and reported for all trade studies. Each element was analyzed to determine what modifications resulted from changing from a PS system to a SDV tanker system. Pertinent cost data from other studies (e.g., ASTS/GO, OTV, P/A) were incorporated as the information became available.

The cost analysis methodology is based on independent parametric cost estimates that are developed from the Martin Marietta cost analysis data books containing historical program cost data as well as other sources (e.g. vendor data). An example of a specific company program that was referenced for a cost estimate is the STS reaction control system (RCS). Cost data from this program was used to develop a tank cost estimating relationship (CER) for determining the propellant storage tank costs.

The rationale for the above procedure is that it allows cost elements to be estimated in a reasonably accurate manner with limited design information. In addition, estimates in parametric form provide a convenient format to support sensitivity analyses and cost trade studies.

2.2 WBS/WBS Dictionary

The WBS was developed early in Part I of the study to provide a comprehensive and consistent format for reporting PS programmatic costs. The WBS and WBS dictionary were developed with NASA approval to ensure that all program hardware/software cost impacts would be identified in the cost model and reported on all trade studies and economic analyses. The WBS is an expansion of the format which was developed for earlier NASA Aft Cargo Carrier (ACC) and Shuttle Derived Vehicle (SDV) studies, and which was modified for a SDV tanker propellant delivery system. The WBS was designed to meet the following criteria: subsystem level definition, flexibility to meet variations in hardware configurations, simplicity in reporting programmatic cost impacts, and conformity with the LCC estimating methodology.

The SDV tanker system WBS (Figure 2.2-1) is arranged in a two-dimensional matrix. The columns represent the cost phases identified by function/subfunction; the rows represent the hardware elements and systems. Definitions of the hardware elements and cost phases are provided in the WBS dictionary. The WBS dictionary was constructed to give a clear understanding

PHASE AND FUNCTION DIMENSION	PROJECT	PROPELLANT DELIVERY SYSTEM 1.00																							
	PHASE	R&T	DDT&E (1.2)											PRODUCTION (1.3)					OPERATIONS (1.4)						
	FUNCTION	(1.1)	PGM MGMT (1.2.1)	ENGINEERING (1.2.2)			MANUFACTURING (1.2.3)			TEST (1.2.4)		OPERATIONS (1.2.5)		PGM MGMT (1.3.1)	ENGINEERING (1.3.2)		MANUFACTURING (1.3.3)		OPERATIONS SUPPORT (1.4.1)					LAUNCH SUPPORT (1.4.2)	
	SUBFUNCTION			SYS ENG & INTEG	DESIGN & DEVELOP	SOFTWARE ENGINEERING	TOOLING &STE	GROUND TEST HDW	FLT TEST HDW	SYS TEST OPS	TEST FIXTURES	OPERATIONS SUPPORT	LAUNCH SUPPORT		SYS ENG & INTEG	DESIGN & DEVELOPMENT	TOOLING & STE	REUSABLE FLIGHT HDW	PROGRAM SUPPORT	REUSABLE HDW SPARES PROCUREMENT	EXPENDABLE HDW PROCUREMENT	FLIGHT OPS	NETWORK SUPPORT	LAUNCH OPERATIONS	PROPELLANT OPERATIONS
HARDWARE/SOFTWARE ELEMENT		WBS COLUMN NUMBER																							
WBS TITLE	WBS ROW #	1.1	1.2.1	1.2.2.1	1.2.2.2	1.2.2.3	1.2.3.1	1.2.3.2	1.2.3.3	1.2.4.1	1.2.4.2	1.2.5.1	1.2.5.2	1.3.1	1.3.2.1	1.3.2.2	1.3.3.1	1.3.3.2	1.4.1.1	1.4.1.2	1.4.1.3	1.4.1.4	1.4.1.5	1.4.2.1	1.4.2.1
PROPELLANT DELIVERY SYSTEM	1.0.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PDS INTEGRATED SYSTEM	1.1.0		X	X						X		X	X	X	X				X	X		X	X	X	
TANKER/SCAVENGING VESSELS	1.2.0	X	X	X	X		X	X	X	X	X			X	X	X	X	X	X	X	X				X
INTEGRATED SYSTEM	1.2.1		X	X	X		X	X	X	X	X			X	X		X	X	X	X	X				
STRUCTURES	1.2.2				X											X		X		X					
PROPELLANT TANKS	1.2.3				X											X		X		X					
PIPING & VALVING	1.2.4				X											X		X		X					
AVIONICS	1.2.5				X											X		X		X					
ELECTRICAL POWER	1.2.6				X											X		X		X					
TPS	1.2.7				X											X		X		X					
PROPULSION SYSTEM	1.2.8				X											X		X		X					
MAIN ENGINES	1.2.9				X											X		X		X					
GSE &ASE	1.2.10				X											X		X		X	X				
SDV	1.3.0	X	X	X	X	X	X	X	X	X	X									X	X	X	X	X	X
INTEGRATED SYSTEM	1.3.1		X	X			X	X	X	X	X									X	X	X	X	X	
STS	1.4.0	X	X	X	X	X	X	X	X	X	X									X	X	X	X	X	X
INTEGRATED SYSTEM	1.4.1		X	X			X	X	X	X	X									X	X	X	X	X	
OMV	1.5.0	X	X	X	X	X	X	X	X	X	X									X	X	X			X
INTEGRATED SYSTEM	1.5.1		X	X			X	X	X	X	X									X	X	X			

FIGURE 2.2-1 SDV TANKER WBS MATRIX FORMAT

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of the hardware and function costs shown in the WBS. The SDV tanker WBS dictionary is described in Appendix A.

The matrix structure of the WBS permits identification of any cost element by subsystem hardware category and LCC phase (i.e., design, development, test and evaluation [DDT&E], production and operations). Each of the three cost phases is further divided into function and subfunction categories (Figure 2.2-1) and defined in the WBS Dictionary (Appendix A). The hardware entries are defined at the fifth level and provide a high degree of cost visibility at the subsystem level while remaining general enough to allow flexibility in using the WBS for many different configurations.

2.3 Ground Rules and Assumptions

The following ground rules and assumptions were used in the SDV tanker propellant delivery system cost analysis. They were adapted from those used in Part II of the PS cost analysis. Modifications were made to the operational time frame and the number of flights. Additionally, OMV costs were included in SDV tanker LCC calculations.

A) All costs are expressed in 1984 dollars and are exclusive of fees, contingencies and government costs.

B) The design is within existing technological capabilities and will not require research and technology funding.

C) The SDV tanker test program requires three test articles: a Structural Test Article (STA), a Ground Vibration Test Article (GVTA), and one flight test article (FTA). The FTA is assumed to be identical to the flight article.

D) The flight test is assumed to be conducted in conjunction with a scheduled SDV flight such that an extra SDV flight is not required. The reusable portion of the test article is assumed to be refurbished and flown again as part of the regular scavenging system fleet.

E) Based on expected turnaround times, a production quantity of four sets of SDV tanker hardware is necessary to fly 144 flights over a period of 16 years.

F) SDV tanker production improvement is calculated using an 86% (Wright) learning curve for structures and a 95% learning curve for propulsion, power, and avionics hardware.

G) The SDV operations cost per flight (CPF) is $80.5M based on NASA provided data.

H) The STS operations CPF is $101.4M based on NASA provided data.

I) The PS system has an initial operational capability (IOC) date of 1995 and an operational timeframe of 1995 through 2010.

J) The cost for refurbishment and checkout of the tanker/scavenging vessels is assumed to be 10% of first unit cost. Learning improvements for refurbishment are assumed identical to production learning improvements (see F).

K) Salvage value calculations for the tanker/scavenging vessels are based on the following subsystem service life capabilities:

- o Structures - 100 missions;
- o Propulsion - 100 missions;
- o Power - 100 missions;
- o Avionics - 100 missions;
- o Engines - 100 missions.

L) The OMV operations costs are included in the program costs. These costs include OMV refurbishment costs, replacement cost of OMV propellant used, and mission operation costs.

M) The lift capability of the SDV to LEO is 150 klb. The SDV lift capability to DOI near the SS is 140 klb.

3.0 SUMMARY COST PRESENTATION

This section contains a summary presentation of the cost analysis performed during Part II for the SDV tanker concept chosen for further development, namely, Option 2. Costs are described at a top level to give an overview of the cost drivers for the concept. Detailed costs to the WBS level are given in Section 4.0.

3.1 Program Cost Analysis - SDV Tanker Option 2

The SDV tanker Option 2 is a propellant tank set mounted on the forward section of the SDV payload (P/L) module. The tank set consists of three tanks: two tanks for LH2 and one tank for LO2. The total capacity of the tanks is 61.4 klb: 8.7 klb LH2, and 52.7 klb LO2. The propellant tanks are ground loaded during prelaunch processing.

The SDV tanker flies a direct injection trajectory to an orbit near the SS. The propellant tank set is removed from the SDV P/L module by the OMV which berths the propellant tank set with the SS. After propellant has been transferred from the tank set to the SS propellant storage facility and an opportunity exists for a scheduled Shuttle flight to return the empty propellant tank set to Earth, the OMV delivers the propellant tank set from the SS to the orbiter. The tank set is then disassembled and the separate tanks are returned to Earth in the orbiter's cargo bay. A detailed technical description of SDV tanker Option 2 is given in Volume I, Section 2.4.

The total program cost estimate of this concept is $7.5B to deliver 8.84 mlb of propellant. A summary of the program costs appears in Figure 3.1-1.

The total DDT&E cost estimate is $63.7M including: design and development, systems engineering, tooling, manufacture of test articles (flight and ground), systems test, and program management. The DDT&E costs are driven by the structural design of the propellant tanks,docking adaptor, and test hardware procurement

The production cost estimate for SDV tanker Option 2 is $19.3M. This cost is composed of the manufacturing cost of four reusable scavenging vehicles (one refurbished from the FTA). Production of the propellant tanks, along with the initial spares and sustaining engineering, are the major production cost drivers. The production phase recurring engineering, systems engineering and integration tooling/special test equipment (STE) and program management are included with reusable flight hardware costs.

The total operations cost estimate for delivering 8.84 mlb of propellant is $7.5B, which includes the recurring cost for SDV tanking hardware

Total Program Cost = $7.5B

Delivered Propellant Cost Per Pound = $852

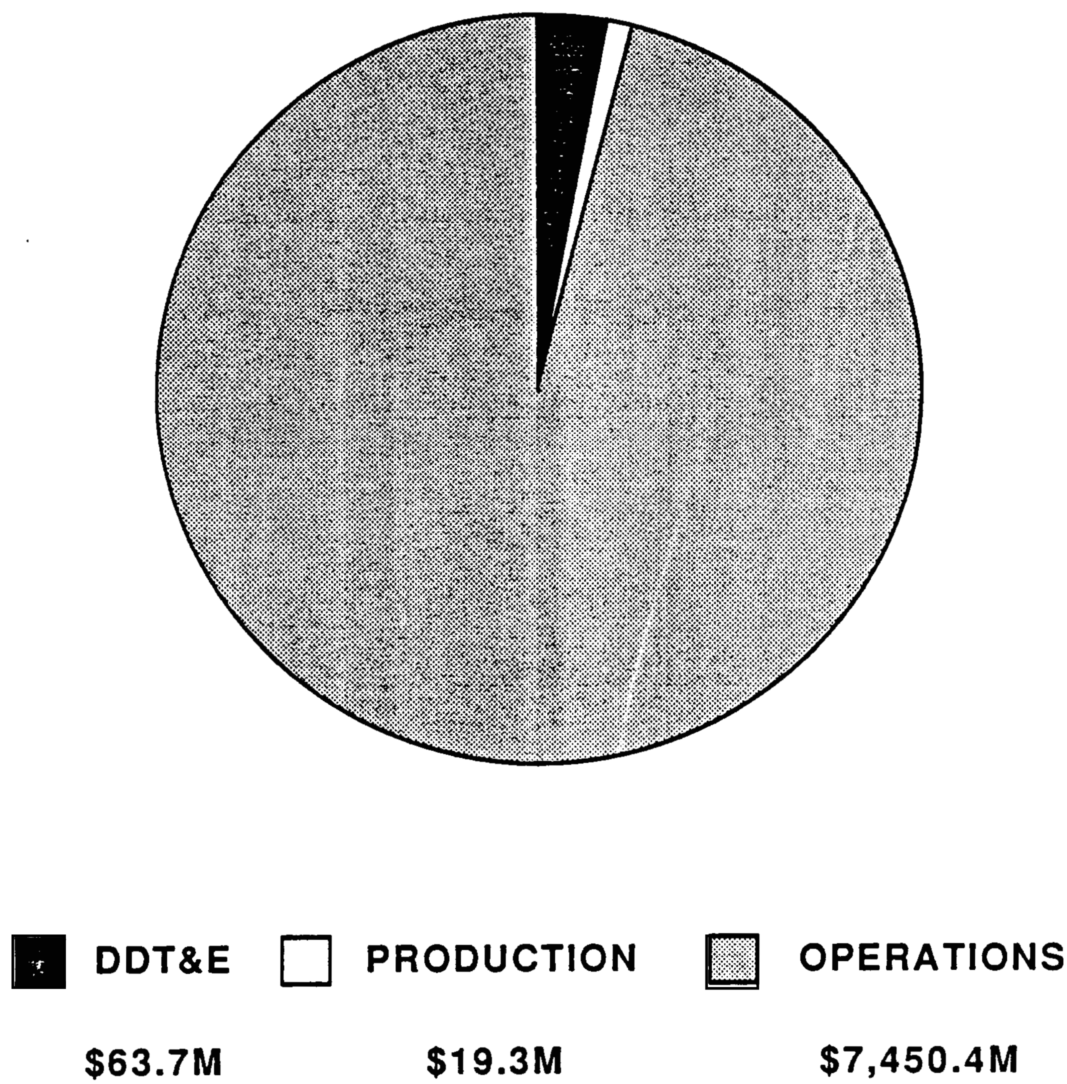


Figure 3.1-1 Program LCC - SDV Tanker Option 2

refurbishment, as well as SDV, STS and OMV users charges. The users charges (transportation costs), especially the SDV users charge, dominate not only the operations cost but also the total LCC. Transportation costs are the main cost drivers of total LCC.

As previously reported in Part II of this study, the STS propellant scavenging system (P/S) is capable of delivering approximately 2.0 mlb propellant. Propellant delivered in excess of 2.0 mlb was assumed to be delivered by dedicated STS tanker at a cost in excess of $2,000 per pound. Additionally, for delivered propellant amounts greater than 2.0 mlb, the program DDT&E, production, and operations costs (other than transportation) rapidly become insignificant compared to the transportation cost. As shown in this addition to Part II of the study, the delivery cost per pound of propellant by a SDV tanker is significantly less (58%) than the STS delivery cost per pound. However, the delivery cost per pound achieved by STS scavenging is still less (51%) than the SDV delivery cost. Since the current mission model requires propellant in excess of the 2.0 mlb that the STS P/S is capable of delivering, it is advantageous to combine the STS PS system with the SDV tanker system to supply the required propellant at the lowest cost per pound.

3.2 Benefits Analysis

An economic analysis determined the cost benefits of carrying propellant to orbit on SDV flights. Previous study results showed the cost benefits of STS scavenging compared to STS tankers. This extension of that study identifies SDV tanker capabilities compared to STS scavenging and tanking.

A graph of propellant mass delivered is provided in Figure 3.2-1 to illustrate the sensitivity of propellant unit cost to demand. The minimum cost per pound of propellant occurs at the limit of the STS PS capability. For quantities less than this amount, the unit cost increases as fixed development costs are spread over fewer missions. Concept 6 STS scavenging has its lowest propellant unit cost ($419/lb) at its delivery capacity of approximately 2.0 mlb. When demand exceeds this capability, STS or SDV tanker flights are required to supply the excess propellant. The propellant delivery cost for STS tankers and SDV Option 2 tankers are provided as references. The slight inclination in tanker $/lb are due to the amortization of tanker DDT&E and production costs. The combination of STS scavenging and SDV tanker programs offer the lowest cost per pound option for propellant requirements in excess of the 2.0 mlb. This result is due to the SDV performance capability above that of the STS.

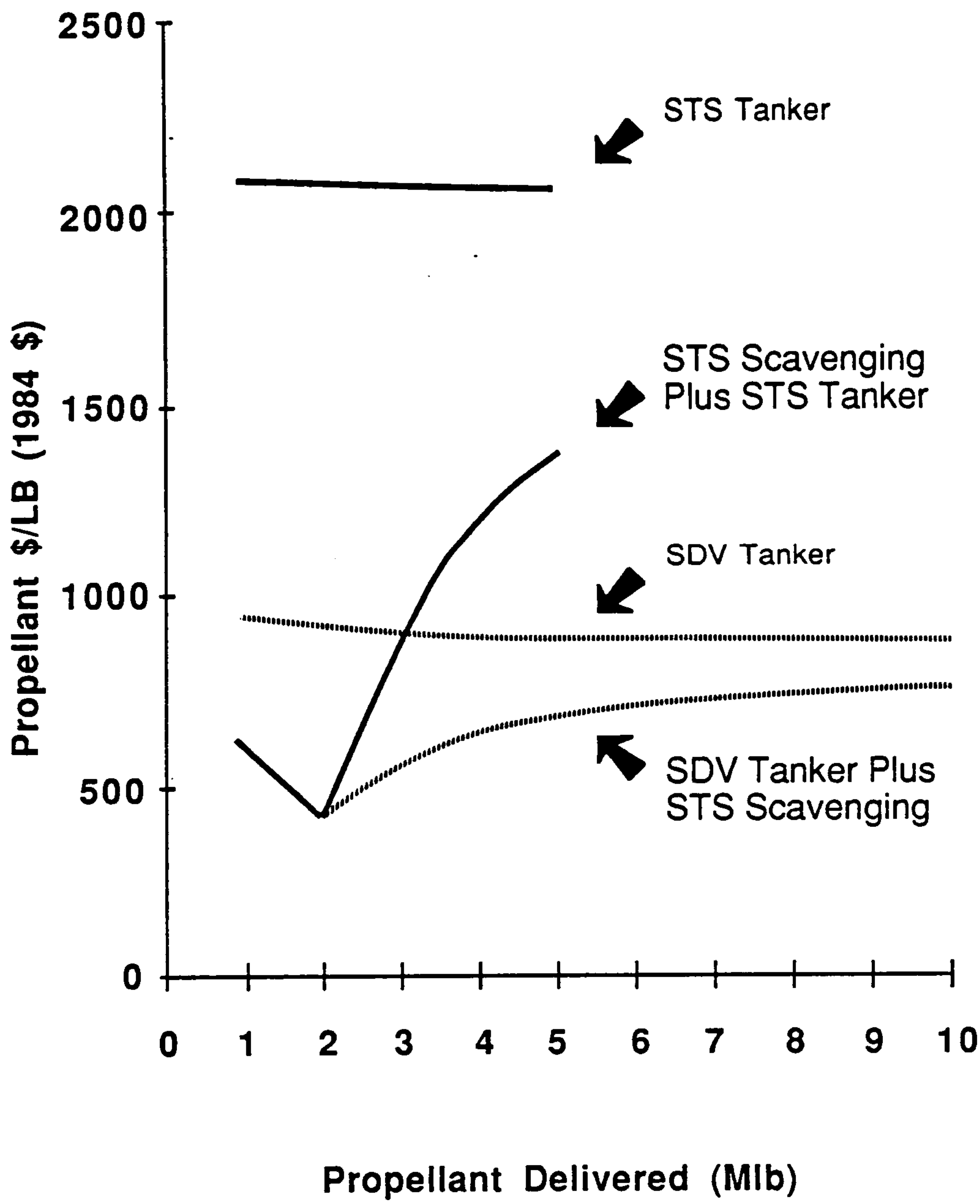


Figure 3.2-1 Propellant Cost Per Pound
Sensitivity To Demand

Both the SDV CPF and performance have major impacts on the delivered propellant cost per pound. Figure 3.2-2 illustrates the propellant cost per pound as a function of demand and the SDV load factor. Load factors of 100%, 90% and 80% are shown for both the SDV tanker Option 2 and the SDV tanker Option 2 augmented by STS scavenging. A decrease in load factor causes a corresponding reduction in the SDV users charge for a propellant delivery mission. Thus for a load factor of 100%, the entire normally assessed SDV users charge is assessed against the propellant delivery mission. If the load factor is 90%, then the SDV users charge assessed the propellant delivery mission is the normal SDV users charge less an equivalent SDV users charge for the 10% unused SDV capacity. The unused excess lift capability of a specific, normally manifested, and scheduled SDV flight is credited to a propellant delivery mission. By using this load factor phenomena, a portion of the propellant delivery payload is given a "free ride", thus reducing the SDV transportation cost.

For the combined SDV tanking and STS scavenging systems, the load factor phenomena does not affect delivered propellant amounts less than 2 mlb, as this propellant is supplied by STS scavenging which is not assessed an STS user charge.

3.3 Summary Mass Properties - SDV Tanker Option 2

The SDV tanker Option 2 summary weight breakdown (Figure 3.3-1) was prepared as input to the LCC model. These data were obtained from Volume I, Appendix I and grouped according to the SDV tanker vessel WBS.

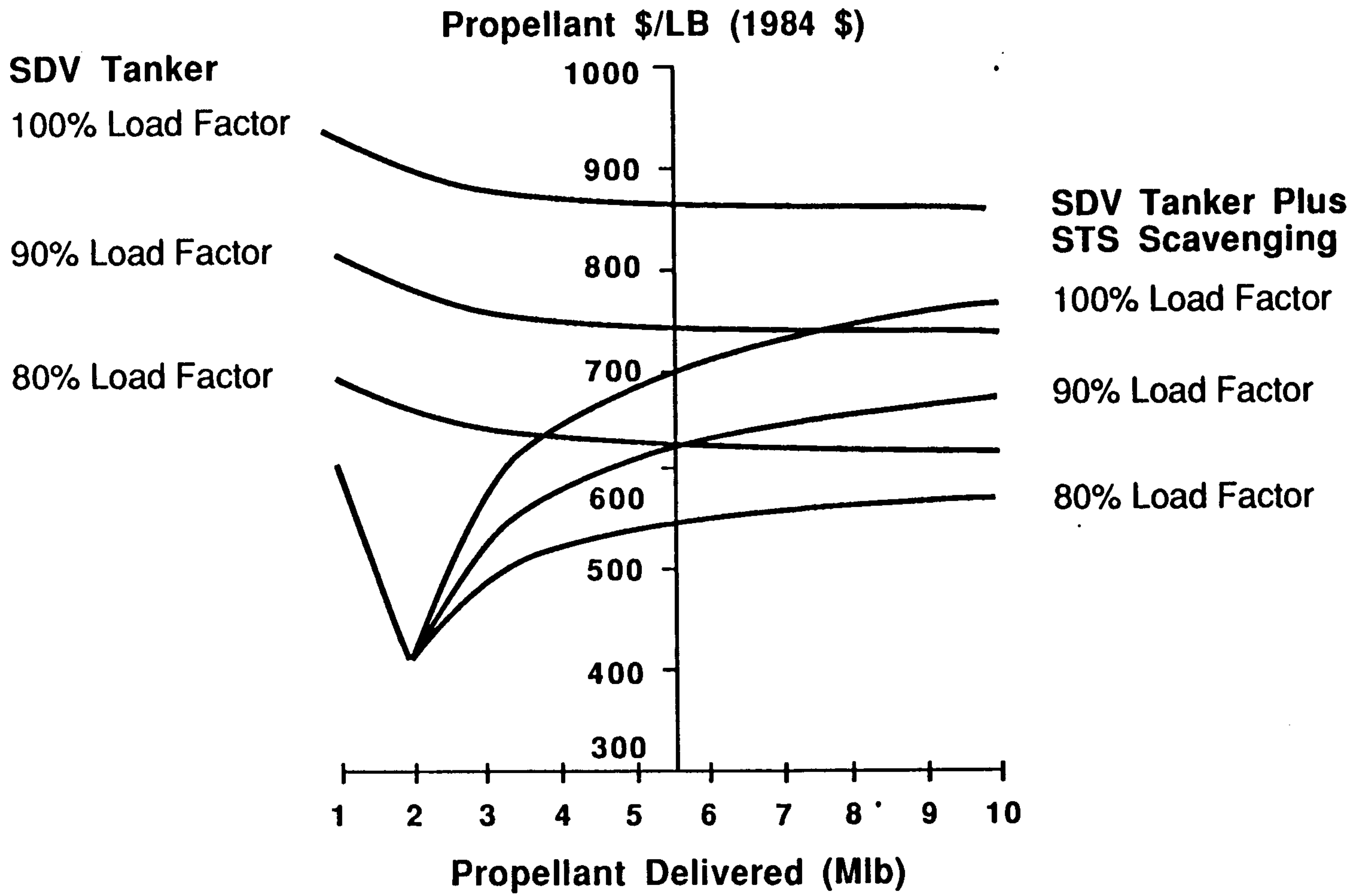


Figure 3.2-2 Propellant Cost Per Pound Sensitivity to Load Factor - STS Scavenging Plus SDV Tanker

SDV Tanker Vessel			2764
Structure		600	
Airframe	411		
Equipment Mounts	50		
Handling and Storage	159		
Propellant Tanks		913	
Tank Structure	822		
Tank Mounts	91		
Propulsion		938	
Pressurant & Pneumatic Systems	167		
Propulsion Feed Vent & Drain Fuel	189		
Propulsion Feed Vent & Drain Oxygen	73		
Propulsion Utilization & Management System	343		
Vent System (nonpropulsive)	97		
Umbilicals	69		
Communications & Data Handling		59	
Electrical Power		35	
Thermal Control		199	
Insulation	179		
Thermal Control (misc)	20		

FIGURE 3.3-1 SUMMARY MASS PROPERTIES - SDV TANKER OPTION 2

4.0 COST ESTIMATES BY WBS ELEMENT

The SDV tanker costs that were summarized in Section 3.0 are reported in this section to the SDV tanker WBS defined in Section 2.2. Formatting of the costs by WBS allows each cost element to be defined by function and cost phase, while permitting detailed configuration comparisons.

A summary of the estimated program LCC costs for SDV tanker Option 2 appears in Figure 4.0-1. The SDV tanker program LCC of $7.5B includes the SDV users charge of $6.5M for 144 regularly scheduled SDV flights. If the SDV tanks were a free ride, the SDV tanker program LCC estimate would be $1.06B. Of this figure, $702M is the STS user charge for returning the SDV tanker vessels to Earth, and $70M is the total OMV user charge for transporting the SDV/tanks to and from the Space Station. A detailed WBS cost breakdown by propellant delilvery subsystem and program function can be found in Appendix B.

Date: Wed., June 10, 1987
Millions of 1984 Dollars

	R&T Costs	DDT&E Costs	Production Costs	Operations Costs	Total Costs
Tanker/Scavenging Vessels	-	63.7	19.3	206.3	289.2
SDV	-	-	-	6472.6	6472.6
STS	-	-	-	701.7	701.7
OMV	-	-	-	69.8	69.8
Totals	-	63.7	19.3	7450.4	7533.3

FIGURE 4.0-1 PROPELLANT DELIVERY SYSTEM LCC SUMMARY
SDV TANKER OPTION 2

4.1 DDT&E

The SDV tanker program DDT&E phase consists of development of the SDV tanker system. A breakdown of the DDT&E costs appears in Figure 4.1-1. SDV tanker DDT&E costs ($63.7M) are driven by design and development of the docking structure and LO2/LH2 tanks. Test hardware procurement is also a major element. Design and development costs for the remainder of the system are low. Systems engineering and integration (SE&I) for SDV tanking is $8.8M, including all Level II efforts necessary to integrate the tanking system into the SDV. Development costs for the SDV tanker system include design and development of the subsystem elements, tooling, ground and flight test hardware (one each), systems test operations and fixtures, systems engineering, and program management. Design and development costs were estimated at the subsystem level.

<u>SDV Tanker System</u>			$63.7M
Design and Development		$ 22.1M	
Structure	$ 5.6M		
Propellant Tanks	13.0M		
Piping and Valving	0.7M		
Avionics	1.3M		
Electrical Power	0.2M		
TPS	0.1M		
GSE & ASE	0.4M		
SE&I		8.5M	
Tooling		7.0M	
Test Hardware		13.0M	
GSE & ASE Hardware		1.2M	
Test Operations/Fixtures		3.6M	
Program Management		5.2M	

FIGURE 4.1-1 PROGRAM DDT&E COST SUMMARY - SDV TANKER OPTION 2

4.2 Production

The Production cost impacts for the SDV tanker vessels include manufacture of the reusable SDV tanker flight hardware ($19.3M). Production of expendable ASE hardware is considered to be an operations cost and is reported under the operations WBS. Four flight articles are needed to support 144 tanker missions for Option 2. Production of one of the flight articles is assumed to originate from refurbishment of the FTA. In addition to the hardware cost, the production cost estimates for the SDV tanker hardware include recurring engineering, SE&I, tooling/STE, and program management. First unit production costs were determined at the subsystem level. Figure 4.2-1 shows the first unit cost, total production cost, and average cost per unit for SDV tanker Option 2.

		First Unit Cost	
SDV Tanker First Unit Cost			$7.4M
Flight Hardware		$ 3.8M	
Structures	0.7M		
Propellant Tanks	1.8M		
Piping and Valving	0.7M		
Avionics	0.4M		
Electrical Power	0.0M		
TPS	0.2M		
Assembly & Checkout		$ 0.4M	
Sustaining Tooling		0.3M	
Initial Spares		1.4M	
Sustaining Engineering		1.2M	
Program Support		0.2M	
Total Production (3 Units)			$19.3M
Average Cost per Unit			$ 6.3M

FIGURE 4.2-1 PROGRAM PRODUCTION COST SUMMARY - SDV TANKER OPTION 2

4.3 Operations

Operations cost estimates for SDV tanking constitute the largest share of program LCC costs. Cost estimates for SDV tanker Option 2 operations include refurbishment of the reusable flight hardware, production of ASE flight hardware, and launch, flight, and mission operations, e.g., SDV, STS and OMV transportation charges. Detailed operations costs appear in Figure 4.3-1. Figure 4.3-2 provides CPF information for SDV tanker Option 2.

The SDV users charges which account for the majority of the operations cost and LCC have been calculated in the same manner as the STS users charge, i.e., on the basis of a shared flight charge. The users charge for a particular payload is obtained by multiplying a charge factor by the CPF of a dedicated flight. The charge factor is obtained by taking the ratio of payload weight to Shuttle capacity and payload length to Shuttle capacity, and dividing the greater of the two by 0.75.

Changes in the above pricing policy, dedicated CPF, or vehicle performance will greatly affect the propellant delivery systems operations cost, total LCC, and delivered propellant LCC. Cost sensitivities to the above parameters are examined in Section 6.5.

5.0 TOTAL PROGRAM FUNDING

This section presents the time-phased fiscal year (FY) funding of the SDV tanker Option 2 cost estimates presented in this volume. These costs represent the costs required to accomplish the total program, including all costs for DDT&E, production, and a sixteen year operational period. The total PS cost for any fiscal year is the sum of all the phase activities in that year.

5.1 Ground Rules and Assumptions

The following ground rules and assumptions were used to generate the PS funding distributions.

A) Funding distributions are in constant FY 1984 dollars.

B) The DDT&E and production funding are based on anticipated hardware development schedules and production rates.

C) Program funding is shown for fiscal years and accounts for the three month offset during the operational period from calendar years 1995-2010 to fiscal years 1995-2010.

D) Each cost phase was distributed according to a selected distribution type that conformed with the expected funding distribution for a particular cost phase.

E) Operations costs assume delivery of 8.84 mlb of propellant.

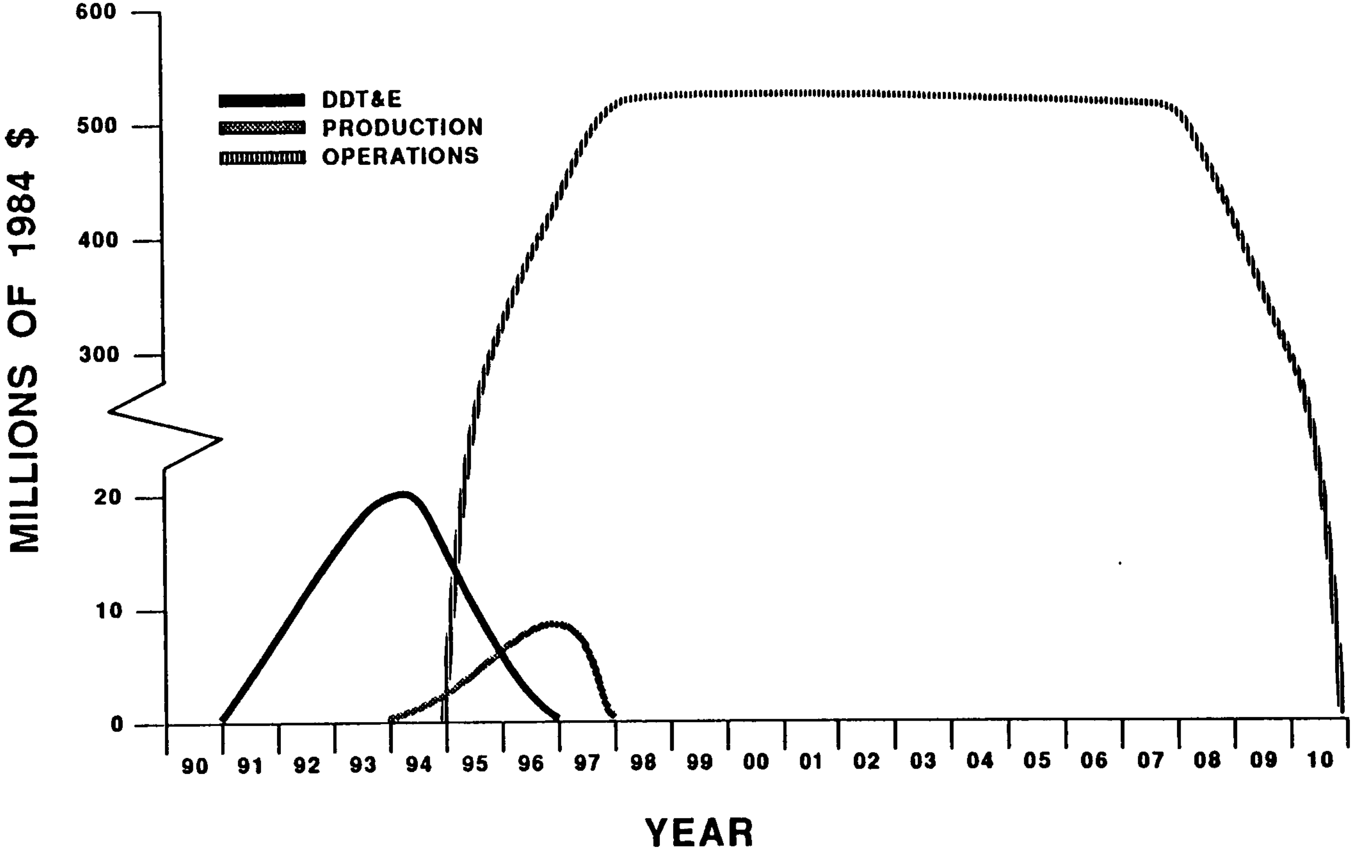
5.2 Program Funding

Program funding distributions for SDV tanker Option 2 (Figure 5.2-1) include all DDT&E, production, and operations costs associated with implementing the SDV tanker program.

The DDT&E funding for the tanker vessel hardware begins at ATP in 1991 and continues through 1996. Peak DDT&E funding of $20M/year occurs in 1994.

Production funding for fabrication of the tanker/scavenging vessel hardware (including refurbishment of the retrieved development flight article) begins in 1993 and continues through 1997. Peak production funding of $8M/year takes place in 1996.

The operational timeframe of the SDV propellant tanking system is 1995-2010. Peak operations funding, expected to fall in the years 1998-2007, is a maximum of $525M/year per year for Option 2.



DDT&E	0	3	11	18	20	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRODUCTION	0	0	0	0	1	4	8	6	0	0	0	0	0	0	0	0	0	0	0	0	0
OPERATIONS	0	0	0	0	0	150	345	480	525	525	525	525	525	525	525	525	525	525	480	345	150
TOTAL	0	3	11	18	20	164	355	486	525	525	525	525	525	525	525	525	525	525	480	345	150

FIGURE 5.2-1 PROGRAM FUNDING DISTRIBUTION
SDV TANKER - OPTION 2

6.0 ECONOMIC ANALYSIS

This section describes the cost trade studies performed for this extension to Phase II of the study.

6.1 Preferred SDV tanker Configuration

Initially, three SDV tanker configurations were evaluated to assess their economic viability and their affect on SDV operations. The individual configurations are described as follows: (1) Option 1 - a tank set mounted to the aft bulkhead of the SDV payload (P/L) module; (2) Option 2 - a tank set mounted to a bulkhead in the forward nose cone area of the SDV P/L module; and (3) Option 2A - similar to Option 2 with the added capability of self-propulsion. Option 2A is designed to be used when the SDV destination is LEO.

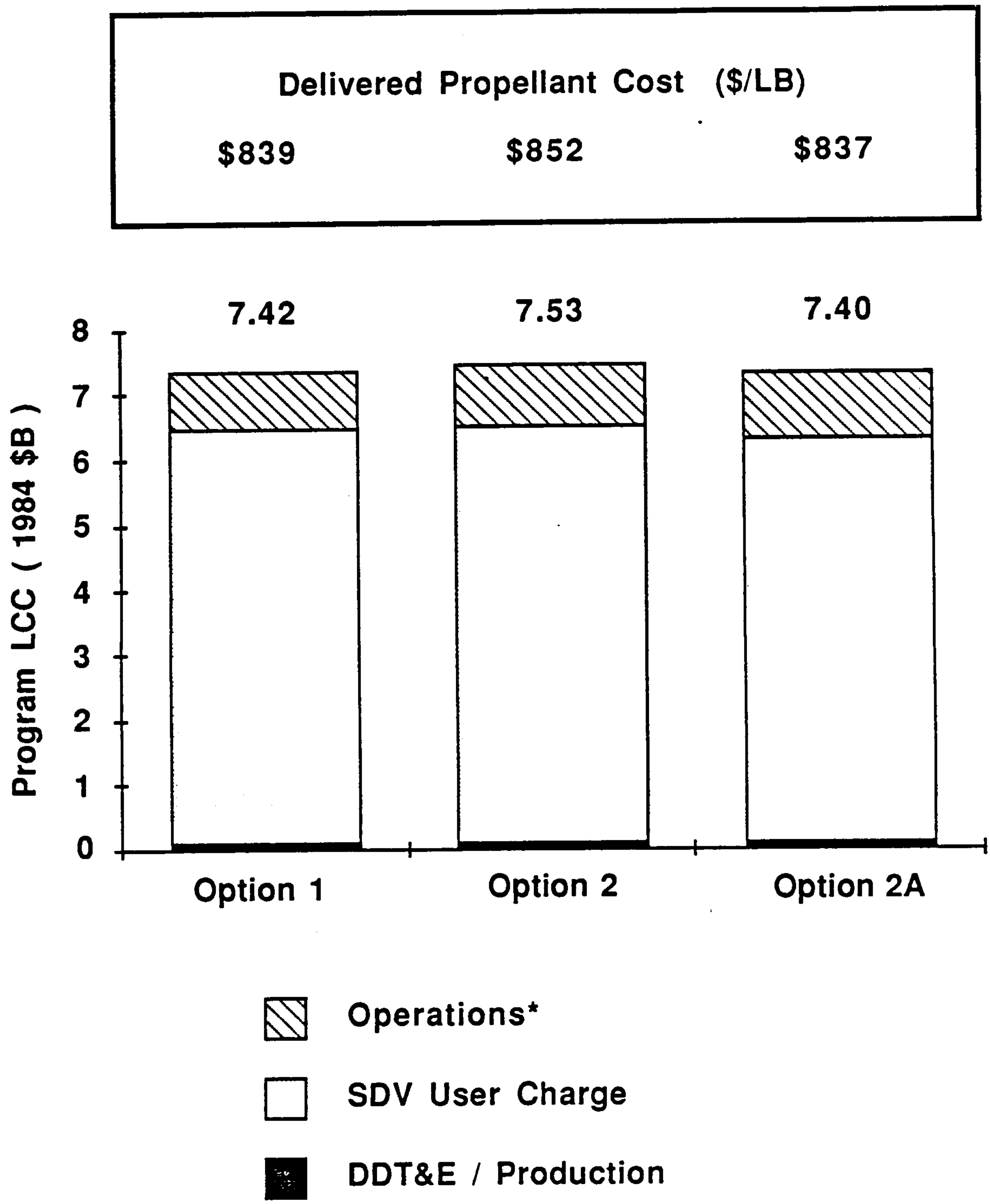
Each option has technical benefits. (A more detailed discussion of this subject appears in Volume I, Section 2.2.)

- The Option 1 location on the aft bulkhead minimizes the length of the umbilical needed to allow propellant loading. As this equipment (propellant lines and associated valving) is part of the expendable ASE hardware, lowering its cost helps lower total operations cost. The aft location also lessens the propellant transfer distances involved in SDV scavenging.
- The Option 2 location in the forward section of the P/L module (with a portion of its volume in the nose cone section) minimizes the impact of SDV tanking on the volume capacity of the SDV. By minimizing this impact, greater payload manifesting flexibility is obtained, e.g., the opportunity of lowering the SDV users charge assessed to SDV tanking by taking advantage of excess SDV lift capability.
- Option 2A exhibits all the benefits of Option 2 plus the added capability of propelling itself from LEO to an orbit near the vicinity of the SS. This capability adds operational flexibility as Option 2A can be used on SDV missions which are not going to an orbit in the vicinity of the SS.

Figure 6.1-1 shows a comparison of the total LCC for each option. The LCC option estimates are within 2% of each other. Operations cost accounts for 99% of the total LCC, while 87% of operations cost is the SDV users charge required to transport the propellant tanks.

6.2 SDV Tanker Scavenging Feasibility

Previous results of this study identified that STS scavenging could obtain up to 50% of its delivered propellant from STS residual propellant. It is anticipated for SDV scavenging that the scavenged propellant will amount to



* SDV User Charge Has Been Separated From Operations Cost

Figure 6.1-1 LCC Comparison - SDV Tanker Options only 10% of the total delivered propellant. However, even this amount lowers total LCC as it affects the major cost driver, the SDV users charge. SDV scavenging will require modifications to the SDV P/L module and propulsion/avionics (P/A) module. In addition, the technical feasibility of scavenging propellant to a forward mounted tank set needs to be assessed. Figure 6.2-1 compares the total LCC of SDV tanker Option 2 with and without scavenging. SDV scavenging achieves a cost saving by reducing the SDV users charge assessed to the propellant delivery system. The system's gross lift off weight (GLOW) is reduced by the weight of the scavenged propellant. This cost savings is balanced against the cost increase of adding the PS subsystem. Therefore, SDV tanking plus SDV scavenging results in a lower LCC and delivered propellant cost per pound.

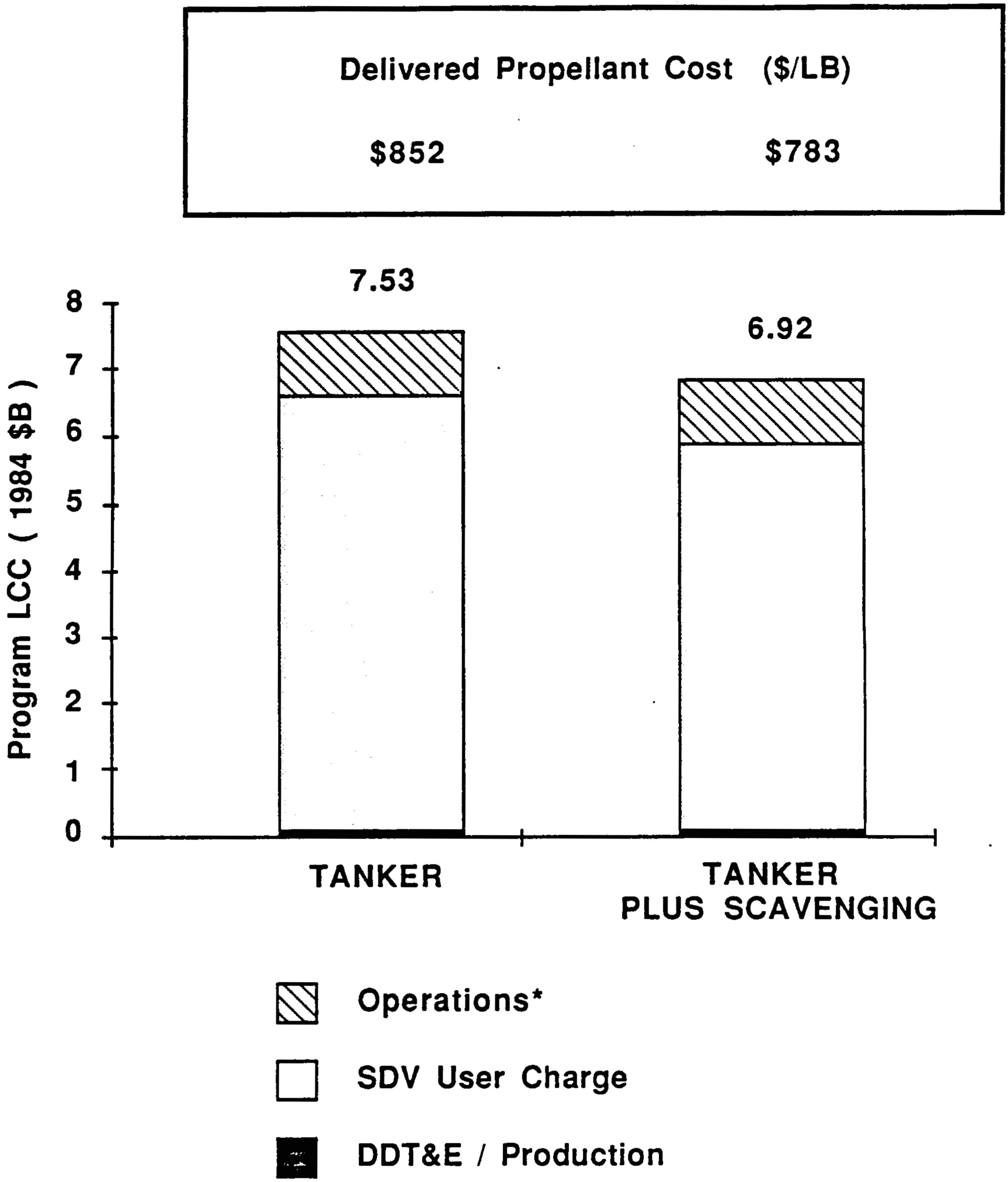
6.3 Expendable Hardware Cost Economics

The STS download capability may be a constraining parameter in returning the reusable STS scavenging tank sets. This problem would be exacerbated by the inclusion of the return requirement for SDV tank sets which are larger than the STS scavenging tank sets. With this in mind, the cost economies of expendable SDV tanker hardware was examined. The trade study compares the cost of building a new set of SDV tanker vessels for each SDV tanker mission against the cost of the reusable hardware described above. Figure 6.3-1 compares the total LCC of SDV tanker Option 2 with expendable hardware, and the SDV tanker Option using reusable hardware.

The LCC cost estimates of a propellant delivery system with reusable hardware or expendable hardware are essentially the same. Factors other than cost (e.g., STS download constraint and operational flexibility) will drive the ultimate selection.

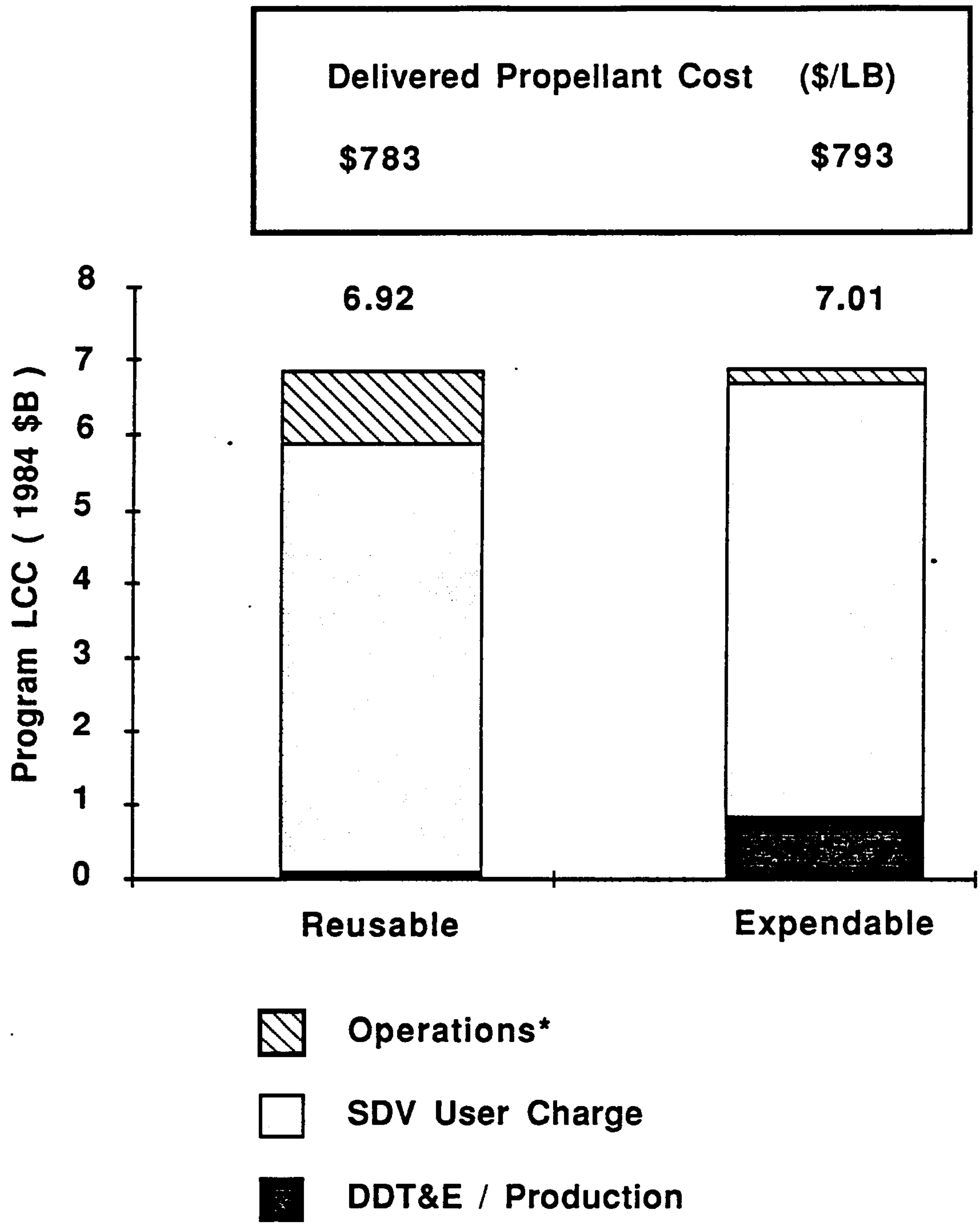
6.4 Combined SDV and STS Propellant Delivery Programs

An examination of the delivered propellant cost per pound, for all the SDV tanker options previously addressed, shows them to be within 10% of each other. The lack of a large cost differential is to be expected given the dominance of the transportation cost estimates in the total LCC. Since the STS scavenging configuration is free of this burden, it offers the lowest cost per pound for delivered propellant. The STS scavenging constraint is its delivery limit of approximately 2.0 mlb, which is only 23% of the 8.64 mlb of propellant required. The combination of these two programs (STS scavenging and SDV tanking) results in greater operational flexibility and the lowest LCC of any propellant delivery system examined to date. Figure 6.4-1 compares the total LCC of SDV Option 2 with SDV scavenging against the same propellant



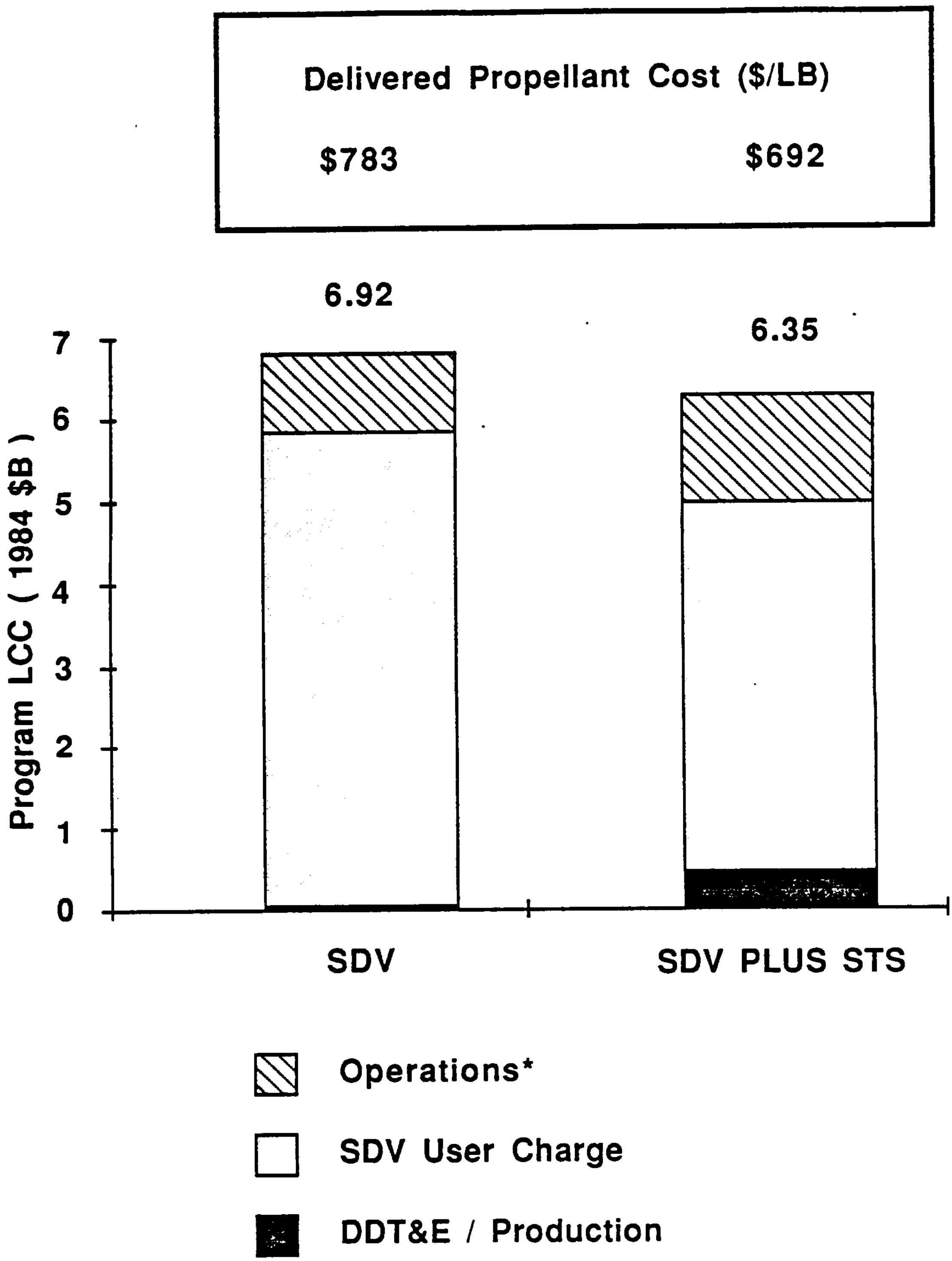
* SDV User Charge Has Been Separated From Operations Cost

Figure 6.2-1 LCC Comparison - SDV Scavenging



* SDV User Charge Has Been Separated From Operations Cost

Figure 6.3-1 LCC Comparison - Expendabale Hardware



* SDV User Charge Has Been Separated From Operations Cost

Figure 6.4-1 LCC Comparison - Combined SDV & STS delivery program combined with STS scavenging. The addition of STS scavenging allows a reduction in the number of SDV tanker flights needed to deliver the required 8.64 mlb propellant. This operations cost saving overcomes the additional cost of acquiring both systems: the delivered propellant cost per pound is reduced to $692; the total LCC is reduced by 8% when compared to the SDV tanking propellant systems alone.

6.5 Program Cost Sensitivities

Since the SDV transportation cost has been identified as the major cost driver of a propellant delivery system, it is apparent that the many factors affecting the SDV transportation cost can significantly drive the overall program cost. Two factors that affect the transportation cost in different but related manners are SDV CPF and SDV lift capability. The SDV user charge is based on both the SDV CPF and the SDV lift capability. Also, the SDV load factor can be viewed as either artificially decreasing the SDV CPF or increasing the SDV lift capability. Figure 6.5-1 shows how changes in the SDV lift capability and the SDV CPF affect the delivered propellant cost per pound. Each change is shown independently. The upper horizontal axis demonstrates how SDV performance affects delivered propellant cost per pound, while the lower horizontal axis demonstrates how SDV CPF affects delivered propellant cost per pound.

In Figure 6.5-1 the baseline delivered propellant cost per pound is $852. As SDV capability (performance) varies $\pm$ 50%, the delivered propellant cost per pound varies from a high of $1,600 to a low of $610 per pound.

Also, as the SDV CPF varies $\pm$ 50%, the delivered propellant CPF varies linearly from $490 to $1225 per pound.

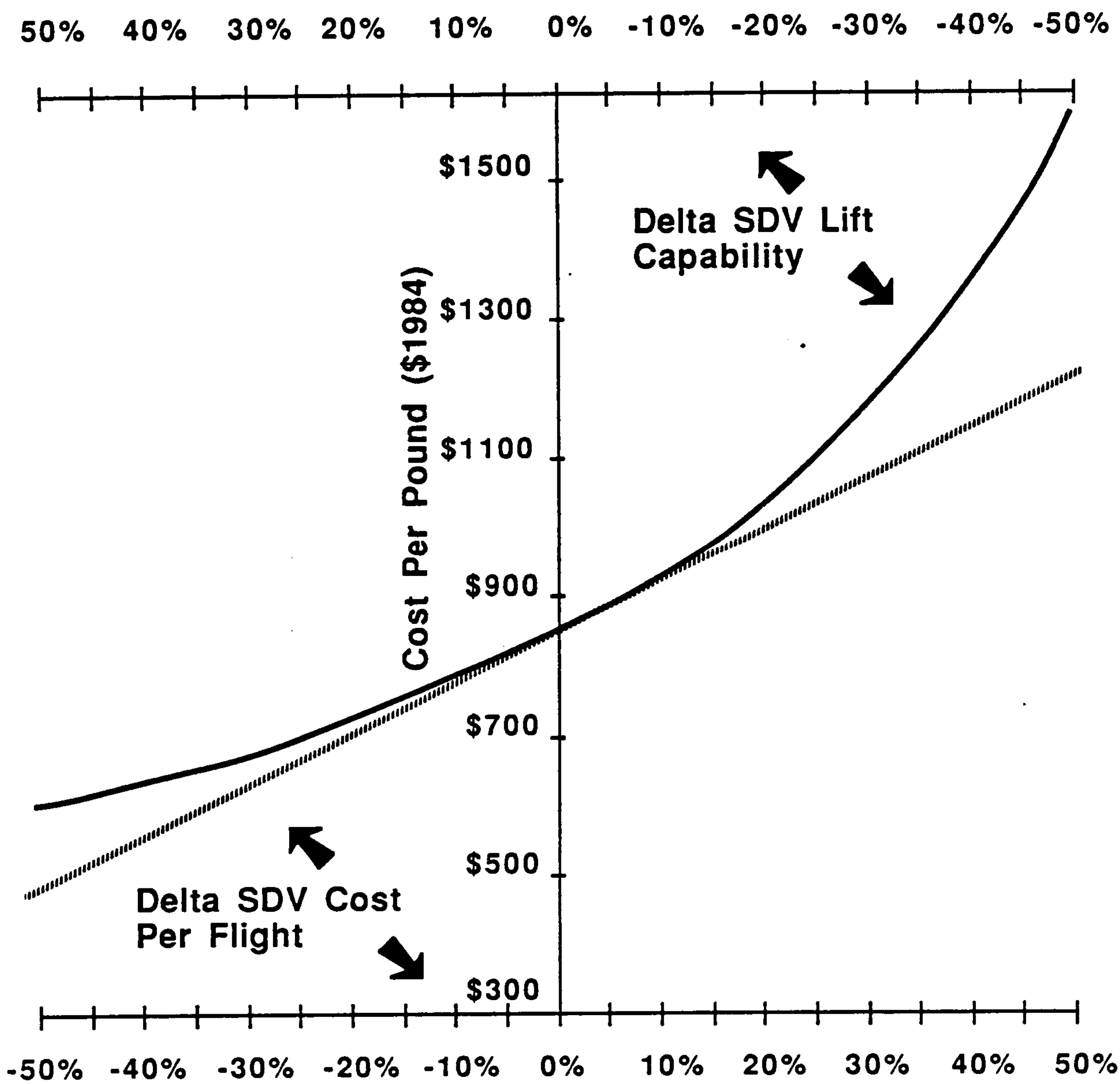


FIGURE 6.5-1 Propellant Cost Per Pound Sensitivity to SDV Cost Per Flight and Lift Capability

7.0 CONCLUSIONS AND OBSERVATIONS

Although STS PS offers propellant delivery at the lowest cost per pound, its capacity is only 25% of the anticipated demand.

SDV tanking delivers propellant at a lower cost per pound than STS tanking. When demand exceeds the capability of STS propellant scavenging, the SDV tanking can provide an economical method of delivering propellant. The combination of both programs--SDV tanking and STS PS--provide the lowest LCC for delivered propellant in excess of 14 klb/year. The availability of both programs provide greater operational flexibility. With the transportation cost as the major cost driver, and the operations cost dominating the total LCC, the large changes in DDT&E and production costs will minimally impact the delivered propellant cost per pound. Thus, different versions of SDV tanking can be developed concurrently to provide greater operational flexibility.

Tank sets can be returned and reused when a return opportunity is available, or they can be treated as expendable when a return is not possible or operationally desirable. An additional advantage of SDV tanking is that propellant can be delivered on an unmanned cargo vehicle as a regular payload. Therefore, the use of the excess SDV lift capability on regularly scheduled missions can be utilized to lower the total LCC. The optimum propellant delivery system is one which minimally affects normal mission operations while taking maximum advantage of mission performance parameters.

REFERENCES

1. "Using OMV to Maneuver OTV in Vicinity of the Space Station," NASA-MSFC Memo PF14(84-138) from R. L. Klan/PF14 to Donald Saxton/PS03, dated December 19, 1984.

2. "Space Transportation System (STS) Propellant Scavenging System Study," Final Report, Vol. II, NASA Contract NAS9-16994, Rockwell International, January 1985.

3. "Advanced Space Transportation System Ground Operations (ASTS/GO) Study Extension," Final Report, Vol II, NASA Contract NAS10-10572, Martin Marietta Corporation, May 1985.

4. "STS Propellant Scavenging Systems Study," Final Report Vol II, NASA Contract NAS8-35614, Martin Marietta Corporation, February 1985.

5. "Dedicated ACC Program Cost and Work Breakdown Structure/Dictionary," Final Report, Vol. II, NASA Contract NAS8-35564, Martin Marietta Corporation, May 1985.

APPENDIX A

PROPELLANT SCAVENGING WBS DICTIONARY

CONTENTS

FIGURES

1.0 INTRODUCTION

To establish consistency and visibility within the Propellant Scavenging Study, a preliminary work breakdown structure (WBS) and dictionary were developed. The dictionary defines the terms to be used with the WBS so that a clear understanding of the content of the hardware, function, and cost elements may be established.

The total WBS matrix (Figure 1) is a two-dimensional structure which shows the relationship of the hardware elements dimension to the phase and function dimension.

Although the dimension of time cannot be shown graphically, it must be considered. Since each cost entry varies with time, it is necessary to know these cost values by year for budget planning and approval as well as to establish cost streams for discounting purposes in the economic analysis.

While the multiple dimensional approach may appear complex, it provides benefits which outweigh any concerns. This structural interrelationship provides the capability to view and analyze the PS costs from a number of different financial and management aspects. Costs may be summed by hardware groupings, phases, functions, etc. The WBS may be used in a number of dimensional or single listing format applications.

PHASE AND FUNCTION DIMENSION																									
	PROJECT	PROPELLANT DELIVERY SYSTEM 1.00																							
	PHASE	R&T	DDT&E (1.2)											PRODUCTION (1.3)					OPERATIONS (1.4)						
	FUNCTION		PGM MGMT	ENGINEERING			MANUFACTURING			TEST		OPERATIONS		PGM MGMT	ENGINEERING		MANUFACTURING		OPERATIONS SUPPORT					LAUNCH SUPPORT	
		(1.1)	(1.2.1)	(1.2.2)			(1.2.3)			(1.2.4)		(1.2.5)		(1.3.1)	(1.3.2)		(1.3.3)		(1.4.1)					(1.4.2)	
	SUBFUNCTION			SYS ENG & INTEG	DESIGN & DEVELOP	SOFTWARE ENGINEERING	TOOLING &STE	GROUND TEST HDW	FLT TEST HDW	SYS TEST OPS	TEST FIXTURES	OPERATIONS SUPPORT	LAUNCH SUPPORT		SYS ENG & INTEG	DESIGN & DEVELOPMENT	TOOLING & STE	REUSABLE FLIGHT HDW	PROGRAM SUPPORT	REUSABLE HDW SPARES PROCUREMENT	EXPENDABLE HDW PROCUREMENT	FLIGHT OPS	NETWORK SUPPORT	LAUNCH OPERATIONS	PROPELLANT OPERATIONS
HARDWARE/SOFTWARE ELEMENT		WBS COLUMN NUMBER																							
WBS TITLE	WBS ROW #	1.1	1.2.1	1.2.2.1	1.2.2.2	1.2.2.3	1.2.3.1	1.2.3.2	1.2.3.3	1.2.4.1	1.2.4.2	1.2.5.1	1.2.5.2	1.3.1	1.3.2.1	1.3.2.2	1.3.3.1	1.3.3.2	1.4.1.1	1.4.1.2	1.4.1.3	1.4.1.4	1.4.1.5	1.4.2.1	1.4.2.2
PROPELLANT DELIVERY SYSTEM	1.0.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PDS INTEGRATED SYSTEM	1.1.0		X	X						X		X	X	X	X				X	X		X	X	X	
TANKER/SCAVENGING VESSELS	1.2.0	X	X	X	X		X	X	X	X	X			X	X	X	X	X	X	X	X				X
INTEGRATED SYSTEM	1.2.1		X	X	X		X	X	X	X	X			X	X		X	X	X	X	X				
STRUCTURES	1.2.2				X											X		X		X					
PROPELLANT TANKS	1.2.3				X											X		X		X					
PIPING & VALVING	1.2.4				X											X		X		X					
AVIONICS	1.2.5				X											X		X		X					
ELECTRICAL POWER	1.2.6				X											X		X		X					
TPS	1.2.7				X											X		X		X					
PROPULSION SYSTEM	1.2.8				X											X		X		X					
MAIN ENGINES	1.2.9				X											X		X		X					
GSE &ASE	1.2.10				X											X		X		X	X				
SDV	1.3.0	X	X	X	X	X	X	X	X	X	X									X	X	X	X	X	X
INTEGRATED SYSTEM	1.3.1		X	X			X	X	X	X	X									X	X	X	X	X	
STS	1.4.0	X	X	X	X	X	X	X	X	X	X									X	X	X	X	X	X
INTEGRATED SYSTEM	1.4.1		X	X			X	X	X	X	X									X	X	X	X	X	
OMV	1.5.0	X	X	X	X	X	X	X	X	X	X									X	X	X			X
INTEGRATED SYSTEM	1.5.1		X	X			X	X	X	X	X									X	X	X			

FIGURE 1. PROPELLANT DELIVERY SYSTEM WBS MATRIX FORMAT

2.0 DICTIONARY ORGANIZATION

The Propellant Scavenging dictionary is divided into:

1) A graphic display of the two-dimensional WBS matrix (Figure 1);
2) The hardware element dimension WBS (Figure 2) and the definition of terms; and
3) The phase and function dimensions WBS phase (Figures 3, 4, 5 and 6) and the definitions of terms.

A numerical coding system coordinates the rows of the hardware element dimension to the columns of the phase and function dimension such that all matrix locations are identifiable by WBS number.

In Figure 1, each "X" represents a matrix position corresponding to an identifiable task that must be completed for PS. Each mark "X" also identifies a cost which will occur and must be accounted for.

3.0 HARDWARE ELEMENTS DIMENSION

The hardware elements dimension contains all of currently defined PS hardware elements broken out into project and system/subsystem levels. Inherent in this dimension is the capability for further expansion to lower levels, e.g., assemblies, subassemblies, components. This capability is limited only by the realism of the requirements. A typical hardware element WBS is shown in Figure 2. Definitions of the individual elements are contained in the following pages.

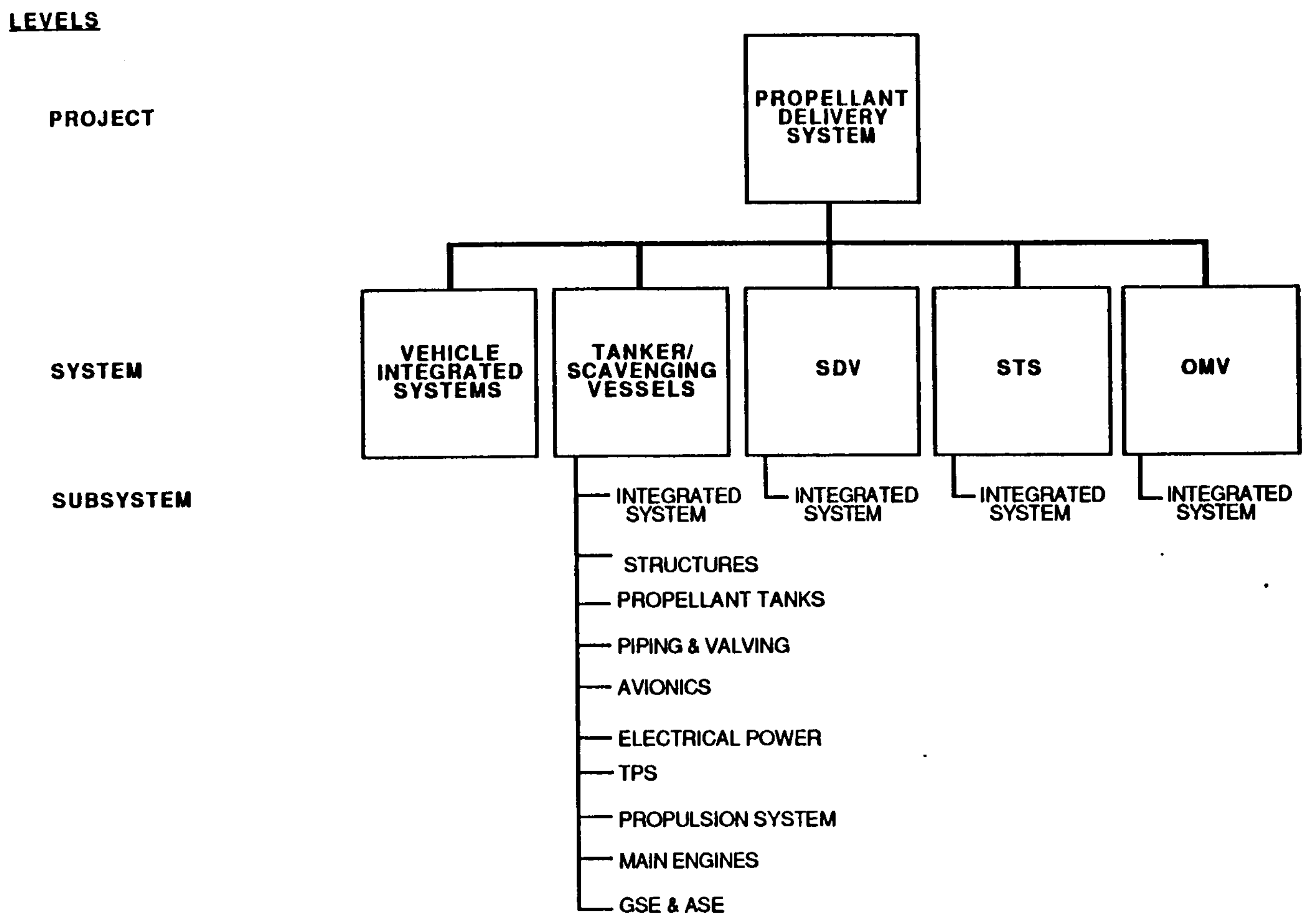


FIGURE 2. HARDWARE ELEMENT WBS - HARDWARE ELEMENT DIMENSION

4.0 DEFINITIONS OF HARDWARE ELEMENTS

1.0.0 PROPELLANT DELIVERY SYSTEM

This hardware element is a summary of all efforts and materials required for research and technology (R&T), design, development, production, and operations of the propellant delivery system. This item includes those elements which are combined to provide a total system:

1.1.0 Vehicle Integrated Systems;

1.2.0 Tanker/Scavenging Vessels;

1.3.0 SDV;

1.4.0 STS;

1.5.0 OMV.

1.1.0 Vehicle Integrated System

This hardware element contains the hardware related efforts and materials required for R&T, design, development, production, and operations of the total vehicle which cannot be allocated to individual hardware elements below the vehicle level. This phase includes elements associated with the integration, test, systems engineering, and management of the total launch vehicle.

1.2.0 Tanker/Scavenging Vessels
1.3.0 SDV
1.4.0 STS
1.5.0 OMV

This hardware element sums all the efforts and materials required for R&T, design, development, production, and operations of the major hardware categories. This phase includes all subsystems: Integrated Systems, Structures, Propellant Tanks, Piping and Valving, Avionics, Electrical Power, TPS, Propulsion System, Main Engines, GSE, and ASE.

1.2.1 Integrated Systems

1.3.1 " "

1.4.1 " "

1.5.1 " "

This hardware element contains the hardware related efforts and materials required for R&T, design, development, production, and operations of the total hardware category which cannot be allocated to individual hardware elements below the hardware category level. This phase includes elements associated with integration, test, systems engineering, and program management of the total hardware category.

1.2.2 Structures

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of the structures subsystem. This phase includes the frame or body structure, stabilizers, docking adapter, fins, fairings, Intertank (I/T), forward and aft skirts, aerodynamic surfaces, tunnels, thrust structure, heat shield, and other tank supports.

1.2.3 Propellant Tanks

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of the propellant tanks subsystem, including the LO2 and LH2 tank structures and tank mounts. It also includes the propellant utilization and management equipment. e.g., channels, screens, perforated plates, standpipes and nozzles and attachment hardware.

1.2.4 Piping and Valving

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of the piping and valving subsystem. This phase includes the propellant supply system elements, e.g., lines, valves, regulators, controls, and the tank venting system. Piping and valving dedicated to the propulsion system are not included (see propulsion system).

1.2.5 Avionics

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of the avionics subsystem. This element includes guidance, navigation and control, data management, flight instrumentation, communications and air traffic control and displays and controls. Typical hardware utilized by this subsystem are: computer complex, recorder and storage units, data bus interface, inertial measurement unit, rate gyro package, signal conditioner, caution and warning, measuring equipment, antenna system, tracking and command, telemetry, flight sensors, and switching networks.

1.2.6 Electrical Power

This hardware element sums all efforts and materials required for research and technology, design, development, production, and operations of the power system. This element includes the electrical and/or hydraulic power for utilization by all vehicle subsystems. Typical hardware contained in this subsystem are generators, batteries, auxiliary power generators, hydraulic pumps, power converters, power distributors, hydraulic lines, valves, cables and wiring, power conditioners, and lights.

1.2.7 TPS

This hardware element sums all efforts and materials required for R&T, design, development, production and operations of the TPS subsystem. This element includes the MLI and SLA insulation for the propellant tanks along with the thermal control for the propellant lines, the electrical subsystem and the instrumentation.

1.2.8 Propulsion System

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of the propulsion subsystem. This element includes the propellant feed system elements between the engine interface and the propellant tankage interface, including such items as lines, valves, regulators, controls, tank venting systems, pressurization system, engine pneumatic system, and other engine accessories. Also included are the OMS and RCS tanks, feed system and engines. The main rocket engines are not included (see Engines).

1.2.9 Main Engines

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of the engine subsystem. This element contains the primary rocket engine only.

1.2.10 GSE & ASE

This hardware element sums all efforts and materials required for R&T, design, development, production, and operations of ground support equipment and airborne support equipment. GSE includes those hardware items used to perform ground tests on the system and/or subsystem items and those used during the operational phase (spares). ASE includes those hardware items required to link with and separate from the SDV payload bay. Included are such items as structural, mechanical equipment, fluid systems, electrical, and avionics equipment that provide interfaces while the tanks are in the payload bay and while it is entering or leaving it during a mission.

5.0 PHASE AND FUNCTION DIMENSION

The phase dimension is divided into four major phases: R&T, DDT&E, production, and operations. The R&T phase is not subdivided and includes top level estimates of the efforts and materials required to establish new technology. The remaining phases are subsequently subdivided into subfunctions, e.g., systems engineering and integration (SE&I), design and development, tooling, flight hardware, and program support. An illustration of a typical WBS for each phase is shown in Figures 3 through 6. Definitions of the individual elements are contained in the following pages.

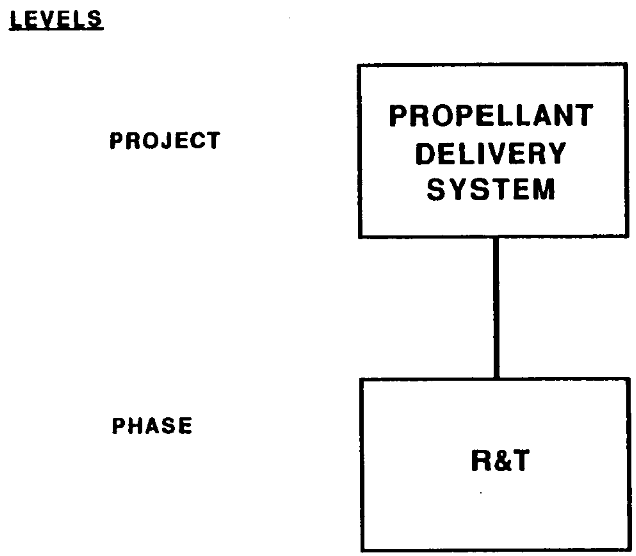


FIGURE 3. RESEARCH & TECHNOLOGY PHASE

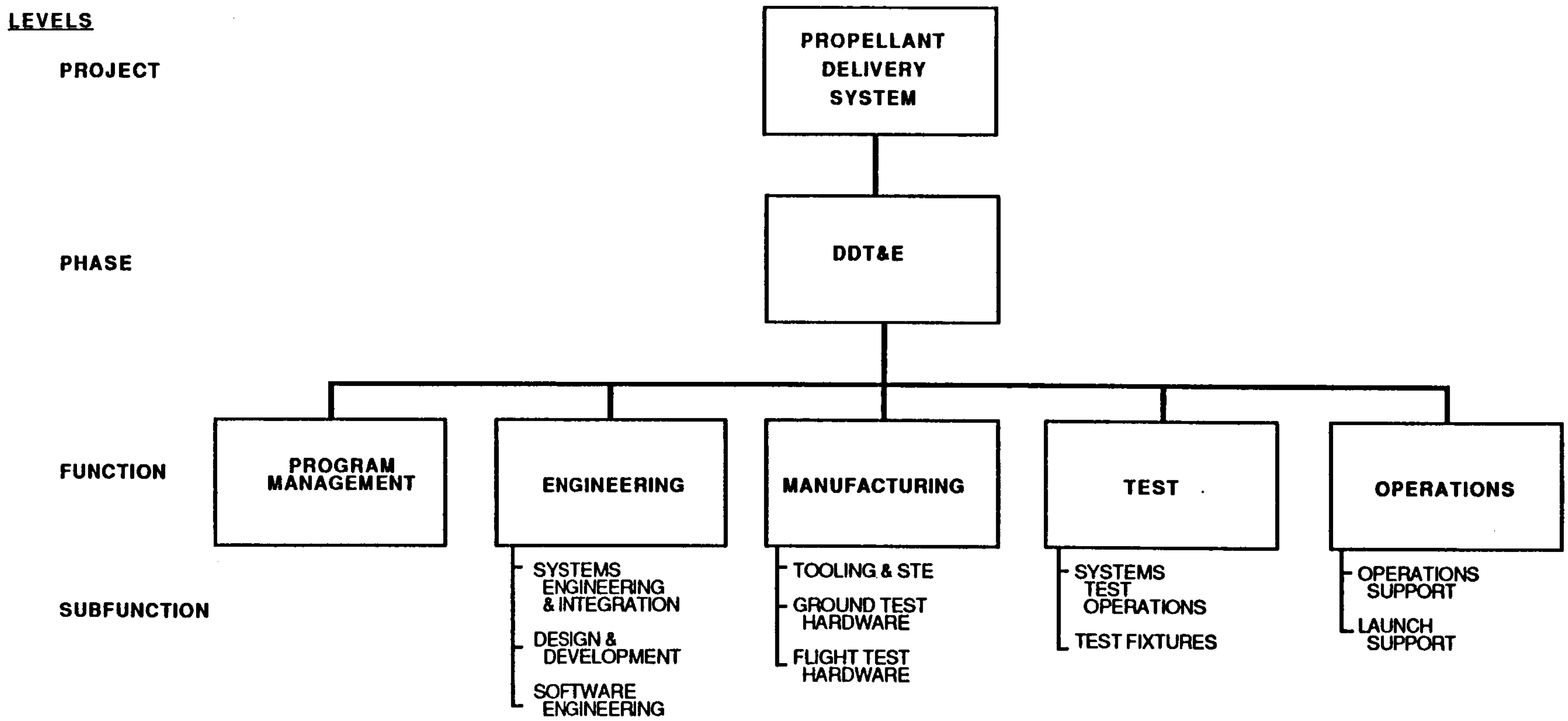


FIGURE 4. DESIGN, DEVELOPMENT, TEST, & EVALUATION (DDT&E) WBS PHASE & FUNCTION DIMENSION

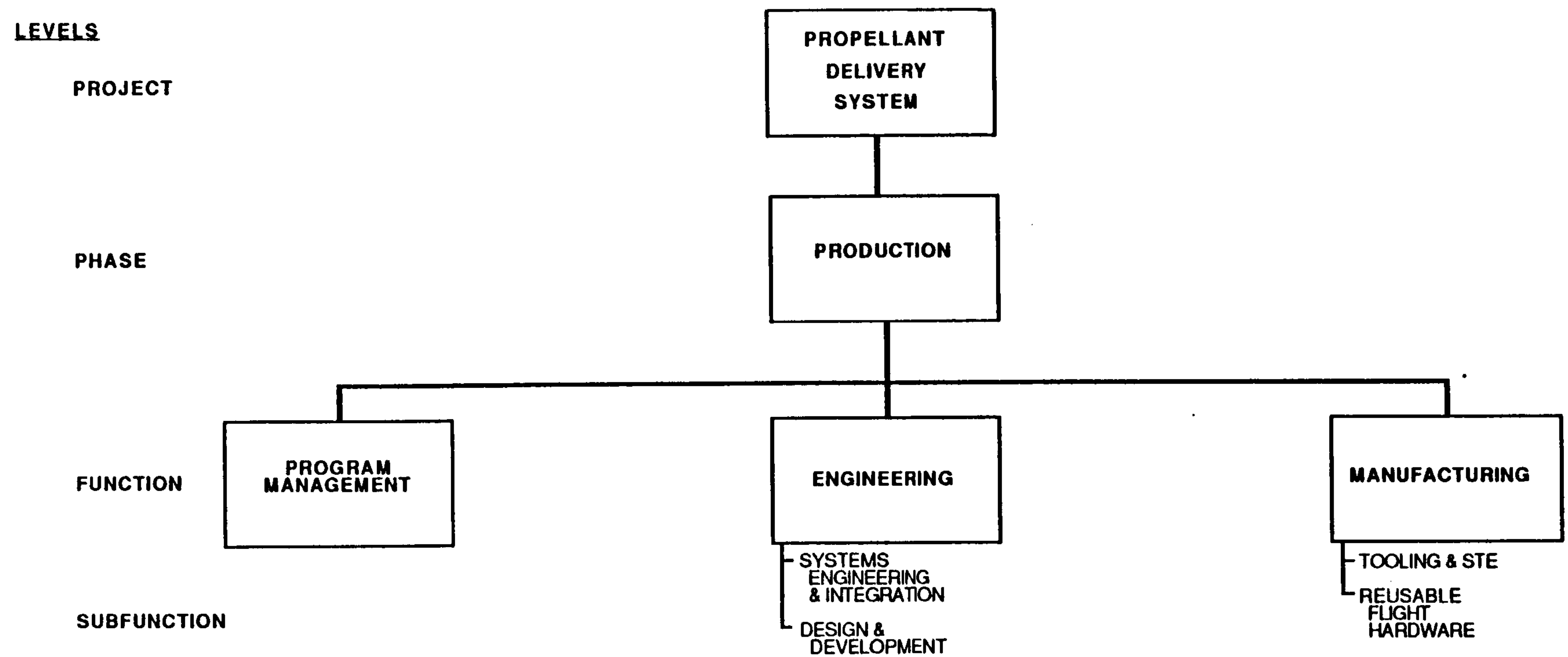


FIGURE 5. PRODUCTION WBS PHASE & FUNCTION DIMENSION

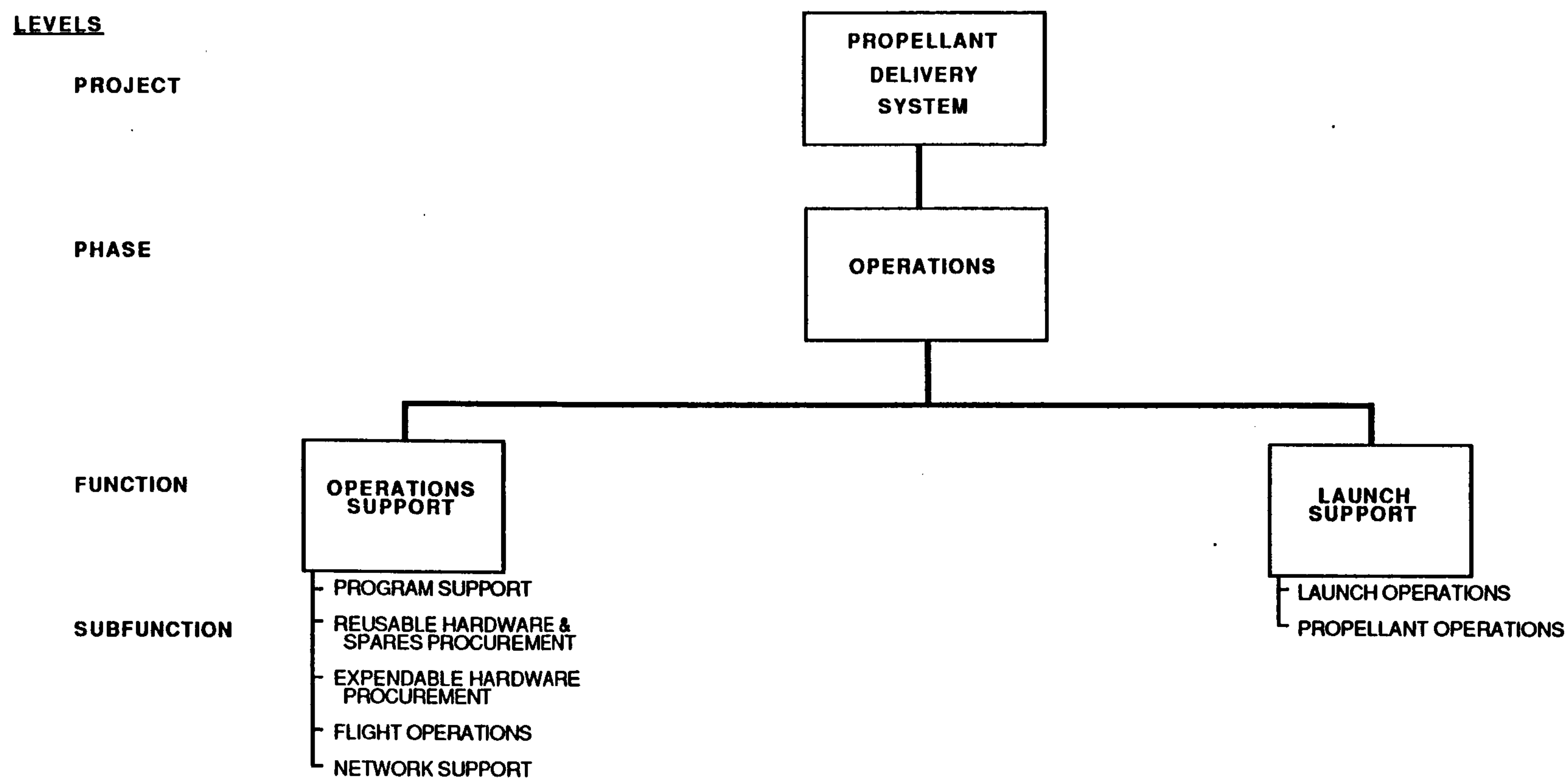


FIGURE 6. OPERATIONS WBS PHASE AND FUNCTION DIMENSION

6.0 DEFINITIONS OF PHASES AND FUNCTIONS

1.0.0.0 Propellant Delivery System

This element sums all the efforts and materials required for the R&T, development, production, and operations of the total propellant delivery program.

1.1.0.0 R&T - R&T Phase

This phase includes all efforts and materials required to advance the state-of-the-art in selected technologies. Areas of emphasis will include, but are not limited to, the following:

Manufacturing;

TPS;

Composite Materials;

Hardware Recovery.

1.2.0.0 DDT&E - DDT&E Phase

This phase encompasses those tasks associated with the DDT&E phase of the vehicle and with the requirement for demonstrating the vehicle's performance capabilities.

1.2.1.0 Program Management;

1.2.2.0 Engineering;

1.2.3.0 Manufacturing;

1.2.4.0 Test;

1.2.5.0 Operations.

Specifically, it includes: the mission analysis and requirements definition; the mission and support hardware functional definition and design specification; design support; test hardware manufacture; functional, qualification, and flight test effort. Also included are: special test equipment and development tooling; mission control and/or launch site activation (if required); logistics; training (that is not covered in operations); developmental spares; and other program peculiar costs not associated with repetitive production.

1.2.1.0 Program Management - DDT&E Phase

This DDT&E element includes all efforts and materials required for management and fundamental direction to ensure that a quality product is produced and delivered on schedule and within budget. Specific lower level items that are included are:

Program Administration;

Program Planning and Control;

Contracts Administration;

Engineering Management;

Manufacturing Management;

Support Management;

Quality Assurance Management;

Configuration Management

Data Management.

These items sum all efforts required to provide direction and control of the development of the system, including planning, organizing, directing, coordination, and controlling the project to ensure that overall project objectives are accomplished.

1.2.2.0 Engineering - DDT&E Phase

This DDT&E element includes all efforts and materials associated with analysis, design, development, evaluation, and redesign for specified hardware element items. This element is subdivided into the following lower elements:

1.2.2.1 Systems Engineering and Integration;

1.2.2.2 Design and Development Engineering;

1.2.2.3 Software Engineering.

1.2.2.1 Systems Engineering and Integration - DDT&E Phase

This DDT&E element includes the engineering efforts related to the establishment of a technical baseline for a system by generation of system configuration parameters, criteria, and requirements. Specifically included are:

Engineering Analysis and Systems Integration;

Human and Value Engineering;

Logistics and Training;

Safety, Reliability, Maintainability, Quality Assurance Requirements.

1.2.2.2 Design and Development Engineering - DDT&E Phase

This DDT&E element includes all efforts associated with analysis, design, development, evaluation, and redesign necessary to translate a performance specification into a design. Specifically included are: the preparation of specification and fabrication drawings, parts lists, wiring diagrams, technical coordination between engineering and manufacturing, vendor coordination, data reduction, and engineering related report preparation. This element can be further subdivided into the following:

Structures;

Mechanical;

Electrical;

Propulsion;

Aerodynamics.

1.2.2.3 Software Engineering - DDT&E Phase

This DDT&E element includes the cost of the design, development, production, checkout, maintenance, and delivery of computer software. Included are ground test, onboard, and mission/flight software.

1.2.3.0 Manufacturing - DDT&E Phase

This DDT&E element includes the efforts and materials required to produce the various items of test hardware required by the program, including inspection assembly, and checkout of tools, parts, material, subassemblies, and assemblies. The hardware testing is accomplished under system test operations. The test articles considered under this element include: development models, engineering models, design verification units, qualifications models, structural test units, thermal models, mechanical models, and prototypes. Also included are the design and construction of DDT&E manufacturing facilities. This element is further subdivided into the following:

1.2.3.1 Tooling and STE;

1.2.3.2 Ground Test Hardware;

1.2.3.3 Flight Test Hardware.

1.2.3.1 Tooling and STE - DDT&E Phase

This DDT&E element includes all efforts and materials associated with the planning, design, fabrication, assembly, inspection, installation, modification, maintenance, and rework of all tools, dies, jigs, fixtures, gauges, handling equipment, work platforms, and special test equipment (STE) necessary for manufacture of the DDT&E vehicles.

1.2.3.2 Ground Test Hardware - DDT&E Phase

This DDT&E element encompasses all efforts and materials required to produce the various items of required ground test hardware, including processing, subassembly, final assembly, reworking, and modification and installation of parts and equipment. Ground test hardware includes such items as static and dynamic test models, thermal and (if required) firing test articles, and the qualification test unit. Also included are those costs chargeable to the acceptance testing, quality control program, and assembly as related to ground test hardware. In addition, the design and construction of manufacturing facilities for DDT&E vehicles are included.

1.2.3.3 Flight Test Hardware - DDT&E Phase

This DDT&E element encompasses all efforts and materials required to produce the various items of flight test hardware, including the same basic operations defined in WBS item number 1.2.3.2 (Ground Test Hardware).

1.2.4.0 Test - DDT&E Phase

This DDT&E element includes all efforts and materials required for qualifications, integration, and system/subsystem development tests, including the design and fabrication of test facilities and fixtures. This element is further subdivided into the following:

1.2.4.1 Systems Test Operations;

1.2.4.2 Test Fixtures.

1.2.4.1 Systems Test Operations - DDT&E Phase

This DDT&E element includes all efforts and materials required for assemblies, subsystems, and systems to determine operational characteristics and compatibility with the overall system and its intended operational/non-operational environment. Such tests include design feasibility tests, design, and integrated systems to verify whether they are unconditionally suitable for their intended use. These tests are conducted on hardware that has been produced, inspected, and assembled by established methods. Tests performed by two or more contractors to substantiate the feasibility compatibility are also included as well as test planning and scheduling, data reduction, and report preparation. Also, the design and construction of DDT&E test facilities are included.

1.2.4.2 Test Fixtures - DDT&E Phase

This DDT&E element includes all the efforts and materials required for the design and fabrication of the unique test fixtures required to support a given system/subsystem test.

1.2.5.0 Operations - DDT&E Phase

This DDT&E element encompasses all efforts and materials required to operate the hardware defined in the corresponding hardware elements during flight test operations, including the design, construction, and operation of the launch, mission, and recovery facilities required for DDT&E test flights. This element further subdivides into the following:

1.2.5.1 Operations Support;

1.2.5.2 Launch Support.

1.2.5.1 Operations Support - DDT&E Phase

This element encompasses all efforts and materials required to support the DDT&E flight test program, including operation of the mission control facilities and equipment. Also included is the mission control monitoring which provides the information required to control, direct, and evaluate the mission from prelaunch through recovery. Moreover, the design and construction of the DDT&E mission control facilities are included.

1.2.5.2 Launch Support - DDT&E Phase

This operations element includes all efforts and materials required to support launch and recovery operations during the DDT&E flight test program. Included are those efforts and materials associated with the receipt of the major hardware categories of the mission hardware. This element does not include payload integration. Included are sub-elements such as ground operations (e.g., recovery) and propellant operations. In addition, the design and construction of DDT&E launch and recovery facilities are included.

1.3.0.0 Production - Production Phase

This phase includes all efforts and materials required for the production of reusable flight hardware to meet the total operational requirements, e.g., the production of initial spares. However this phase excludes operational spares which are included under the operations phase. Specifically, this phase includes the following functions:

1.3.1.0 Program Management;

1.3.2.0 Engineering;

1.3.3.0 Manufacturing.

1.3.1.0 Program Management - Production Phase

This element encompasses all efforts and materials required to ensure fundamental direction, and to make decisions that ensure a quality product is produced and delivered on schedule and within budget. Specifically included are: program administration, program planning and control, contracts administration, engineering management, manufacturing management, project management, and documentation. This item sums all efforts required to provide direction and control of the production of the system, including the efforts required for planning, organizing, direction, coordination, and controlling the project to ensure that overall project objectives are accomplished. These efforts overlay the other functional categories and assure that they are properly integrated.

1.3.2.0 Engineering - Production Phase

This element includes those sustaining engineering efforts and materials necessary to facilitate production and to resolve day-to-day production problems, including:

1.3.2.1 Systems Engineering and Integration;

1.3.2.2 Design and Development Engineering.

1.3.2.1 Systems Engineering and Integration - Production Phase

This element includes the recurring engineering efforts related to the maintenance of a technical baseline for systems configuration parameters, criteria, and requirements. This baseline may include specifications, procedures, reports, technical evaluation, software, and interface definition. This phase also encompasses those efforts required to monitor the system during production to ensure that the hardware conforms to the baseline specifications.

1.3.2.2 Design and Development Engineering - Production Phase

This element includes all recurring efforts and materials associated with the sustaining engineering required during the production of reusable flight hardware and initial spares.

1.3.3.0 Manufacturing - Production Phase

This element includes all recurring efforts and materials associated with the production of reusable flight hardware, initial spares, tooling, and special test equipment (STE). Also included are the design and construction of additional manufacturing facilities during the production phase. This element includes:

1.3.3.1 Tooling and STE;

1.3.3.2 Reusable Flight Hardware.

1.3.3.1 Tooling and STE - Production Phase

This element includes the fabrication of production tooling and those sustaining efforts necessary to facilitate production and to resolve production problems involving tooling and STE. This element also includes the production and/or procurement of replacement parts and spares.

1.3.3.2 Reusable Flight Hardware - Production Phase

This element includes all efforts and materials required to produce production flight units. This item includes time expended on, or chargeable to, such operations as: fabrication processing, subassembly, final assembly, reworking, modification, and installation of parts and equipment (including Government furnished equipment). Included are those costs chargeable to acceptance testing, the quality control program, and assembly as related to flight units. Also included are the design and construction of additional manufacturing facilities required during the production phase.

1.4.0.0 Operations - Operations Phase

This phase includes those efforts and materials associated with the receipt of the stages, shrouds, etc., at the launch site and the processing, testing, and integration required to prepare for the launch and recovery of mission hardware. This phase also includes reusable hardware spares procurement to support hardware refurbishment and replenishment operations, expendable hardware and initial spares procurement, and GSE maintenance. Additional facilities required to meet updated mission requirements are also included. This element is subdivided into the following:

1.4.1.0 Operations Support;

1.4.2.0 Launch Support.

1.4.1.0 Operations Support - Operations Phase

This operations element includes the efforts and materials required to support the operational program, including the operations and program support of the mission control facilities and equipment. It also includes reusable hardware spares procurement to support hardware refurbishment and replenishment operations, expendable hardware procurement, and GSE Maintenance. This element is subdivided into the following:

1.4.1.1 Program Support;

1.4.1.2 Reusable Hardware and Spares Procurement;

1.4.1.3 Expendable Hardware Procurement;

1.4.1.4 Flight Operations;

1.4.1.5 Network Support.

1.4.1.1 Program Support - Operations

This operations element encompasses the efforts and materials required to support the operational program, e.g., the hardware/mission control center effort, and the associated contractor effort to support the operations phase of the program. Also included are: mission planning, mission control, sustaining engineering, program management activities (for hardware delivery in direct support of the program), and the indirect effort required to support the program or provide multi-program support which must be pro-rated to the program. Both civil service and support contractor effort at the hardware/mission control centers are included. This item includes such functions as:

Management Systems;

Operations and Maintenance of Computers and Terminals;

Systems Engineering Support Requirements;

Documents;

Flight Planning Support;

National Weather Service;

Sustaining Engineering.

Any additional mission control facility design and construction required in the operational phase are included here.

1.4.1.2 Reusable Hardware Spares Procurement - Operations Phase

This operations element includes all production, refurbishment, and spares costs of the reusable tanker/scavenging vessels in the operational phase of the program.

1.4.1.3 Expendable Hardware Procurement - Operations Phase

This operations element includes all the production and spares costs of the ASE flight hardware that is expended in the operational phase of the program.

1.4.1.4 Flight Operations - Operations Phase

This operations element includes all efforts and materials required to support the mission hardware after launch, including the following:

- o Mission control operations, simulator operations, software production facility, orbiter flight software and flight design.
- o Engineering support, e.g., flight systems lab, data processing system maintenance, avionics laboratory, mockups/trainers, simulator software support, and other engineering support functions.
- o Program management and support

1.4.1.5 Network Support - Operations Phase

This operations element includes the operations and maintenance of the NASCOM communication links.

1.4.2.0 Launch Support - Operations Phase

This operations element encompasses all the efforts and materials required for launch support, including those efforts and materials associated with the receipt of the major hardware elements at the launch site and the processing, testing, and integration required for preparation and launch of the mission hardware. This element does not include payload integration. In addition, this item covers the design and construction of operational launch/recovery facilities above those provided in the DDT&E phase. Further sub-elements are:

1.4.2.1 Launch Operations;

1.4.2.2 Propellant Operations.

1.4.2.1 Launch Operations - Operations Phase

This operations element includes all the effort and materials required for the receipt of the vehicle hardware at the launch site, and the processing, testing, and integration required to prepare for launching mission hardware. This effort includes the manpower associated with the:

- o Processing, testing, and integration of the flight hardware;
- o Operation and maintenance of launch-related GSE;
- o Offline ground systems activities (e.g., shops, labs,) required to support vehicle turnaround activities;
- o GSE sustaining engineering efforts to support the modification design and configuration control of all launch site related GSE;
- o Direct/indirect civil service efforts for program management of all prelaunch/launch site activities;
- o Direct/indirect contractor activities at the launch site, including a pro rata share of base support functions;
- o Production and inventory/control of launch site related GSE replenishment/refurbishment spares.

Any additional launch/recovery facilities and landing/recovery operations required for the operational phase are included in this event.

1.4.2.2 Propellant Operations - Operations Phase

This operations element encompasses all flight propellant costs at the launch site that support the operational phase of the program, e.g., fuel and oxidizers, pressurants, purging gases, and fluids. These costs reflect annual the base requirements in addition to the total flight requirements. Also included are any additional manufacturing facilities required above those provided in the DDT&E phase.

APPENDIX B

SDV TANKER - OPTION 2 COST ESTIMATES BY WBS

PROPELLANT DELIVERY SYSTEM LCC

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

144 PROPELLANT TANKING FLIGHTS

	RESEARCH & TECHNOLOGY COSTS	D D T & E COSTS	PRODUCTION COSTS	OPERATIONS COSTS	T O T A L COSTS
TANKER/SCAVENGING VESSELS	-	63.7	19.3	206.3	289.2
SDV	-	-	-	6472.6	6472.6
[illegible]S	-	-	-	701.7	701.7
OMV	-	-	-	69.8	69.8
TOTALS	0.0	63.7	19.3	7450.4	7533.3

PROPELLANT DELIVERY SYTEM LCC: 7533.3
SDV TANKER - OPTION 2

TANKER/SCAVENGING VESSEL

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

144 PROPELLANT TANKING FLIGHTS

	RESEARCH & TECHNOLOGY COSTS	D D T & E COSTS	PRODUCTION COSTS	OPERATIONS COSTS	T O T A L COSTS
INTEGRATED SYSTEMS	-	30.1	9.2	66.0	105.3
STRUCTURES	-	7.9	1.7	9.8	19.4
PROPELLANT TANKS	-	19.2	4.8	29.9	53.8
PIPING & VALVING	-	0.7	0.0	0.0	0.7
AVIONICS	-	3.2	1.2	0.5	4.9
ELECTRICAL POWER	-	0.2	0.1	5.4	5.7
TPS	-	0.1	0.4	-	0.5
PROPULSION SYSTEM	-	1.5	1.8	-	3.3
MAIN ENGINES	-	-	-	-	-
GSE &ASE	-	0.8	-	94.7	-
TANKER/SCAVENGING VESSEL TOTALS	0.0	63.7	19.3	206.3	289.2

TANKER/SCAVENGING VEHICLE LCC: 289.2
SDV TANKER - OPTION 2

HARDWARE ELEMENT SUMMARY: DDT&E

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

D D T & E

63.7

	PROGRAM MANAGEMENT	ENGINEERING			MANUFACTURING			TEST	OPERATIONS		
	5.5	30.9			23.4			3.9	0		
		SYS ENG & INTEG	DESIGN & DEVELMNT	SOFTWARE ENGINEER	TOOLING & STE	GND TEST HARDWARE	FLT TEST HARDWARE	SYS TEST OPER	TEST FIXTURE	OPER. SUPP.	LAUNCH SUPP.
TANKER/SCAVENGING VESSELS	5.5	8.8	22.1	0.0	8.5	9.2	5.7	3.3	0.6	0	-
INTEGRATED SYSTEMS	5.5	8.8	-	-	8.5	2.5	0.9	3.3	0.6	-	-
STRUCTURES	-	-	5.9	-	-	1.3	0.7	-	-	-	-
PROPELLANT TANKS	-	-	13.0	-	-	4.0	2.2	-	-	-	-
PIPING & VALVING	-	-	0.7	-	-	-	-	-	-	-	-
AVIONICS	-	-	1.3	-	-	1.4	0.5	-	-	-	-
ELECTRICAL POWER	-	-	0.2	-	-	-	-	-	-	-	-
TPS	-	-	0.1	-	-	-	-	-	-	-	-
PROPULSION SYSTEM	-	-	-	-	-	-	1.5	-	-	-	-
MAIN ENGINES	-	-	-	-	-	-	-	-	-	-	-
GSE & ASE	-	-	0.8	-	-	-	-	-	-	-	-

HARDWARE ELEMENT SUMMARY: PRODUCTION

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

	PROGRAM MANAGEMENT	ENGINEERING		MANUFACTURING	
PRODUCTION 19.3	0.4	0		18.9	
		SYSTEM ENGINEER AND INTEGRATION	DESIGN AND DEVELOPMENT	TOOLING AND STE	REUSABLE FLIGHT HARD
TANKER/SCAVENGING VESSELS	0.4	0	0	4.2	14.7
INTEGRATED SYSTEMS	0.4	-	-	4.2	4.6
STRUCTURES	-	-	-	-	1.7
PROPELLANT TANKS	-	-	-	-	4.8
PIPING & VALVING	-	-	-	-	-
AVIONICS	-	-	-	-	1.2
ELECTRICAL POWER	-	-	-	-	0.1
TPS	-	-	-	-	0.4
PROPULSION SYSTEM	-	-	-	-	1.8
MAIN ENGINES	-	-	-	-	-
GSE & ASE	-	-	-	-	-

HARDWARE ELEMENT SUMMARY: OPERATIONS

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

	OPERATIONS						
	206.3						
	OPERATIONS SUPPORT					LAUNCH SUPPORT	
	204.4					1.9	
	PROGRAM SUPPORT	REUS HARD & SPARES	EXPENDABLE HARD PROC	FLIGHT OPS	NETWORK SUPPORT	LAUNCH OPS	PROPELLANT OPS
TANKER/SCAVENGING VESSELS	0	45.6	94.7	64.1	0	0	1.9
INTEGRATED SYSTEMS	-	-	-	64.1	-	-	1.9
STRUCTURES	-	9.8	-	-	-	-	-
PROPELLANT TANKS	-	29.9	-	-	-	-	-
PIPING & VALVING	-	-	-	-	-	-	-
AVIONICS	-	0.5	-	-	-	-	-
ELECTRICAL POWER	-	5.4	-	-	-	-	-
TPS	-	-	-	-	-	-	-
PROPULSION SYSTEM	-	-	-	-	-	-	-
MAIN ENGINES	-	-	-	-	-	-	-
GSE & ASE	-	-	94.7	-	-	-	-

HARDWARE ELEMENT SUMMARY: OPERATIONS

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

O P E R A T I O N S

6472.6

	OPERATIONS SUPPORT					LAUNCH SUPPORT	
	0					6472.6	
	PROGRAM SUPPORT	REUS HARD & SPARES	EXPENDABLE HARD PROC	FLIGHT OPS	NETWORK SUPPORT	LAUNCH OPS	PROPELLANT OPS
SDV	0	0	0	0	0	6472.6	0
INTEGRATED SYSTEMS	-	-	-	-	-	6472.6	-

HARDWARE ELEMENT SUMMARY: OPERATIONS

DATE: WED, JUNE 10, 1987
MILLIONS OF 1984 DOLLARS

	OPERATIONS						
	701.7						
	OPERATIONS SUPPORT					LAUNCH SUPPORT	
	0					701.7	
	PROGRAM SUPPORT	REUS HARD & SPARES	EXPENDABLE HARD PROC	FLIGHT OPS	NETWORK SUPPORT	LAUNCH OPS	PROPELLANT OPS
	0	0	0	0	0	701.7	0
?ATED SYSTEMS	-	-	-	-	-	701.7	-

HARDWARE ELEMENT SUMMARY: OPERATIONS

DATE: WED, JUNE 10, 198
MILLIONS OF 1984 DOLLAR

	OPERATIONS 69.8						
	OPERATIONS SUPPORT 0					LAUNCH SUPPORT 69.8	
	PROGRAM SUPPORT	REUS HARD & SPARES	EXPENDABLE HARD PROC	FLIGHT OPS	NETWORK SUPPORT	LAUNCH OPS	PROPELLANT OPS
OMV	0	0	0	0	0	69.8	0
INTEGRATED SYSTEMS	-	-	-	-	-	69.8	-