

NASA-CR-192447

N95-15552

**SPACE TRANSFER VEHICLE
CONCEPTS AND REQUIREMENTS STUDY**

Phase I Final Report
Volume III, Book 2
WBS and Dictionary
D180-32040-2
April, 1991

D180-32040-3

DPD NUMBER-709
DR NUMBER-4 & 5
CONTRACT NAS8-37855

Submitted to
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ABSTRACT

This document describes the products and services to be developed, tested, produced, and operated for the Space Transfer Vehicle (STV) Program. The Work Breakdown Structure (WBS) and WBS Dictionary are program management tools used to catalog, account by task, and summarize work packages of a space system program. The products or services to be delivered or accomplished during the STV C/D phase are the primary focus of this work breakdown structure document.

KEY WORDS

Boeing Aerospace & Electronics (BA&E)
Correlated Cost and Performance Data
Cost Estimating
Crew Module (or Cabin)
Design, Development, Test, & Evaluation (DDT&E)
Equipment List
Element of Cost
Full-Scale Development (FSD)
Functional Element
Interface Element
Life Cycle Phase
Objective
Organization
Program Work Breakdown Structure (PWBS)
Software Computer Program Configuration Item (CPCI)
Space Transfer Vehicle (STV)
Project Task
Work Package

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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 vulcanizing
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

2-1.0 INTRODUCTION

The work breakdown structure (WBS) is a family tree subdivision of effort required to achieve an objective (e.g., program, project, and contract). For a program, which contains a series of contracts, the project WBS is developed by starting with the end objectives in the contract statement of work outlines, then successively dividing the objectives into manageable components (or work packages) in terms of size, duration (time period axis), and responsibility (normally referred to as systems, subsystems, components, tasks, subtasks, and work packages), which include all the necessary steps to achieve the end objective. It establishes the basic framework in which all effort required to meet the project objectives is identified and scheduled and, therefore, provides the logical structure for planning, estimating, and managing space program costs (reference NASA document NHB 9501.2B, February 1985 issue).

The specific formulation of the Lunar Transportation System (LTS) program and project work breakdown structure (PWBS) is developed by direction in the STV Concepts and Requirements Study contract statement of work, paragraph 5.4, entitled "Programmatics." Data requirement 5 of the study contract contains the definition of the levels and element titles for the STV work breakdown.

2-1.1 OBJECTIVES AND SCOPE

The Space Transfer Vehicle (STV) Concepts and Requirements Study is a NASA concept definition, phase A study contract. The study is structured to define a highly flexible space vehicle, capable of performing space transportation missions starting in this decade (late 1990s) and extending service beyond the year 2022 (the last Lunar Initiative mission is projected to be in the year 2026.) The multimission role of the STV system includes such tasks as lunar exploration cargo and personnel delivery, geosynchronous delivery, planetary unmanned delivery, low Earth orbit (LEO) free-flying platform reboost tasks, and other unique LEO space tug missions.

An optional node for future STV space operations is a growth version of the Space Station Freedom, starting in calendar year 1999. The Shuttle-C (conceptual design), the Advanced Launch System (ALS conceptual design)

family of heavy lift launch vehicles (HLLV), and the growth Titan IV (conceptual modification design) are defined by NASA-MSFC as Earth launch systems for interface definition and summary-level transportation program descriptions. The WBS development includes considerations for using the existing space transportation system (STS) and future STS derivatives (defined by NASA) as an optional Earth to orbit (ETO) launch vehicle for LEO crew and/or cargo delivery to the STV.

STV design reference mission (DRM) information, generated from Task 1 of the study and the resulting design reference scenarios (DRS), provide the operational background for this WBS development project. Mission capability is expanded by the requirement to carry manned crew modules to the lunar surface and high-energy orbits. Several crew module WBS item lists and descriptions have been formulated to establish hardware and interface definitions in the WBS dictionary. The ground-orbital and ground configurations require some unique WBS elements like a launch escape system.

Program planning is based on a phase B contract start date of April 1, 1994. Special focus is on full-scale development (phase C/D). The life cycle schedules are analyzed for several different advanced subsystems applications. A primary objective of the WBS dictionary development is to produce realistic cost and schedule estimates for each STV program phase and major configuration candidate after system trades are completed. The baseline or "reference" system cost estimate (used to select the best system candidates through life cycle cost (LCC) trade studies) is developed using the preliminary STV WBS dictionary contained in this document.

2-1.2 NASA WBS FORMAT GUIDELINES

NASA NHB 9501.2B and NHB 5601.1 handbooks are used as guidelines to develop the STV work breakdown structure and WBS dictionary. The NASA guidelines and study instructions of "The Next Manned Transportation System Cost and Programmatic" working group exercise (December 13, 1990) were also reviewed for ideas to incorporate into this document. The terminology used for hardware breakdown nomenclature is derived from the DR-5 instructions,

page 2, paragraph 13.4 (see appendix A for copy of contract data description sheet).

The definition of the WBS dictionary content is contained in paragraph 13.2 of the data requirement sheet. Prior OTV and OMV studies documentation has also been reviewed for format and description terminology to be included in the dictionary definitions, where appropriate.

2-1.3 PROGRAM LIFE CYCLE PHASES

One primary goal of the study is to develop C/D planning and estimates. The LCC estimate is also an equally important tool in making a selection of the most effective configuration concept. The STV WBS is developed as a single structure to be used throughout the program life cycle. The major life cycle phases for the STV program WBS are shown in Figure 2-1.3-1.

I. ACQUISITION PHASES:

Design, Development, Test & Evaluation (DDT&E)

Concept Definition (Phase A/B & Technology Demos)

Full Scale Development (Phase C/D)

Production (Phase E)

II. OPERATIONS & SUPPORT PHASE (Phase F)

III. PROGRAM PHASEOUT

Figure 2-1.3-1. Space Program Phases

The acquisition phase is broken down further into two major budgeting summary phases: (1) design, development, test, and evaluation (DDT&E) and (2) production. DDT&E is further broken down into concept definition (including advanced development demonstrations of new technology subsystem components) and full-scale development. Production is normally scheduled and estimated by Government fiscal year procurement lot buys.

Operations and support includes system operations setup at the launch sites and the space station, flight test support, ground operations, space operations, spares, training, and mission control operations. On-orbit node control is included.

Program phaseout is not addressed in this study.

2-2.0 WORK BREAKDOWN STRUCTURE SUMMARIES

The STV program cost estimating and planning structure includes a three-dimensional element breakout of information. The three dimensions are illustrated in Figure 2-2.0-1.

The time period dimension consists of the periods of performance for the program phases previously described. The configuration breakdown dimension is a series of indentured item breakdowns consisting of STV hardware items, STV software computer program configuration items (CPCI), and work package labor tasks or services items. The functional breakdown dimension contains summaries of contractor and Government organizational department labor task estimates by hardware item and time (e.g., system engineering, design engineering, factory labor, and test laboratory labor).

The initial step in developing the STV Program Preliminary WBS Dictionary is to develop a top level WBS tree diagram. This diagram was presented at the Orientation Briefing in December, 1989. The top level system WBS tree is then broken down (decomposed) into further detail as the system requirements and configuration candidates are established in the study. The "STV" abbreviation at WBS level three has been replaced by "LTS," an abbreviation for the "Lunar Transportation System."

2-2.1 TOP-LEVEL PROGRAM WBS TREE

Figure 2-2.1-1 is the point of departure diagram for the WBS development process. The LTS program is a level-3 element of the overall United States of America, Presidential Space Exploration Initiative (SEI) program. The top-level tree is shown to give an overview of the primary STV application program of interest and to illustrate the major space transportation system interfaces that will drive LTS program planning and cost. In the figure of the NASA master program (initiative level) WBS tree, the area of LTS project expansion for this dictionary is highlighted.

The LTS contract work breakdown structures (CWBS) will be developed as extensions of the NASA PWBS. The contractors will expand the lower

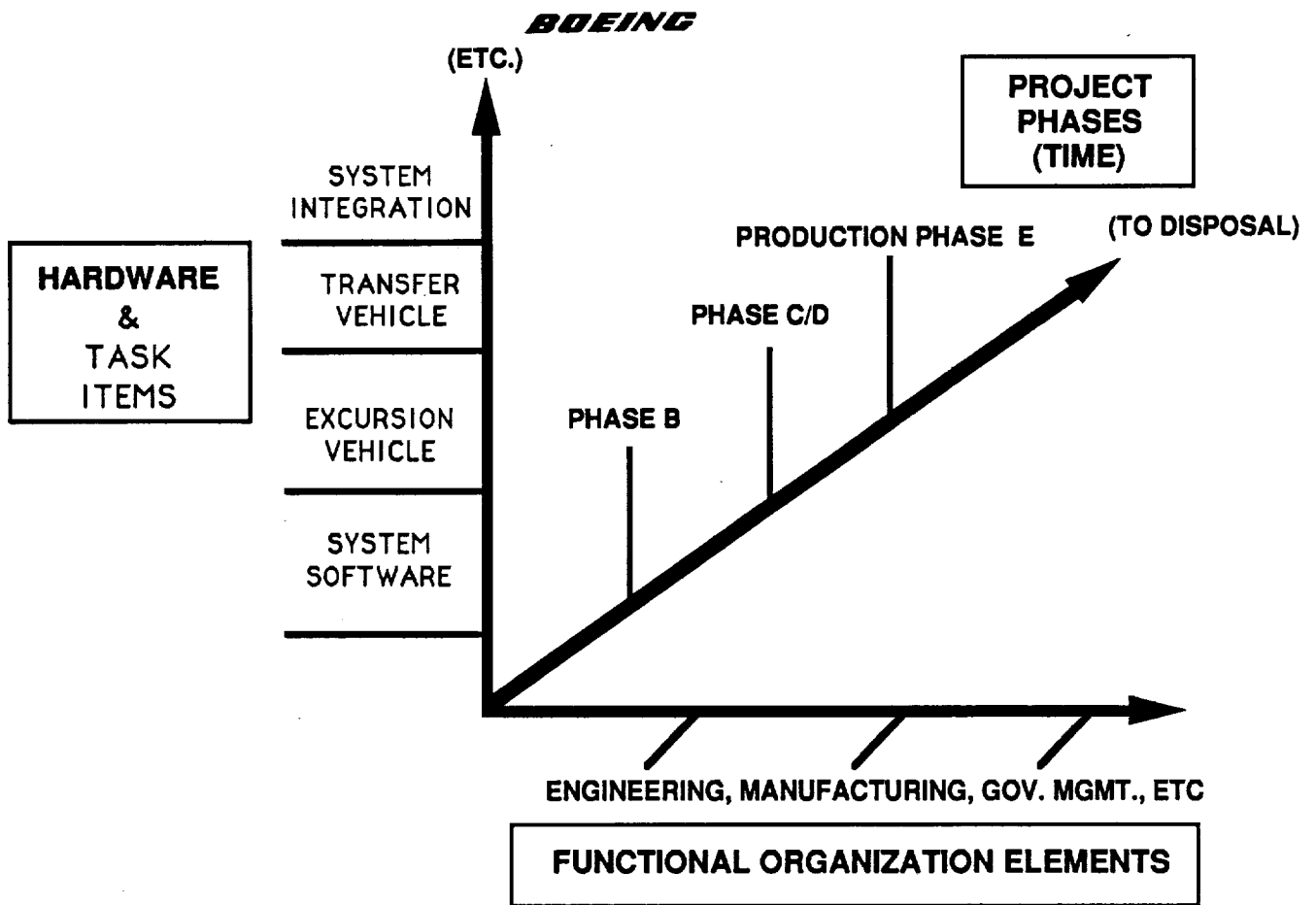


Figure 2-2.0-1. Work Breakdown Structure Dimensions Example

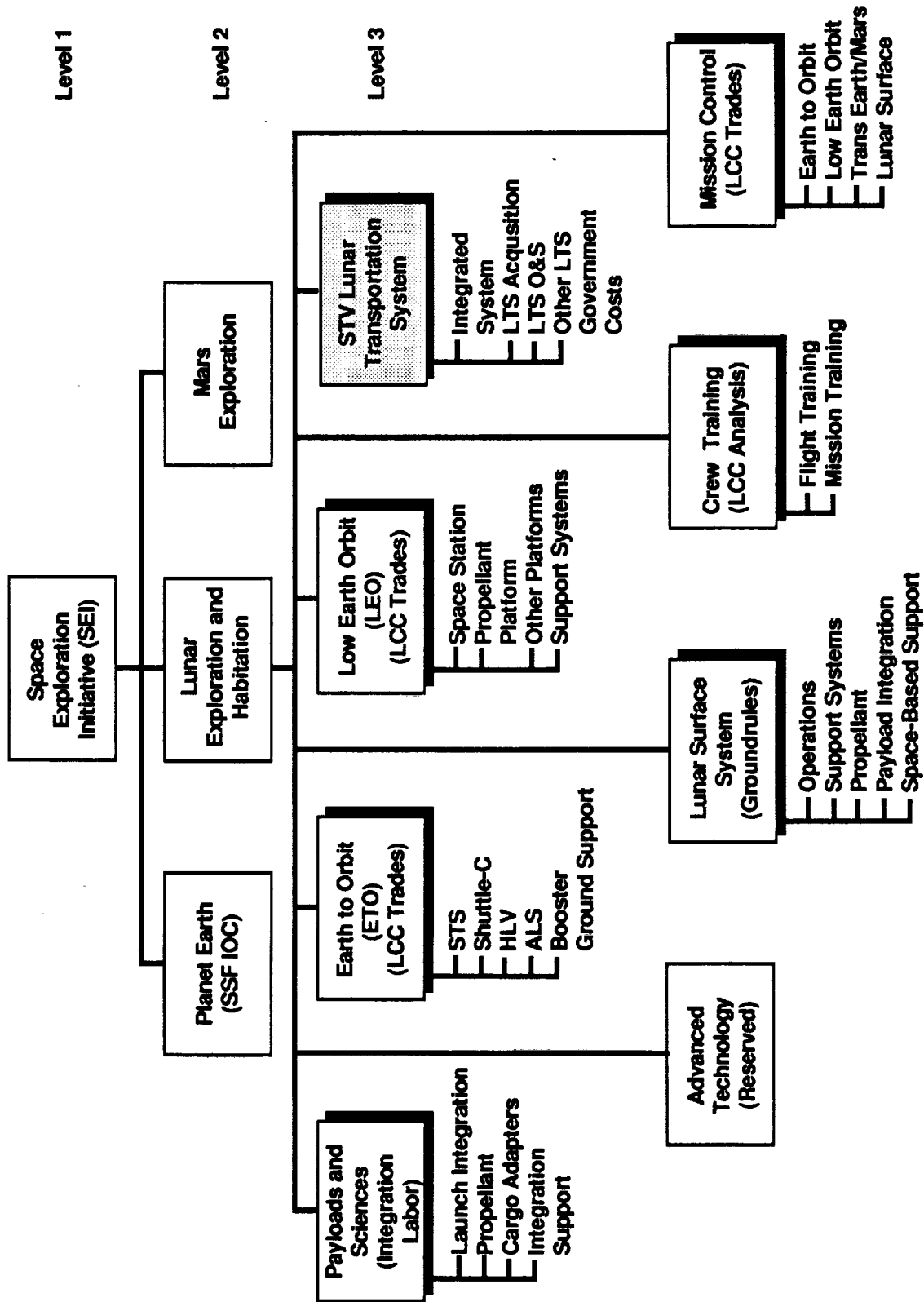


Figure 2-2.1-1. NASA Point-of-Departure Top-Level WBS Tree

subdivisions of the preliminary CWBSs in a manner that will ensure compatibility with each contractors accounting system structure. This document is expanded for estimating and planning purposes only. The WBS and dictionary will evolve and be updated as the NASA acquisition process proceeds. Figure 2-2.1-2 is an extract from NASA handbook NHB-5610.1. It depicts the PWBS/CWBS evolution process and indicates where this document fits in that process (see indicator arrow).

2-2.2 LUNAR TRANSPORTATION SYSTEM WBS TREE

Figure 2-2.2-1 is a level-3 to level-6 expansion of the LTS program WBS summary items shown in Figure 2-2.1-2. The WBS listing is developed at lower levels of detail. It is not implied that every item must be estimated at a very low level of detail for each LTS candidate. The further decomposition of the preliminary PWBS provides planners, managers, and cost analysts with equipment lists. The expanded equipment item descriptions help define system attributes (when a discrete statement of work is not available for future program subphases or evolutionary design subsystem details).

Crew module (cabin) WBS listings are presented in the body of the dictionary. These listings were generated from Boeing, Huntsville conceptual design information, shuttle crew cab descriptions, prior Apollo spacecraft descriptions, Space Station Freedom design data, and various spacecraft and space physiology reference books (e.g., Nicogossian, Huntoon, and Pool; "Space Physiology and Medicine," second edition; Lea & Febiger, 1989). The listing provides a conceptual description of subsystems in the crew module for LTS system-level trade studies and subsystem sizing and interface analyses.

Figure 2-2.2-2 contains an operations and support (O&S) phase WBS tree summary. This O&S summary contains a preliminary group of functional task items that will be expanded in definition during phase C/D of the STV program.

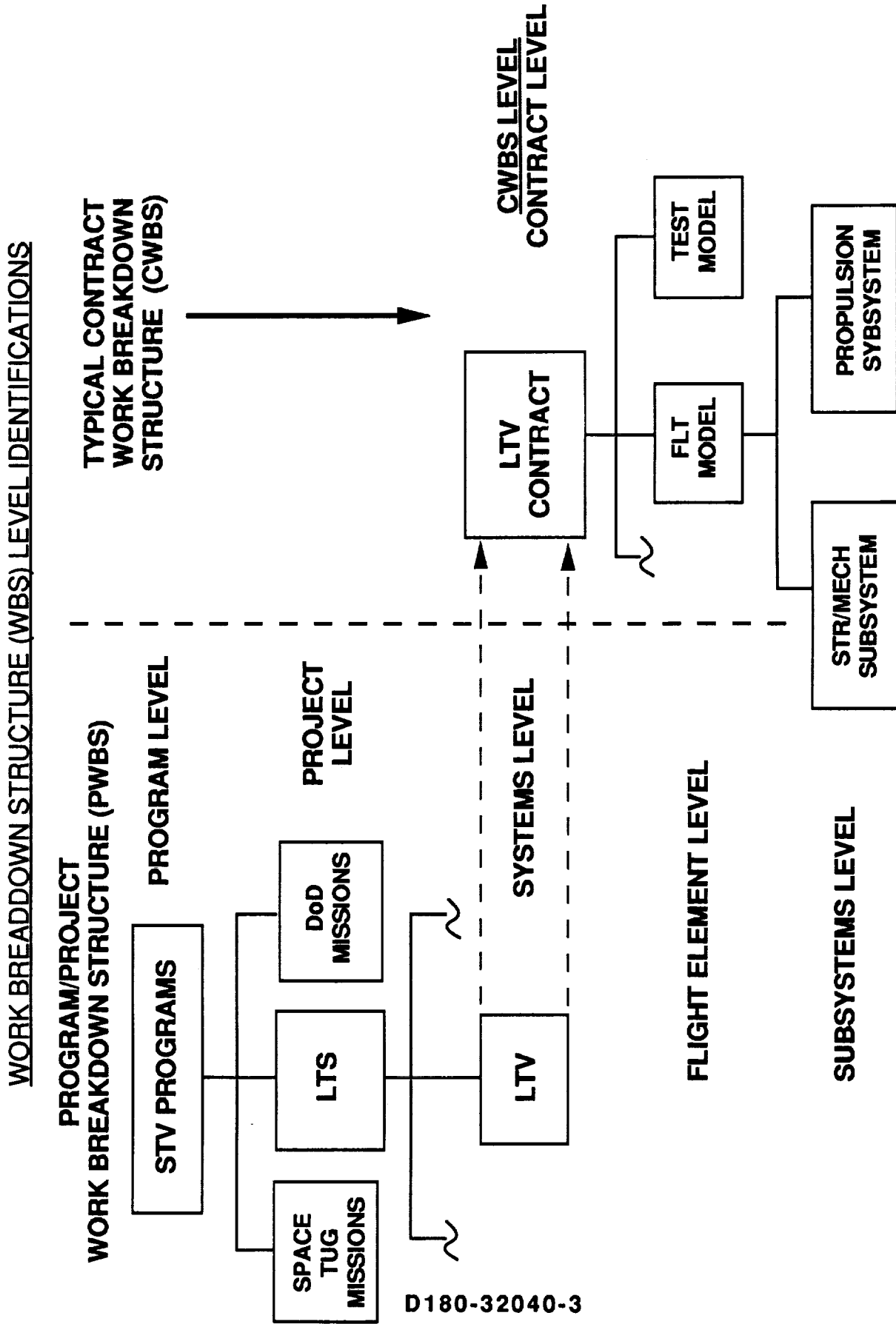


Figure 2-2.1-2. Typical PWBS/CWBS Evolution Process

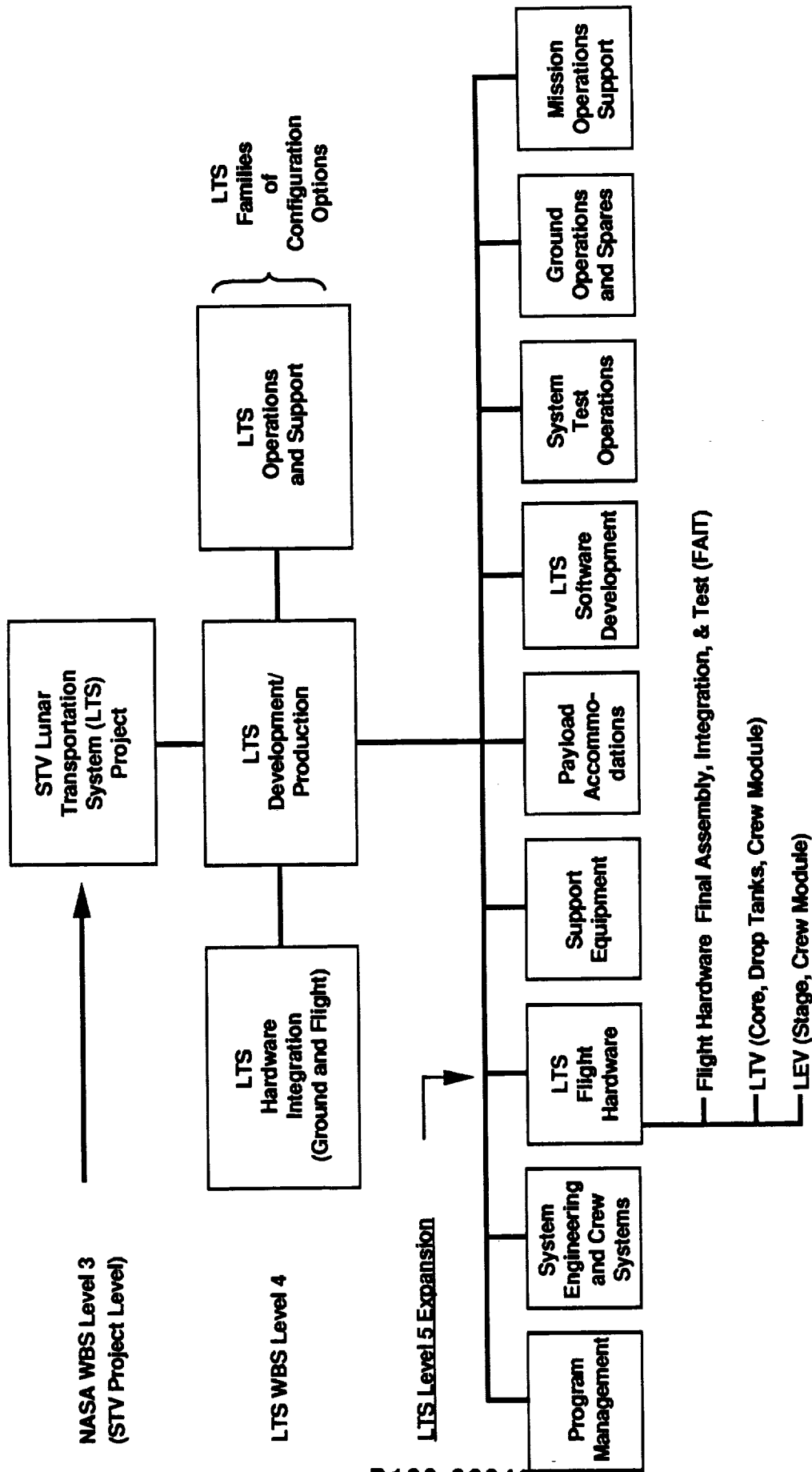


Figure 2-2.2-1. Preliminary LTS Project-Level WBS Expansion Tree

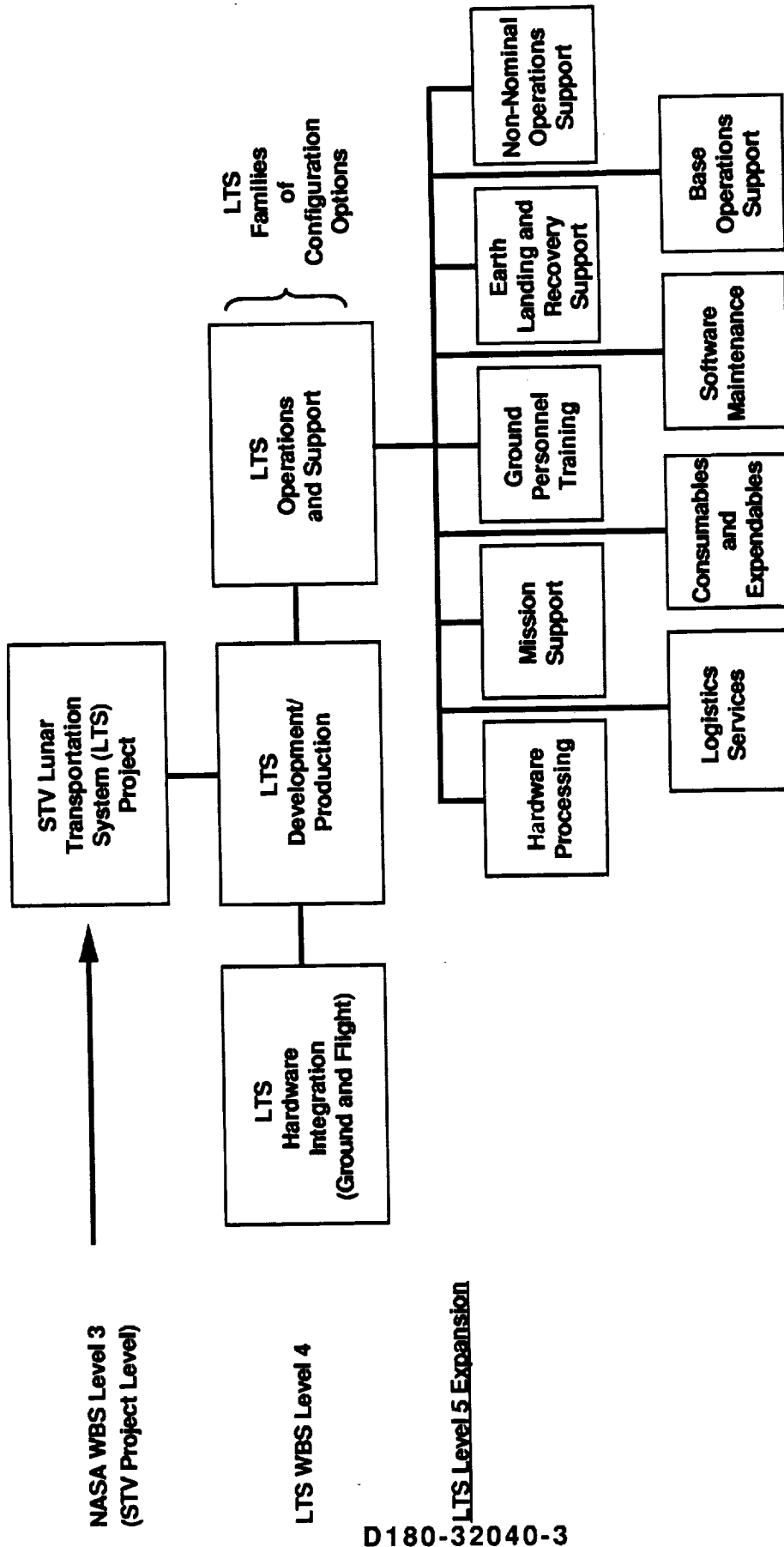


Figure 2-2.2-2. Preliminary LTS Operations and Support Phase WBS Expansion

2-2.3 TOTAL PROGRAM WBS LISTING

Figure 2-2.3-1 is a six page listing of the Lunar Transportation System project breakdown at the PWBS level of indenture. The list expands the definition of the levels 4 and 5 summary items. The preliminary WBS dictionary presented in section 2-3.0 expands the definition by providing narrative on WBS items content for planning and estimating purposes. The Figure 2-2.3-1 listing contains columns indicating which program phase and summary functional elements each work package relates to in a traditional program structure.

WBS Item Name										LCC Phase Application				
Level	1	2	3	4	5	6	7	8	9	B	C/D	Prod	O&S	
7.0										Lunar Transportation System (LTS) Project	S	S	S	S
7.1										LTS Hardware Integration	S	S	S	S
7.2										LTS Development/Production	S	S	S	
7.2.1										LTS Program Management	X	X	X	
7.2.2										LTS System Engineering and Crew Systems	S	S	S	
7.2.2.1										System Engineering	X	X	X	
7.2.2.2										Logistics Engineering Analysis and Eval.	X	X	X	
7.2.2.3										System Simulation	X	X		
7.2.2.4										Product Assurance and Safety	X	X	X	
7.2.2.5										Human Engineering/Crew Systems		X	X	
7.2.3										LTS Flight Hardware	S	S	S	
7.2.3.1										Lunar Transfer Vehicle (LTV)	S	S	S	
7.2.3.1.1										LTV Core Stage	S	S	S	
7.2.3.1.1.1										Core Structures and Mechanisms	S	S	S	
7.2.3.1.1.1.1										Core Body and Interface Struct	X	X	X	
7.2.3.1.1.1.2										Core Secondary & Equip. Struct.	X	X	X	
7.2.3.1.1.1.3										Core Landing & Aux. Sys. (Mech)	X	X	X	
7.2.3.1.1.2										Core Thermal Protection	X	X	X	
7.2.3.1.1.3										Aerobrake Subassembly	X	X	X	
7.2.3.1.1.4										Core Propulsion	S	S	S	
7.2.3.1.1.4.1										Core Primary Engines	X	X	X	
7.2.3.1.1.4.2										Core Fluid Supply System	X	X	X	
7.2.3.1.1.4.3										Reusable Tankage	X	X	X	
7.2.3.1.1.4.4										Core Prop Integ., Test, & Assy.	X	X	X	
7.2.3.1.1.5										Core Reaction Control System (RCS)	X	X	X	
7.2.3.1.1.6										Core Electrical Power	S	S	S	
7.2.3.1.1.6.1										Core Primary Power (Electric)	X	X	X	
7.2.3.1.1.6.2										Core Power Distribution	X	X	X	
Note: S = Summary item only; X = Input level														

Figure 2-2.3-1. STV Lunar Transportation System WBS Listing (Sheet 1 of 6)

WBS Item Name										LCC Phase Application			
Level	1	2	3	4	5	6	7	8	9	B	C/D	Prod	O&S
7.2.3.1.1.7									Core Stage Avionics	S	S	S	
7.2.3.1.1.7.1									Core Guidance, Navigation, and Control (GN&C) Avionics	X	X	X	
7.2.3.1.1.7.2									Core Comm and Data Handling	X	X	X	
7.2.3.1.1.7.3									Core Veh Health Main Subsystem	X	X	X	
7.2.3.1.1.7.4									Core Avionics, Integration, Wiring and Interfaces	X	X	X	
7.2.3.1.1.8									Core Stage Assembly and Checkout	X	X	X	
7.2.3.1.1.9									Core Stage H/W Eval and Analysis	X	X		
7.2.3.1.2									LTV Drop Tanks	S	S	S	
7.2.3.1.2.1									Liquid Oxygen Drop Tank(s)	X	X	X	
7.2.3.1.2.2									Liquid Hydrogen Drop Tank(s)	X	X	X	
7.2.3.1.2.3									Drop Tanks Struct. and Mechanisms	X	X	X	
7.2.3.1.2.4									Drop Tanks Fluid Supply	X	X	X	
7.2.3.1.2.5									Drop Tank Module Avionics	X	X	X	
7.2.3.1.2.6									Drop Tank Module Attitude Control	X	X	X	
7.2.3.1.2.7									LTV Drop Tanks Integration	X	X	X	
7.2.3.1.3									LTS Tanker (Ground Based Only)	X	X	X	
7.2.3.1.4									LTV Crew Module	S	S	S	
7.2.3.1.4.1									LTV Crew Module Struct. and Mech.	S	S	S	
7.2.3.1.4.1.1									LTV Crew Module Structure	X	X	X	
7.2.3.1.4.1.2									LTV Crew Mod Secondary Struct.	X	X	X	
7.2.3.1.4.2									LTV Crew Module Thermal Protect	X	X	X	
7.2.3.1.4.3									LTV Crew Module Attitude Control	X	X	X	
7.2.3.1.4.4									LTV Crew Module Electrical Power	S	S	S	
7.2.3.1.4.4.1									LTV Crew Module Primary Power	X	X	X	
7.2.3.1.4.4.2									LTV Crew Mod. Pwr. Dist & Ctrl.	X	X	X	
7.2.3.1.4.5									LTV Crew Module Avionics	S	S	S	
Note: S = Summary item only; X = Input level													

Figure 2-2.3-1. STV Lunar Transportation System WBS Listing (Sheet 2 of 6)

BOEING

WBS Item Name										LCC Phase Application			
Level	1	2	3	4	5	6	7	8	9	B	C/D	Prod	O&S
7.2.3.1.4.5.1									LTV Crew Module GN&C Elect.	X	X	X	
7.2.3.1.4.5.2									LTV Crew Module Com. & Data Handling	X	X	X	
7.2.3.1.4.5.3									LTV Crew Module Vehicle Health Monitoring Subsystem	X	X	X	
7.2.3.1.4.5.4									LTV Crew Mod Ctrl and Displays	X	X	X	
7.2.3.1.4.5.5									LTV Crew Module Avionics Integration and Maintainability	X	X	X	
7.2.3.1.4.6									LTV Crew Module Flight Software	X	X	X	
7.2.3.1.4.7									LTV Crew Module ECLSS	X	X	X	
7.2.3.1.4.8									LTV Crew Module Crew Provisions and EVA Support	X	X	X	
7.2.3.1.4.9									LTV Crew Module Final Assembly, Integration and Test	X	X	X	
7.2.3.1.4.10									LTV Launch Escape System (LES)	X	X	X	
7.2.3.1.5									LTV Final Assembly, Integ. and Test	X	X	X	
7.2.3.2									Lunar Excursion Vehicle (LEV)	S	S	S	
7.2.3.2.1									LEV Stage	S	S	S	
7.2.3.2.1.1									LEV Structures and Mechanisms	S	S	S	
7.2.3.2.1.1.1									LEV Body and Interface Structures	X	X	X	
7.2.3.2.1.1.2									LEV Secondary and Equip. Struct.	X	X	X	
7.2.3.2.1.1.3									LEV Landing & Aux. Sys. (Mech)	X	X	X	
7.2.3.2.1.2									LEV Thermal Protection	X	X	X	
7.2.3.2.1.3									LEV Propulsion	S	S	S	
7.2.3.2.1.3.1									LEV Ascent/Descent Engines	X	X	X	
7.2.3.2.1.3.2									LEV Fluid Supply System	X	X	X	
7.2.3.2.1.3.3									LEV Reusable Tankage	X	X	X	
7.2.3.2.1.3.4									LEV Prop Integ., Test and Assy.	X	X	X	
Note: S = Summary item only; X = Input level													

Figure 2-2.3-1. STV Lunar Transportation System WBS Listing (Sheet 3 of 6)

WBS Item Name										LCC Phase Application			
Level	1	2	3	4	5	6	7	8	9	B	C/D	Prod	O&S
7.2.3.2.1.4									LEV Reaction Control System (RCS)	X	X	X	
7.2.3.2.1.5									LEV Electrical Power	S	S	S	
7.2.3.2.1.5.1									LEV Primary Power (Electrical)	X	X	X	
7.2.3.2.1.5.2									LEV Power Distribution	X	X	X	
7.2.3.2.1.6									LEV Stage Avionics	S	S	S	
7.2.3.2.1.6.1									LEV Guidance, Navigation and	X	X	X	
									Control (GN&C) Avionics	X	X	X	
7.2.3.2.1.6.2									LEV Comm and Data Handling	X	X	X	
7.2.3.2.1.6.3									LEV Health Maintenance Subsys.	X	X	X	
7.2.3.2.1.6.4									LEV Avionics Pallet Integration,	X	X	X	
									Wiring, and Interfaces				
7.2.3.2.1.7									LEV Stage Assembly and Checkout	X	X	X	
7.2.3.2.1.8									LEV Stage H/W Eval. and Analysis	X	X	X	
7.2.3.2.2									LEV Crew Module	S	S	S	
7.2.3.2.2.1									LEV Crew Module Struct. and Mech.	S	S	S	
7.2.3.2.2.1.1									LEV Crew Module Structure	X	X	X	
7.2.3.2.2.1.2									LEV Crew Mod Secondary Struct.	X	X	X	
7.2.3.2.2.2									LEV Crew Module Thermal Protect	X	X	X	
7.2.3.2.2.3									LEV Crew Module Electrical Power	S	S	S	
7.2.3.2.2.3.1									LEV Crew Mod. Primary Power	X	X	X	
7.2.3.2.2.3.2									LEV Crew Mod Pwr Dist and Ctrl	X	X	X	
7.2.3.2.2.4									LEV Crew Module Avionics	S	S	S	
7.2.3.2.2.4.1									LEV Crew Mod GN&C Electronic	X	X	X	
7.2.3.2.2.4.2									LEV Crew Module Comm. and	X	X	X	
									Data Handling				
7.2.3.2.2.4.3									LEV Crew Module Vehicle Health	X	X	X	
									Monitoring Subsystem	X	X	X	
7.2.3.2.2.4.4									LEV Crew Mod Ctrls and Displays	X	X	X	
Note: S = Summary item only; X = Input level													

Figure 2-2.3-1. STV Lunar Transportation System WBS Listing (Sheet 4 of 6)

WBS Item Name										LCC Phase Application			
Level	1	2	3	4	5	6	7	8	9	B	C/D	Prod	O&S
7.2.3.2.2.4.5									LEV Crew Module Avionics	X	X	X	
									Integration and Maintainability	X	X	X	
7.2.3.2.2.5									LEV Crew Module Flight Software	X	X	X	
7.2.3.2.2.6									LEV Crew Module ECLSS	X	X	X	
7.2.3.2.2.7									LEV Crew Module Crew Provisions and EVA Support	X	X	X	
7.2.3.2.2.8									LEV Crew Module Final Assembly, Integration and Test (FAIT)	X	X	X	
7.2.3.2.3									LEV Stage and Crew Module FAIT	X	X	X	
7.2.4									LTS Support Equipment	S	S	S	S
7.2.4.1									Ground (Launch) Support Equip (GSE)	X	X	X	X
7.2.4.2									Space (incl. Lunar) Support Equip. (SSE)	X	X	X	X
7.2.5									LTS Payload Accommodations	X	X	X	X
7.2.6									Software (S/W) Development and Integration	S	S	S	S
7.2.6.1									Software Development Facility (SDF)	X	X		X
7.2.6.2									LTV/LEV Flight Software	X	X		X
7.2.6.3									LTV/LEV Avionics Laboratory Software	X	X	X	
7.2.6.4									LTS Launch Support and Ctrl. (LSC) S/W	X	X		
7.2.6.5									Mission Operations Software	X	X		
7.2.6.6									Software Productivity Management	X	X		
7.2.7									System Test Operations	S	S	S	
7.2.7.1									LTS Ground Testing	X	X	X	
7.2.7.2									LTS Flight Testing	X	X		X
7.2.8									Ground Operations and Control	S	S		S
7.2.8.1									Ground Operations Development	X	X		
7.2.8.2									Ground Processing and Launch Facilities	X	X		X
7.2.8.3									Base Site Operations Engineering Develop.	X	X		
7.2.8.4									Initial Spares and Repair Parts Setup	X	X	X	
Note: S = Summary item only; X = Input level													

Figure 2-2.3-1. STV Lunar Transportation System WBS Listing (Sheet 5 of 6)

WBS Item Name										LCC Phase Application			
Level	1	2	3	4	5	6	7	8	9	B	C/D	Prod	O&S
7.2.9									LTS Mission Operations Non-recurring	X	X		
7.3									LTS Operations and Support (O&S) Phase				S
7.3.1									LTS Hardware O&S Processing				X
7.3.2									LTS O&S Mission Support				X
7.3.3									LTS Ground Personnel Training				X
7.3.4									LTS Earth Landing and Recovery Support				X
7.3.5									LTS Non-Nominal Operations Support				X
7.3.6									LTS O&S Logistics Services				X
7.3.7									LTS Consumables and Expendables				X
7.3.8									LTS Software Maintenance				X
7.3.9									LTS Base Operations Support				X
Note: S = Summary item only; X = Input level													

Figure 2-2.3-1. STV Lunar Transportation System WBS Listing (Sheet 6 of 6)

BOEING

2-3.0 WORK BREAKDOWN STRUCTURE DICTIONARY

WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(1)	NASA Total	<u>Space Exploration Initiative (SEI):</u> A total summary-level item that is for NASA use only.
(2)	0.0	<u>Lunar Exploration & Habitation Initiative:</u> A NASA summary item that includes the total effort involved in performing payloads & sciences, ETO, LEO, and Space Transfer Vehicle space transportation tasks. One contractor Lunar Transportation System summary estimate is input to NASA at this level.
(3)	1.0	<u>Payloads & Sciences:</u> Vehicle integrator, propellant, and cargo adapter cost estimates related to the lunar to the to the LTS requirements. Contractor inputs to this WBS item are interface and integration labor, GFP propellant costs, and GFP adapters (if required). For the current STV study contract, only system contractor(s) engineering and management interface labor for LTS/booster integration will be estimated.
(3)	2.0	<u>Advanced Technology:</u> (RESERVED)
(3)	3.0	<u>Earth to Orbit:</u> Dollars per pound or average cost per flight (recurring cost) estimates to be used to develop LCC estimates and evaluate configuration alternatives for LTS or STV missions. Included are STV effort for pad integration with the boosters, but not STV ground processing (see WBS 7.3.8 for LTS flight element recurring ground processing).

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WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(3)	4.0	<u>Lunar Surface Systems:</u> STV flight elements requiring labor and peculiar support equipment resources are tended and prepared for return flight at lunar nodes or bases. Lunar crew EVA/IVA costs and NASA-JSC support equipment GFE estimates are Government-furnished equipment and services for lunar operations (to be added by NASA-JSC).
(3)	5.0	<u>Low Earth Orbit:</u> This element includes the sunken cost (added facilitization, development, and procurement) and in-space operations resources required to support a STV transportation element. Operational cost increases for LTS-driven expenses at Space Station Freedom (SSF) or a dedicated free-flyer node are included. Support system costs for fuel tankers and supply or service vehicle operations are a part of the LCC analysis. Examples of facilities costs are a new SSF hanger, aerobrake assembly node, logistics module for spares storage, and spares pallets.
(3)	6.0	<u>Crew Training:</u> Flight and space support crew mission training at Earth, SSF, and lunar base sites for astronauts and support personnel associated with the LTS and other STV projects. ETO booster crew training costs are excluded.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(3)	7.0	<u>Lunar Transportation System Project:</u> The LTS summary element contains the compilation of system, subsystems, components, software end items, tasks, subtasks, and work elements for this special STV mission project. No cost estimating inputs are allowed at this WBS level.
(4)	7.1	<u>LTS Hardware Integration:</u> Management and integration support labor to combine system hardware elements into a LTS mission set. It includes all effort associated with the design, development, and production of mating hardware, integration structures, special integration equipment, and raw materials required to assemble the LTS WBS level-5 flight hardware elements into a mission vehicle, which includes stack testing, customer buyoff, liaison and administrative engineering services, range safety support, and final assembly tooling and integration simulators.
(4)	7.2	<u>LTS Development/Production:</u> This summary WBS element is provided to total all LTS flight system elements into a top-level summary of acquisition (Investment) costs. No estimate inputs are desired at this summary level.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(5)	7.2.1	<u>LTS Program Management:</u> All labor and systems effort required to perform level of effort work packages for configuration management, engineering operations, total quality management training, quality assurance engineering, procurement management (task direct), GFP management (direct), and operations/facility planning (before O&S phase starts.) <u>Note:</u> NASA program support is calculated in WBS 7.2 after requirements change and contractor fee is applied.
(5)	7.2.2	<u>LTS System Engineering and Crew Systems:</u> A summary of all level-6 activities associated with systems engineering, logistics, simulation, safety engineering, and crew systems engineering disciplines. No estimate inputs are desired at this WBS level.
(6)	7.2.2.1	<u>System Engineering:</u> LTS system engineering labor resources required to develop, document, and maintain system requirements and specifications data; conduct system analyses and flight operations audits of the mission system; and perform special analyses for mission design changes.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.2.2	<u>Logistics Engineering Analysis and Evaluation:</u> Supportability, maintainability, spares management, IOC repair parts planning, and logistics support analysis level of effort labor work packages. Includes ground training development. Excludes repair parts and initial spares (see WBS 7.2.8.4).
(6)	7.2.2.3	<u>System Simulation:</u> Level of effort labor work package resources required to manage and operate non-real-time simulators for systems development and integration. Includes non-deliverable equipment (DT&E residual assets at contract closeout) such as mission equipment development simulators, proof-of-principle robotics lab equipment, system integration lab equipment and technicians, and so forth. Also includes contractor support labor for NASA "inhouse" simulations activities.
(6)	7.2.2.4	<u>Product Assurance and Safety:</u> Level of effort labor to develop, implement, and maintain a quality, reliability, and safety program. Encompasses analysis, requirements compliance management, supplier control, audits, and reporting. Included are support of test reporting, resolving alerts, and resolution and statusing of failure reports. Safety engineering includes NASA man-rating requirements analysis, documentation, and audits; range safety interface; and mission/launch/refurbishment safety training.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.2.5	<u>Human Engineering/Crew Systems:</u> Research, development, documentation, and training using man-machine interface concepts and ergonomics in the design and development process. Space survival analysis, emergency abort analysis, EVA interface analysis, autonomy override, and space medicine considerations are also addressed in this level of effort task.
(5)	7.2.3	<u>LTS Flight Hardware:</u> A summary of the mission flight hardware for an integrated LTS with a core stage (sometimes called a lunar transfer vehicle (LTV), crew modules (when required), lunar excursion vehicle (LEV) (when required), and LTS payload accommodations equipment. No inputs are desired at this WBS level.
(6)	7.2.3.1	<u>Lunar Transfer Vehicle:</u> The LTV flight element summary item. The flight elements are the core stage; the droptanks (LTS missions only), derivative stage, and tanker (ground-based only); a crew module (required for manned missions only); and LTV final assembly, integration, and test (FAIT.) No inputs are desired at this level.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(7)	7.2.3.1.1	<u>LTV Core Stage:</u> The transfer vehicle summary of the main propulsive stage. Includes core integration and assembly, structures, thermal protection, aerobrake, propulsion, reuseable tankage, avionics, and power subsystems. Excludes droptanks (WBS 7.2.3.1.2) and crew module (WBS 7.2.3.1.3). No inputs are desired at this level.
(8)	7.2.3.1.1.1	<u>Core Structures and Mechanisms:</u> A summary-level item for core stage structures (primary and secondary), landing and auxiliary systems, and mechanisms. No inputs are desired at this level.
(9)	7.2.3.1.1.1.1	<u>Core Body and Interface Structures:</u> Longerons, shells, panels, bulkheads, struts, and beams that carry primary loads of the vehicle through main body, fairing, or adapter structures. Thrust structures are included in this WBS item.
(9)	7.2.3.1.1.1.2	<u>Core Secondary and Equipment Structures:</u> Attachment fittings, racks, lockers, sway struts, equipment panels, separation panels, and meteor protection panels that <u>do not carry primary load</u> . Includes simple mechanical mechanisms and equipment pallets (as required).

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.1.1.3	<u>Core Landing and Auxiliary Systems (mechanical)</u> : Landing gear components and subassembly integration; grapple rings, hooks, or equipment for docking the core vehicle to other flight elements during the mission. Includes special equipment for EVA and space tug interface activities (e.g., maintenance and movement of the core vehicle). Includes remote manipulator arm equipment, excluding teleoperator control and display equipment (see crew module or mission operations WBS for manned mission teleoperator displays, controls and labor). Also includes pyrotechnics for separation and activation.
(8)	7.2.3.1.1.2	<u>Core Thermal Protection</u> : Active and passive thermal control hardware required to keep the core vehicle within acceptable operating temperatures during space flight. Included in this item are multilayer insulation (MLI) blankets, heaters, cold plates, forced air systems, ablators, tiles, or heat shunts. ECLSS heat control and propulsion heat exchangers are located in their respective subsystem WBS items and are excluded.
(8)	7.2.3.1.1.3	<u>Aerobrake Subassembly</u> : A major flight element subassembly of the core stage consisting of structure, interface mechanisms, auxiliary equipment, thermal protection, reaction control, battery power, and health monitoring equipment. Includes aerobrake assembly and checkout as a major core vehicle subassembly.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.1.1.4	<u>Core Propulsion</u> : A summary of primary stage cryogenic propulsion components including engines, reuseable tankage, fluid supply systems, and engine controllers. Also includes resupply-defueling equipment for in-space operations. No inputs are desired at this WBS level.
(9)	7.2.3.1.1.4.1	<u>Core Primary Engines and Optional RL10 Derivative Small Stage Engine</u> : Development and production effort to procure the advanced, primary cryogenic engines. Included are the engine core, nozzle, skirts, thrust vector control, gimbling mechanisms, engine controller, and vehicle health monitoring system (VHMS) sensors, and FAIT. Includes non-recurring technical (level of effort labor) support and prime-level liaison engineering and data support at the supplier level.
(9)	7.2.3.1.1.4.2	<u>Core Fluid Supply System</u> : Development and production plumbing equipment for propulsion fluid supply. Purchased equipment such as vacuum jacketed lines, regulators, valves, vents, fill/drain connectors, heat exchangers, and VHMS sensors (leak sensors, function assessment, and so forth). Includes special resupply-defueling couplers and assemblies.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.1.4.3	<u>Reusable Tankage:</u> Internal tanks for LO2 and LH2 storage. Includes internal LAD, TVS, other liquid controls, and foam or MLI blanket insulation. Includes development, certification, and production effort. Excludes expendable drop tankage and fuel tankers (see WBS 7.2.3.1.2).
(9)	7.2.3.1.1.4.4	<u>Core Propulsion Integration, Test, and Assembly:</u> Integration contractor effort to assemble and test the primary propulsion elements with other core stage subsystems. Includes engine vendor interface, customer interface, and national testbed project coordination level-of-effort labor. Includes subsystem-level special test equipment, facilitization setup, and tooling.
(8)	7.2.3.1.1.5	<u>Core Reaction Control System (RCS):</u> Development and production of thruster modules, RCS modular tankage (if non-cryogenic), manifolds, valves, heaters and other RCS components. Includes spin, despin, nutation damper, gravity boom, welding (if required), and VHMS sensors equipments. Also includes FAIT labor, special RCS tank loading and settling (if required), and RCS isovalve hardware.
(8)	7.2.3.1.1.6	<u>Core Electrical Power:</u> A summary of primary power and power distribution equipment for the core stage. No inputs are desired at this level.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.1.6.1	<u>Core Primary Power (electric):</u> Solar panels, fuel cells, batteries, and hybrid power cells used for collection, generation, and storage of primary electrical power. Includes VHMS sensors and development, test, certification, and production of power source and storage equipment in a man-rated system, or similar parts for an unmanned derivative system conversion kit.
(9)	7.2.3.1.1.6.2	<u>Core Power Distribution:</u> All power distribution and control equipment development, integration, test, and production effort, including integration contractor FAIT of entire power subsystem. Equipment and components include power wiring, navigation lights, regulation, power supply boxes, inversion, conversion, conditioning, power interface, and remote switching units for the core stage. Total power subsystem FAIT is included. Excluded is mission wiring and fiber-optics network interfaces (see avionics WBSs).
(8)	7.2.3.1.1.7	<u>Core Stage Avionics:</u> This a summary-level item for the core stage avionics. No inputs are desired at this WBS level.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.1.7.1	<u>Core Guidance, Navigation, and Control (GN&C) Avionics:</u> Stabilization and control avionics associated with the RCS subsystem and engine flight controls. Typical hardware is composed of fiber-optics or ring laser gyroscope inertial measurement units, accelerometer sets, rendezvous radar, optical/laser range and object designators, star sensors, horizon sensors, sun sensors, and analog-to-digital interface equipment. Includes GN&C equipment real-time software and GN&C development, test, certification, and production activities of the integration contractor and suppliers. Excludes system-level software development (see system flight software WBS).
(9)	7.2.3.1.1.7.2	<u>Core Communication and Data Handling:</u> Design, analysis, development, test, and production of the communication and data management electronics suite in the core stage. Includes ATDRSS, laser communication, other telemetry, navigation beacon, central computer, signal conditioner, digital data bus interface, infrared or neural network interfaces, antennas, and interface switching device (multiplexer) equipments. Also includes embedded software for equipment with unique, real-time processor chips and logic circuits (e.g., LISP and symbolic). May include some valve control functions, if combined with central computer functions.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.1.7.3	<u>Core Vehicle Health Maintenance Subsystem:</u> VHMS management equipment and avionics VHMS sensors. Includes network interface unit, sensor interface unit, mass memory, fiber-optics network, and special neural equipments. Also includes special VHMS software (embedded) and VHMS development, testbeds, analysis, vendor surveillance, certification, and production FAIT.
(9)	7.2.3.1.1.7.4	<u>Core Avionics Integration, Wiring, and Interfaces:</u> Mission equipment wiring/waveguides/coax, data bus cables or fiber-optics carriers, infrared coupler hardware, interface boxes and filters, and total avionics suite integration. Includes level of effort architecture analysis for all LTS flight elements that directly interface with the core stage.
(8)	7.2.3.1.1.8	<u>Core Stage Assembly and Checkout:</u> This item collects the labor effort and materials required for FAIT of the core stage. The FAIT activities are initial assembly planning and manufacturing development, final assembly tooling and special test equipment (factory support equipment similar to deliverable launch support equipment), hardware integration, in-process testing, and final acceptance testing. Excluded is total LTS FAIT (see WBS 7.1) and booster to LTS assembly (see WBS 3.0).

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.1.1.9	<u>Core Stage Hardware Evaluation and Analysis:</u> Technical engineering analysis (stress, thermal, loads, and EMI) and manufacturing engineering level of effort labor related to hardware development and production phase setup. Includes design engineering liaison support for the test and production hardware fabrication.
(7)	7.2.3.1.2	<u>LTV and Derivative Droptanks:</u> A summary of large cryogenic droptank modules, tanker hardware, and derivative stage core hardware that are required to be integrated with core vehicle fuel supply equipment for LTS trips or support ground-based derivatives (small stage) hardware requirements. No inputs are desired at this WBS level.
(8)	7.2.3.1.2.1	<u>Liquid Oxygen Droptanks:</u> Tank domes, cylinder, insulation, and internal fluid control devices (e.g., LADs and TVS mixers) that make up a cryogenic fluid supply vessel. Includes tank assembly and checkout before integration into the droptank module.
(8)	7.2.3.1.2.2	<u>Liquid Hydrogen Droptanks:</u> Tank domes, cylinder, insulation, and internal fluid control devices that comprise the hydrogen fluid supply vessel. Includes hydrogen tankage assembly and checkout.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.1.2.3	<u>Droptanks Structures and Mechanisms:</u> Connecting structures, docking mechanisms, and fluid supply mechanisms and plumbing required to integrate and fuel/defuel the tank module assembly. Includes hardware separation devices (if required). Also includes any active thermal control subsystems for long-term orbit storage.
(8)	7.2.3.1.2.4	<u>Droptank Fluid Supply Subsystem and Optional Small Stage Propulsion (if applicable):</u> Lines, valves, vents, regulators, and other fluid supply components required to interface with the core stage, small stage derivative, or advanced space engine (ASE) decent engine (LTS ground-based vehicle only.) Includes optional RL10 derivative engine interface equipment on ground-based small stage configurations.
(8)	7.2.3.1.2.5	<u>Droptank Module Avionics:</u> Stationkeeping avionics equipment required to control the module in low Earth and lunar orbits during or between missions. The avionics could be as simple as just VHMS and fluid control electronics to a complete suite that also contains GN&C, communications and tracking (e.g., beacons) and docking sensors.
(8)	7.2.3.1.2.6	<u>Droptank Module Attitude Control:</u> Reaction control or mechanical spin/despin devices required to maintain attitude control during periods of long-term orbit storage (not required on some mission scenarios).

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.1.2.7	<u>LTV Droptanks Integration</u> : Final Assembly of the droptanks module and its subsystems. Includes tooling, on-orbit assembly aids and EVA tools, and special test equipment.
(7)	7.2.3.1.3	<u>LTS (Fuel Supply) Tanker</u> : A droptank derivative flight element used to supply LO2 fuel to a ground-orbital-based LTV. Includes many of the droptank subsystems shown above, with the addition of some docking adapter equipment. May include some RCS equipment, if required.
(7)	7.2.3.1.4	<u>LTV Crew Module</u> : A summary WBS item that accumulates the costs and task resources for a four-man crew module used to accomplish a LTS mission to the Moon. No inputs are desired at this WBS level.
(8)	7.2.3.1.4.1	<u>LTV Crew Module Structures and Mechanisms</u> : A summary of the level-9 structures and mechanisms items. No inputs are desired at this level.
(9)	7.2.3.1.4.1.1	<u>LTV Crew Module Structure</u> : Primary structure consisting of the body shell and debris shield, inner cabin panels, flight deck section, radiation storm shelter and airlock structure, and core stage interface structure (cab to LTV).

BOEING

WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(9)	7.2.3.1.4.1.2	<u>LTV Crew Module Secondary Structure:</u> Secondary structure consisting of equipment racks, ladders, lockers, cabin inner trim panels, hatches, and brackets. Excludes load carrying structure, crew provisions, and thermal protection. Includes hatch and equipment provisioning mechanisms.
(8)	7.2.3.1.4.2	<u>LTV Crew Module Thermal Protection:</u> Passive multilayer insulation thermal blankets, heat rejection panels, protective paints, heat sinks, window/hatch conditioning, transpiration panels (water wall), and avionics thermal control equipment. Includes reradiative tiles for the ground-based biconic crew module and TABI panels, if required. Excludes other ECLSS, engine system, and primary power heat exchangers or closed-loop radiators for internal temperature control requirements.
(8)	7.2.3.1.4.3	<u>LTV Crew Module Attitude Control:</u> Active reaction control equipment required for the biconic, ground-based crew module designs. (Not required for the space based configurations.)
(8)	7.2.3.1.4.4	<u>LTV Crew Module Electrical Power:</u> Primary solar cell and fuel cell power sources, electrical storage devices, and power distribution equipment summary. No inputs are desired at this WBS level.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.4.4.1	<u>LTV Crew Module Primary Power:</u> Power sources such as solar cells, fuel cells, and battery storage devices needed for over 30 days of operation. Includes electrolyzer storage units.
(9)	7.2.3.1.4.4.2	<u>LTV Crew Module Power Distribution and Control:</u> Power conditioning, inversion, conversion, regulation, and distribution hardware. Includes power wiring and breaker panels. Excludes mission and controls wiring and fiber-optic hardware.
(8)	7.2.3.1.4.5	<u>LTV Crew Module Avionics:</u> A summary of the avionics suite required to interface with the LTV and internal crew module subsystems. No inputs are desired at this WBS level.
(9)	7.2.3.1.4.5.1	<u>LTV Crew Module GN&C Electronics:</u> Design, analysis, and fabrication of control and inertial guidance interface units that are primary navigation equipment for manned missions. Includes gyroscopes, accelerometers, range-range-rate radars (Doppler), optical sensors, signal conditioners, network interface boxes, and laser equipment used for navigation and docking with other space nodes or flight elements.

BOEING

WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(9)	7.2.3.1.4.5.2	<u>LTV Crew Module Communication and Data Handling:</u> Design, analysis, and fabrication of space communications and data management equipment that is used on manned missions. ATDRSS and laser communications, telemetry transceivers for intravehicle and vehicle/mission control data transfers, navigation beacon, central computers, signal conditioner, data buses, fiber-optic lines, neural network interfaces, antennas, and imbedded software. May include some valve controls (if included in the central computer functions). Includes multiplexers and filters.
(9)	7.2.3.1.4.5.3	<u>LTV Crew Module Vehicle Health Monitoring Subsystem:</u> VHMS sensors and maintenance interface equipment consisting of a complete avionics sensor array, built-in test (BIT) function and BIT equipment interfaces, network interface units, sensor interface units, fiber-optic components, mass memories, and special neural equipment. Includes object-oriented expert system software and VHMS development, testbeds, analysis, vendor surveillance, procurement, certification, and production integration. Also includes extensive human engineering effort at vendors for man-machine interfaces and astronaut training.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.1.4.5.4	<u>LTV Crew Module Controls and Displays:</u> Next-generation flat screen displays with multifunction capability, smart helmet interface, multifunction keyboards, expert system Ada and assembly language real-time software (imbedded), decentralized processors networked to the central computer, and redundant display controller units. Includes some voice-activated control capability and an extensive integration task. Vendor non-recurring also includes certification, human engineering, avionics integration lab support, and technical publications support. Equipment will have self-contained emergency power batteries in every unit.
(9)	7.2.3.1.4.5.5	<u>LTV Crew Module Avionics Integration and Maintainability:</u> Architecture design and optimization (level of effort), environmental testing, failure testing, maintainability/access evaluation, integration and final acceptance testing of the entire crew module avionics suite for manned missions. Includes special studies on thermal and flight critical/safety critical issues, as directed by NASA, and crew module avionics special test equipment from vendors for suite checkout.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.1.4.6	<u>LTV Crew Module Flight Software</u> : Real-time flight software design, development, test, verification and validation (V&V), integration, and delivery. Includes control and display vendor requirements definition and interface tasks by the prime integration contractor and independent software V&V contractor. Excludes imbedded software (see WBS 7.3.1.3.4.4 above).
(8)	7.2.3.1.4.7	<u>LTV Crew Module ECLSS</u> : Environmental control and life support systems (ECLSS), including cabin environmental controls, pressure, humidity, breathing atmosphere, temperature, heat rejection, and carbon dioxide removal equipment. Includes development, testing, and integration of the equipment into an efficient ECLSS/avionics package and the necessary interface equipments.
(8)	7.2.3.1.4.8	<u>LTV Crew Module Crew Provisions and EVA Support</u> : Crew provisioning equipment such as flight couches, hygiene equipment, waste and potable water management, cabin lighting, medical science equipment, extravehicular activity (EVA) supplies, travel kits, work tools, sleep stations and restraints, and exercise equipment. Includes entertainment audio/video equipment and also special emergency gear.

BOEING

<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.1.4.9	<u>LTV Crew Module Final Assembly, Integration, and Test:</u> FAIT labor and materials planning, development, coordination, accomplishment, crew module certification, acceptance test, and delivery effort. Includes engineering liaison effort and special integration analyses level of effort tasks in support of development and production.
(8)	7.2.3.1.4.10	<u>LTV Crew Module Launch Escape System:</u> Crew emergency escape equipment and structural tower with docking adapter hardware, which is unique to ground-based LTV configurations launched with the crew on board (similar to Apollo program LES hardware).
(7)	7.2.3.1.5	<u>LTV Final Assembly, Integration, and Test:</u> Assembly of the core stage, droptanks set, and LTV crew module (manned missions only) into an LTS mission configuration vehicle. Includes planning, analysis, development, special integration tooling and test equipment, and production labor/materials tasks. On-orbit assembly tasks are accounted for in the O&S phase WBS.
(6)	7.2.3.2	<u>Lunar Excursion Vehicle (LEV):</u> This is a summary element for a second stage design of an LTS mission configuration. No inputs are desired at this summary WBS level.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(7)	7.2.3.2.1	<u>LEV Stage:</u> The basic stage hardware less the LEV crew module. This is a summary item, inputs are not desired at this WBS level. (See WBS 7.2.3.1.1 for LTV core stage descriptions when estimating a LTS two-stage vehicle.)
(8)	7.2.3.2.1.1	<u>LEV Structures and Mechanisms:</u> A summary-level item for LEV stage structures (primary and secondary), landing and auxiliary systems, and mechanisms. No inputs are desired at this level.
(9)	7.2.3.2.1.1.1	<u>LEV Body and Interface Structures:</u> Longerons, shells, panels, bulkheads, struts, and beams that carry primary loads of the vehicle through main body, fairing, or adapter structures. Thrust structures are included in this WBS item.
(9)	7.2.3.2.1.1.2	<u>LEV Secondary and Equipment Structures:</u> Attachment fittings, racks, lockers, sway struts, equipment panels, separation panels, and meteor protection panels that <u>do not carry primary load</u> . Includes simple mechanical mechanisms, cargo structures and equipment pallets (as required).

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WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(9)	7.2.3.2.1.1.3	<u>LEV Landing and Auxiliary Systems (mechanical)</u> : Landing gear components and subassembly integration; grapple rings, hooks, or equipment for docking the lunar excursion vehicle to other flight elements during the mission. Includes special equipment for EVA/OMV interface activities (e.g., maintenance and repositioning of the LEV). Includes remote manipulator arm equipment, remote teleoperator control equipment, and cargo jettison equipment for an abort condition (see crew module or mission operations WBS for teleoperator displays, controls & labor).
(8)	7.2.3.2.1.2	<u>LEV Thermal Protection</u> : Active and passive thermal control hardware required to keep the LEV within acceptable operating temperatures during space flight. Included in this item are multilayer insulation blankets, heaters, cold plates, forced air systems, ablators, tiles, or heat shunts. ECLSS heat control and propulsion heat exchangers are located in their respective subsystem WBS items and are excluded.
(8)	7.2.3.2.1.3	<u>LEV Propulsion</u> : A summary of primary stage cryogenic propulsion components including engines, reuseable tankage, fluid supply systems, and engine controllers. Also includes resupply-defueling equipment for in-space operations. No inputs are desired at this WBS level.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.1.3.1	<u>LEV Ascent/Descent Engines:</u> Development and production effort to procure the advanced, primary cryogenic engines. Included are the engine core, nozzle, skirts, thrust vector control, gimbling mechanisms, engine controller, and VHMS sensors, and FAIT. Includes non-recurring technical (level of effort labor) support and prime level liaison engineering/data support at the supplier level.
(9)	7.2.3.2.1.3.2	<u>LEV Fluid Supply System:</u> Development and production plumbing equipment for propulsion fluid supply. Purchased equipment such as vacuum-jacketed lines, regulators, valves, vents, fill/drain connectors, heat exchangers, and VHMS sensors (e.g., leak sensors and function assessment). Includes special resupply-defueling couplers and assemblies.
(9)	7.2.3.2.1.3.3	<u>LEV Reusable Tankage:</u> Internal tanks for LOX and LH2 storage. Includes internal LAD, TVS, other liquid controls, and foam or MLI blanket insulation. Includes development, certification, and production effort. Excludes expendable LTV drop tankage (see WBS 7.2.3.1.2).

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.1.3.4	<u>LEV Propulsion Integration, Test, and Assembly:</u> Integration contractor effort to assemble and test the primary propulsion elements with other core stage subsystems. Includes engine vendor interface, customer interface, and national testbed project coordination level of effort labor. Includes subsystem-level special test equipment, facilitization setup, and tooling.
(8)	7.2.3.2.1.4	<u>LEV Reaction Control System (RCS):</u> Development and production of thruster modules, RCS modular tankage (if non-cryogenic), manifolds, valves, heaters and other RCS components. Includes spin, despin, nutation damper, gravity boom, welding (if required), and VHMS sensors equipments. Also includes FAIT labor and special RCS tank loading and settling (if required).
(8)	7.2.3.2.1.5	<u>LEV Electrical Power:</u> A summary of primary power and power distribution equipment for the core stage. No inputs are desired at this level.
(9)	7.2.3.2.1.5.1	<u>LEV Primary Power (electric):</u> Solar panels, fuel cells, batteries, and hybrid power cells used for collection, generation, and storage of primary electrical power. Includes VHMS sensors and development, test, certification, and production of power source/storage equipment in a man-rated system.

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WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(9)	7.2.3.2.1.5.2	<u>LEV Power Distribution:</u> All power distribution and control equipment development, integration, test, and production effort, including integration contractor FAIT of entire power subsystem. Equipment and components include power wiring, navigation lights, regulation, power supply boxes, inversion, conversion, conditioning, power interface, and remote switching units for the core stage. Total power subsystem FAIT is included. Excluded is mission wiring and fiber-optic network interfaces (see avionics WBSs).
(8)	7.2.3.2.1.6	<u>LEV Stage Avionics:</u> This a summary-level item for the LEV stage (palletized) avionics. No inputs are desired at this WBS level.
(9)	7.2.3.2.1.6.1	<u>LEV Guidance, Navigation, and Control (GN&C) Avionics:</u> Stabilization and control avionics associated with the RCS subsystem and engine flight controls. Typical hardware is composed of fiber optics or ring laser gyroscope inertial measurement units, accelerometer sets, rendezvous radar, optical/laser range and object designators, star sensors, horizon sensors, sun sensors, and analog-to-digital interface equipment. Includes GN&C equipment real-time software and GN&C development, test, certification, and production activities of the integration contractor and suppliers. Excludes system-level software development (see system flight software WBS).

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.1.6.2	<u>LEV Communication and Data Handling:</u> Design, analysis, development, test, and production of the communication and data management electronics suite in the LEV stage. Includes ATDRSS and laser communication, telemetry, navigation beacon, central computer, signal conditioner, digital data bus interface, neural network interface, antennas, and interface switching device (multiplexer) equipments. Also includes embedded software for equipment with unique processor chips and logic circuits (e.g., LISP and symbolic). May include some valve control functions, if combined with central computer.
(9)	7.2.3.2.1.6.3	<u>LEV Health Maintenance Subsystem:</u> VHMS management equipment and avionics VHMS sensors. Includes network interface unit, sensor interface unit, mass memory, fiber-optic network, and special neural equipments. Also includes special VHMS expert systems software (embedded), and VHMS development, testbeds, analysis, vendor surveillance, certification, and production FAIT.
(9)	7.2.3.2.1.6.4	<u>LEV Avionics Pallet Integration, Wiring, and Interfaces:</u> Mission equipment wiring/wave guides/coax, data bus cables or fiber-optic carriers, interface boxes/filters, and total avionics suite integration. Includes level of effort architecture analysis for all LTS flight elements that directly interface with the LEV stage.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.2.1.7	<u>LEV Stage Assembly and Checkout:</u> This item collects the labor effort and materials required for FAIT of the LEV stage. The FAIT activities are initial assembly planning and manufacturing development, final assembly tooling and special test equipment (factory support equipment similar to deliverable launch support equipment), hardware integration, in-process testing, and final acceptance testing. Excluded is total LTS FAIT (see WBS 7.1) and booster to LTS assembly (see WBS 3.0).
(8)	7.2.3.2.1.8	<u>LEV Stage Hardware Evaluation and Analysis:</u> Technical engineering analysis (stress, thermal, loads, and EMI) and manufacturing engineering level of effort labor related to hardware development and production phase setup. Includes design engineering liaison support for the test and production hardware fabrication.
(7)	7.2.3.2.2	<u>LEV Crew Module:</u> A summary WBS item that accumulates the costs and task resources for a four-man crew module used to accomplish a LTS mission to the Moon. No inputs are desired at this WBS level.
(8)	7.2.3.2.2.1	<u>LEV Crew Module Structures and Mechanisms:</u> A summary of the level-9 structures and mechanisms items. No inputs are desired at this level.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.2.1.1	<u>LEV Crew Module Structure:</u> Primary structure consisting of the body shell and debris shield, inner cabin panels, flight deck section, storm shelter and airlock structure, and LEV stage interface structure (cab to LEV).
(9)	7.2.3.2.2.1.2	<u>LEV Crew Module Secondary Structure:</u> Secondary structure consisting of equipment racks, ladders, lockers, cabin inner trim panels, hatches, and brackets. Excludes load carrying structure, crew provisions, and thermal protection. Includes hatch and equipment provisioning mechanisms.
(8)	7.2.3.2.2.2	<u>LEV Crew Module Thermal Protection:</u> Passive multilayer insulation thermal blankets, heat radiator panels, protective paints, heat sinks, window/hatch conditioning, transpiration panels (water wall), and avionics thermal control equipment. Excludes ECLSS, engine system, and primary power heat exchangers or closed-loop radiators for separate temperature requirements.
(8)	7.2.3.2.2.3	<u>LEV Crew Module Electrical Power:</u> Primary solar cell and fuel cell power sources, electrical storage devices, and power distribution equipment summary. No inputs are desired at this WBS level.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.2.3.1	<u>LEV Crew Module Primary Power:</u> Power sources such as solar cells, fuel cells, and battery storage devices needed for extended surface operation. Includes electrolyzer storage units.
(9)	7.2.3.2.2.3.2	<u>LEV Crew Module Power Distribution and Control:</u> Power conditioning, inversion, conversion, regulation, and distribution hardware. Includes power wiring and breaker panels. Excludes mission and controls wiring and fiber-optic hardware.
(8)	7.2.3.2.2.4	<u>LEV Crew Module Avionics:</u> A summary of the avionics suite required to interface with the LEV and internal crew module subsystems. No inputs are desired at this WBS level.
(9)	7.2.3.2.2.4.1	<u>LEV Crew Module GN&C Electronics:</u> Design, analysis, and fabrication of control and inertial guidance interface units that are primary navigation equipment for manned missions. Includes gyroscopes, accelerometers, range-range-rate radars (Doppler), optical sensors, signal conditioners, network interface boxes, and laser equipment used for navigation and docking with other space nodes or flight elements.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.2.4.2	<u>LEV Crew Module Communication and Data Handling:</u> Design, analysis, and fabrication of space communications and data management equipment used on manned missions. Also includes ATDRSS equipment and laser communications, telemetry transceivers for intravehicle and vehicle/mission control data transfers, navigation beacon, central computers, signal conditioner, data buses, fiber-optic lines, IR or neural network interfaces, antennas, and imbedded software. May include some valve controls (if included in the central computer functions). Includes multiplexers and filters.
(9)	7.2.3.2.2.4.3	<u>LEV Crew Module Vehicle Health Monitoring Subsystem:</u> VHMS sensors and maintenance interface equipment consisting of a complete avionics sensor array, BIT function and BIT equipment interfaces, network interface units, sensor interface units, fiber-optic components, mass memories, and special neural equipment. Includes object-oriented expert system software and VHMS development, testbeds, analysis, vendor surveillance, procurement, certification, and production integration. Also includes extensive human engineering effort at vendors for man-machine interfaces and astronaut training.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(9)	7.2.3.2.2.4.4	<u>LEV Crew Module Controls and Displays:</u> Next-generation flat screen displays with multifunction capability, smart helmet interface, multifunction keyboards, expert system Ada and assembly language real-time software (imbedded), decentralized processors networked to the central computer, and redundant display controller units. Includes some voice-activated control capability and an extensive integration task. Vendor non-recurring also includes certification, human engineering, avionics integration lab support, and technical publications support. Equipment will have self-contained emergency power batteries in every unit.
(9)	7.2.3.2.2.4.5	<u>LEV Crew Module Avionics Integration and Maintainability:</u> Architecture design and optimization (level of effort), environmental testing, failure testing, maintainability/access evaluation, integration, and final acceptance testing of the entire crew module avionics suite for manned missions. Includes special studies on thermal and flight critical/safety critical issues, as directed by NASA, and crew module avionics special test equipment from vendors for suite checkout.

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WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(8)	7.2.3.2.2.5	<u>LEV Crew Module Flight Software</u> : Real-time flight software design, development, test, V&V, integration, and delivery. Includes control and display vendor requirements definition and interface tasks by the prime integration contractor and independent software V&V contractor. Excludes imbedded software (see WBS 7.2.3.2.2.4.4 above).
(8)	7.2.3.2.2.6	<u>LEV Crew Module ECLSS</u> : Environmental control and life support systems (ECLSS), including cabin environmental controls, pressure, humidity, breathing atmosphere, temperature, heat rejection, and carbon dioxide removal equipment. Includes development, testing, and integration of the equipment into an efficient ECLSS/avionics package and the necessary interface equipments.
(8)	7.2.3.2.2.7	<u>LEV Crew Module Crew Provisions and EVA Support</u> : Crew provisioning equipment such as flight couches, hygiene equipment, waste and potable water management, cabin lighting, medical science equipment, extra vehicular activity (EVA) supplies, travel kits, work tools, sleep stations and restraints, and exercise equipment. Includes entertainment audio/video equipment and also special emergency gear.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(8)	7.2.3.2.2.8	<u>LEV Crew Module Final Assembly, Integration and Test:</u> FAIT labor and materials planning, development, coordination, accomplishment, crew module certification, acceptance test, and delivery effort. Includes engineering liaison effort and special integration analyses level of effort tasks in support of development and production.
(7)	7.2.3.2.3	<u>LEV Stage and Crew Module FAIT:</u> Assembly of the LEV stage and LEV crew module (manned missions only) into an LTS excursion configuration vehicle. Includes planning, analysis, development, special integration tooling and test equipment, and production labor/materials tasks. On-orbit assembly tasks are accounted for in the O&S phase WBS 7.3.
(5)	7.2.4	<u>LTS Support Equipment:</u> A summary of the mission ground and space support equipment (SE) hardware and software for an integrated LTS. Includes SE for supporting operations of: a core stage (sometimes called a lunar Transfer Vehicle or "LTV"), crew module(s) (when required), lunar excursion vehicle or "LEV" (when required), and LTS payload accommodations equipment. Includes design, development, fabrication, test, delivery or request, and management costs associated with support equipment. No inputs are desired at this WBS level.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.4.1	<u>Ground (Launch) Support Equipment (GSE)</u> : Handling, checkout, purge, fueling, defueling, crew loading, portable power, air bearing platform, portable work platforms, sling, transporter, and launch adapter equipments for ground processing and launch support at the primary launch site (KSC). Also includes emergency abort equipment for alternative Earth ground and/or water landings. Includes both Government-furnished equipment (GFE) and procured equipment peculiar to the space transportation vehicle requirements.
(6)	7.2.4.2	<u>Space (including Special lunar) Support Equipment (SSE)</u> : Handling, checkout, meteorite protection, purge, fueling, defueling, crew ingress/egress adapter, EVA work platform, EVA tool, teleoperator free-flyer, space transporter interface, and space node maintenance adapter equipments for on-orbit processing and/or launch support at the primary space or lunar launch sites (SSF or lunar base nodes). Includes both GFE and procured equipment peculiar to the space transportation vehicle requirements. Lunar surface systems equipment is accounted for in a separate NASA-JSC project (considered GFE to LTS; see WBS 4.0 description). Includes SSF and lunar surface systems integration engineering and interface control definition tasks during development and initial deployment.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(5)	7.2.5	<u>LTS Payload Accommodations:</u> This element includes systems design engineering labor to provide definition and support necessary to accommodate payloads on LTS vehicles. See WBS 1.0 for payload integration labor effort.
(5)	7.2.6	<u>Software Development and Integration:</u> A summary of the development facility, LTV/LEV flight software, and LTS avionics integration laboratory facilities effort associated with software architecture design, test, verification, and validation. This is a summary level WBS, no inputs are desired at this level.
(6)	7.2.6.1	<u>Software Development Facility (SDF):</u> All software development effort and computer equipment required to test, verify, validate, and maintain databases for the LTS flight and mission software. The SDF software functional work packages include special compilers and build tools, analysis and statistics software, control functions software, math models, common functions, preprocessor and post processor software, link editor, flight equipment interface development (FEID) software, communicator, and plotter application software. Computer equipment includes large-scale mainframe, minicomputer, microcomputer, and computer vendor application software costs associated with SDF setup.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.6.2	<u>LTV/LEV Flight Software:</u> LTV/LEV software effort to establish requirements, design, develop, code, integrate, and implement flight software. Flight software (deliverable) functional work packages include guidance and navigation software, operating system software, COMPOOLS, vehicle utility software, system control software, system management software, and I-loads (individual mission data load) and payload interfaces software (varies by sortie type.) Excludes crew module equipment flight software (see WBS 7.2.3.1.3.5 and 7.2.3.2.2.5 for explanation of crew modules flight software). Includes independent V&V contractor effort.
(6)	7.2.6.3	<u>LTV/LEV Avionics Laboratory Software:</u> Avionics integration laboratory (AIL) software effort associated with both hardware and software development. Integration test software required to verify and validate flight and ground support equipment software with the avionics as an integrated LTS function. Includes a substantial amount of equipment vendor technical support and purchased test software.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.6.4	<u>LTS Launch Support & Control (LSC) Software:</u> Software used for launch support at the primary launch site (KSC). Includes software functional work packages such as factory integration and test equipment software, launch support equipment software, range management communications and network software, maintenance and processing database system, booster interface software, and other verification and checkout software.
(6)	7.2.6.5	<u>Mission Operations Software:</u> Requirements development, design, development , coding, test, verification, validation, and implementation of LTS mission operations software for Earth, lunar base, and SSF mission (traffic) control (MC) nodes. Excludes booster and payload mission control software. Typical software (deliverable) functional work packages include mission control interfaces, MC operating system, orbital mechanics and modeling support, MC system controls and displays software, executive management and security, communication and network services (can be similar to WBS 7.2.6.4 function), database management and control, and mission schedules and analysis software. Excludes MC center hardware (see facilities under Mission Operations Support, WBS 7.2.9).

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.6.6	<u>Software Productivity Management:</u> A management council of representatives from each software development area to develop overall goals and objectives; teach, coordinate, develop an integration plan; and provide LTS projects status and integration performance statistics in a TQM environment. Includes special funds for consulting services.
(5)	7.2.7	<u>System Test Operations:</u> A summary item for hardware ground and flight test effort. No inputs are desired at this WBS level.
(6)	7.2.7.1	<u>LTS Ground Testing:</u> Ground testing of LTV/LEV hardware articles in aerospace laboratory, buoyancy tank, wind tunnel, and environmental chamber simulated environments. Includes labor, materials, and test facilities costs for test requirements development, planning, setup, accomplishment, coordination, and documentation. Excludes software development and the SDF (see WBS 7.2.6). Includes national testbed systems test engineering interface effort.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.7.2	<u>LTS Flight Testing:</u> Flight test requirements development, design, coordination, planning, and test engineering sustaining support for the LTS. Includes flight test data systems management and postflight data reduction. Also includes any flight test-unique hardware required as special test equipment, which is not required to accomplish any other program work packages and flight test hardware maintenance at the test site. Excludes recurring mission launch and launch services support of operational vehicles (see WBS 7.3).
(5)	7.2.8	<u>Ground Operations and Control:</u> A summary-level WBS item for ground operations and control development during the DDT&E phases and initial production phase. No inputs are desired at this WBS level.
(6)	7.2.8.1	<u>Ground Operations Development:</u> Non-recurring, level of effort work package labor to develop an efficient Earth ground operations system for LTS. Includes contractor planning and range coordination support at KSC and CCAFS. Also includes major subcontract effort from construction engineering firms and major ground equipment suppliers for ground systems architecture and design tasks.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(6)	7.2.8.2	<u>Ground Processing and Launch Facilities:</u> Facilities development and construction costs associated with the processing and launch of LTS hardware from the primary launch center. Includes resources required to modify any facilities needed for processing not on the primary launch site property (outside KSC/CCAFS) that would be dedicated solely to the LTV/LEV hardware assembly and test.
(6)	7.2.8.3	<u>Base Site Operations Engineering Development:</u> Level of effort liaison engineering for KSC range safety, NASA and Government support contractors interfaces during the development subphases. Non-recurring labor effort only. Includes primary launch site property management and engineering support.
(6)	7.2.8.4	<u>Initial spares and Repair Parts Setup:</u> Initial LTS LTV/LEV and support equipment spares hardware costs are estimated here. Includes initial spares management labor support and inventory storage costs during the flight test program. Transitions into replenishment spares WBS work in O&S phase after the last flight test in development is completed. See flight test WBS 7.2 for flight test maintenance labor.

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WBS (LEVEL)	WBS ITEM NO.	WBS DESCRIPTION
(5)	7.2.9	<u>LTS Mission Operations Non-recurring:</u> LTS mission operations planning, development, analysis, orbital mechanics engineering, ITS/payload interface effort, and transportation node mission requirements development tasks during phase C/D and the initial years of production. See WBS 7.3 for recurring LTS level mission operations support effort and WBS 8.0 for space transportation system-level effort of mission control.
(4)	7.3	<u>LTS Operations & Support (O&S) Phase:</u> A summary of LTS operations and support phase estimates for a specified mission model duration of time. No inputs are desired at this summary WBS level.
(5)	7.3.1	<u>LTS Hardware O&S Processing:</u> Recurring operations receiving, inspection, offloading, safeing, scheduled maintenance, unscheduled maintenance, launch site modifications implementation, verification and checkout, and transfer efforts required to achieve the LTS mission model operations and maintenance objectives. Includes both Earth and space processing and refurbishment activities.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(5)	7.3.2	<u>LTS O&S Mission Support:</u> Contractor mission support teams located at mission control sites around the world during LTS mission periods for recurring operations support. Includes preflight, flight, and postflight support tasks. Also includes relocation and special travel and per diem costs when required. Excludes central transportation control center estimates (see WBS 8.0.).
(5)	7.3.3	<u>LTS Ground Personnel Training:</u> Recurring training equipment and labor costs associated with training ground personnel involving safety, operations, and non-nominal operations tasks and event simulations. Non-recurring setup is accounted for in WBS 7.2.2.2 and WBS 7.2.2.4. Flight and space support crew training is accounted in WBS 6.0.
(5)	7.3.4	<u>LTS Earth Landing and Recovery Support:</u> Flight element recovery and crew recovery support for earth return mission sorties only. Excludes SSF and lunar base node operations support (see WBS 4.0 and WBS 5.0.) Includes alternate landing sites labor and emergency equipment support, if required.

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(5)	7.3.5	<u>LTS Non-Nominal Operations Support:</u> Abort and standdown contingency resources budget for delayed or emergency recurring operations. Includes backup crews and overtime allowances for pad aborts, stranded crews, and emergency interface systems support (e.g., ACRV, SSF, lunar base, international space vehicle support).
(5)	7.3.6	<u>LTS O&S Logistics Services:</u> Recurring spares, depot repair, SRQ&M recurring support, transportation, storage, and launch/postlaunch cleanup resources after the last development phase flight test and pathfinder activities.
(5)	7.3.7	<u>LTS Consumables and Expendables:</u> Flight and ground operations cryogenic fluids, gases, lubricants, and expended service materials required to accomplish missions. Excludes ETO consumables and expendables in all mission scenarios.
(5)	7.3.8	<u>LTS Software Maintenance:</u> Fully functional updates and documentation maintenance of the deliverable and test software packages for LTS operation. Includes update V&V effort and new computer/software training to LTS operations personnel as required. (At least 50% of deliverable software life cycle costs for preliminary planning estimates; reference Mr. Barry Boehm: "Software Engineering Economics," Prentice Hall, N.J., 1981; page 533.)

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<u>WBS (LEVEL)</u>	<u>WBS ITEM NO.</u>	<u>WBS DESCRIPTION</u>
(5)	7.3.9	<u>LTS Base Operations Support:</u> Fire protection, security, janitorial, common support equipment transportation, and other base support personnel and materials costs allocated to the LTS at the mission control center and primary launch sites. Usually referred to as "Government overhead support costs." Commonly estimated as a factor of LTS contractor direct O&S labor costs at the O&S base operations support sites.
(3)	8.0	<u>Mission Control:</u> Central control center facilities, labor resources, and equipment required to develop, set up, construct, integrate, and operate an international Lunar Exploration and Habitation Program. Includes ETO, LEO, Lunar Transportation System, trans-Earth and trans-Mars, and lunar surface system (LSS) mission and teleoperator controls support as a part of a total space transportation architecture. Includes overall integration of LTS mission planning with other major space transportation and space science programs, as well as possible concurrent DoD space operations coordination.

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2-4.0 FUNCTIONAL ELEMENT DESCRIPTIONS

This section contains a listing of the functional labor, facilities, and material resource categories to be used for estimating STV lunar transportation system configuration options. The generic list of functional elements resembles NASCOM-H and GE Price cost model labor elements to assist in coordination of inputs with the Boeing proprietary parametric cost model (PCM). PCM is used by the Boeing team to develop acquisition phase cost estimates for the STV concepts and requirements study contract.

The functional elements list will be modified for different contractor accounting systems as parametric estimating methods are replaced by firm proposal detail estimating methods. Depending on the contractor, some summary-level categories may remain the same as those shown in the following:

**FUNCTIONAL
ELEMENT****ELEMENT DESCRIPTION****Engineering**

Design, technical staff, and dDrafting engineering direct labor. Includes specifications development at the component or subassembly procurement level.

**Systems
Engineering**

Engineering labor effort to convert performance requirements to into system specifications. Includes mission analysis, system trade studies, system requirements development, system interfaces definition and management, integration engineering, and system engineering management studies support (e.g., DTC/LCC and system effectiveness analysis).

**FUNCTIONAL
ELEMENT**

ELEMENT DESCRIPTION

Software

Software engineering and programmer labor associated with requirements development, design, coding, test, validation, verification, implementation, maintenance, and upgrades software effort.

Liaison

Engineering

Design engineering support during the production phase of the project. Includes technical staff engineering support during production.

Manufacturing

Engineering

Manufacturing engineering direct labor performs producibility studies, test article fabrication planning, design coordination, long lead materials coordination, shop planning papers development, and factory setup special studies effort in development. Production phase activities include tool and production planning, factory/design engineering coordination, and production management staff support tasks.

**FUNCTIONAL
ELEMENT****ELEMENT DESCRIPTION****Logistics**

Development tasks include spares management setup, repair and maintenance analysis and planning, and logistics support analysis and database setup. Production tasks include initial spares management, repair parts and maintenance setup, launch site equipment tryout support, ground crew training, and depot maintenance setup. Operations and support phase tasks include all levels of logistics management operational system support.

**Project
Management**

Program management and control, travel and living (per diem) expenses, business computer systems operations costs, and preparation of inhouse reports. Includes Data Management, Facilities Engineering, Safety Engineering, Outplant Support, and Quality Assurance (QA) direct labor. The QA direct engineering and management services labor is that which is not included in the recurring manufacturing shop and technicians labor wraparound rates (Q.A. inspection and shop supervision).

**Development
Technicians**

Manufacturing shop technicians assigned to the engineering laboratories for hardware and software ground and flight testing tasks. Includes breadboard, wind tunnel, engineering model, environmental, protoflight assembly, ground subsystem testing, integration labs, and qualification testing support during development.

**FUNCTIONAL
ELEMENT****ELEMENT DESCRIPTION****Tooling
Shop**

Tool design and factory test and handling equipment fabrication labor during development (soft tooling concept). Production tooling fabrication labor for all hard tooling items. Includes labor to produce and procure special factory test equipment for use in minor and major assembly of flight elements before system buyoff.

Subcontract

Major subsystem items procured from second-tier aerospace hardware or software vendors. Generally considered to be direct materials cost above a fixed dollar threshold level for a specific contract.

**Purchased
Equipment**

Subsystem "black box level" or replaceable unit level hardware or application module software that is procured from a vendor to be integrated into a larger subsystem or subassembly. These vendors are also second-tier suppliers to the flight element integration contractor.

Remote Site

Contractor support labor at the operating bases, which is a separate services division from the hardware production division of the contractors. Usually estimated with different labor wraprates than contractor inplant effort.

**FUNCTIONAL
ELEMENT****ELEMENT DESCRIPTION****Space Operations****Factors**

Special wraprate estimating factors for IVA, EVA, SSF, and other in-space costs in support of the mission. Figure 2-4.0-1 contains the listing of space operations factors, in FY1991 dollars, used in performing life cycle cost trades.

Spares**Factors**

These hardware estimating factors are selected from historical cost ratio data. IUS and Burner II (expendable) systems ran around 3% of total estimated contractor flight hardware cost (the space hardware factor lower boundry). Reusable commercial air transportation systems, such as Boeing airplanes, require approximately 25% for low-utilization, medium quantity flight operations (more than five airplanes delivered). Saturn 1C spares were about 16% of total (dry weight) flight hardware costs. Therefore, percentages for initial spares in DDT&E are 3% for expendable hardware, and 9% to 10% for reusable elements. Recurring spares factor is selected at 3% per year for LCC planning estimates.

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

<u>SERVICE OR LABOR TASK, ON-ORBIT OR IN-SPACE</u>	<u>UNIT OF MEASURE</u>	<u>UNIT ESTIMATE (1991 DOLLARS)</u>
Extravehicular Activity (EVA)	Crew (2) + IVA Obsvr. Hour	\$ 135,500 /hr.
Intravehicular Activity (IVA)	Astronaut (1) Labor Hour	21,000 /hr.
<u>SSF/Free Flyer Services:</u>		
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 2-4.0-1. Preliminary Space Operations Factors for LCC Estimating

**FUNCTIONAL
ELEMENT****ELEMENT DESCRIPTION****Requirements
Factor**

This project level factor of 30% is a contingency estimating factor for future changes in program requirements. These undefined major budgeting and mission need requirements changes have traditionally increased hardware and software project costs on major space programs of this magnitude. The factor is provided by NASA.

**Contractor
Fee**

The fee and profit factor for first-tier contractor effort on the Lunar Transportation System project is set at 10% for all LCC phases. This factor is provided by NASA. The base is the estimated contractor dollars plus requirements contingency factor dollars.

**NASA Program
Support**

A factor of 5% to 15% (depending on the flight element type and maturity of the hardware or program phase) is allocated at the project level. Each LCC phase summary estimate includes this estimating factor for Government program management and support costs. The base is the sum of estimated contractor dollars, requirements contingency dollars, and contractor fee dollars.

NASA National Aeronautics and Space Administration		Report Documentation Page	
1. Report No. DRD MA-182TE/No. 13		2. Government Accession No. N/A	
3. Recipient's Catalog No. N/A		4. Title and Subtitle "Space Transfer Vehicle (STV) Concepts & Requirements Study Phase I Final Report"	
5. Report Date 4-1-91		6. Performing Organization Code PT, NASA MSFC	
7. Author(s) T. Vinopal Boeing Aerospace and Electronics		8. Performing Organization Code No. N/A	
9. Performing Organization Name and Address Boeing Aerospace and Electronics Business Development P.O. Box 3999 - Seattle, WA 98124		10. Work Unit No. N/A	
11. Contract or Grant No. NAS8-37855		12. Sponsoring Agency Name and Address NASA George C. Marshall Space Flight Center Huntsville, AL 35812	
13. Type of Report and Period Covered Final Report, Phase I 8/1/89 - 4/1/91		14. Sponsoring Agency Code N/A	
15. Supplementary Notes N/A			
16. Abstract This report presents the results of systems analyses and conceptual design of space transfer vehicles (STV). The missions examined included piloted and unpiloted lunar outpost support and spacecraft servicing, and unpiloted payload delivery to various earth and solar orbits. The study goal was to examine the mission requirements and provide a decision data base for future programmatic development plans. The final lunar transfer vehicles provided a wide range of capabilities and interface requirements while maintaining a constant payload mission model. Launch vehicle and space station sensitivity was examined, with the final vehicles as point designs covering the range of possible options. Development programs were defined and technology readiness levels for different options were determined. Volume I presents the executive summary, Volume II provides the study results, and Volume III the cost and WBS data.			
17. Key Words (Suggested by Author(s)) Lunar Transfer Vehicle, Upper Stage, SSF, SEI, Manned Spacecraft, Launch Escape System, Operability, 90 day study.		18. Distribution Statement N/A	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of pages	22. Price N/A

NASA FORM 1626 OCT 86