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ORBITAL TRANSFER VEHICLE

CONCEPT DEFINITION AND SYSTEMS ANALYSIS STUDY

FINAL REPORT – PHASE I
VOLUME V

WBS AND DICTIONARY
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Final Report

Volume V

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FOREWORD

This final report of the Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Study was prepared by Boeing Aerospace Company for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-36107. The study was conducted under the direction of the NASA OTV Study Manager, Mr. Donald Saxton and during the period from August 1984 to September 1986.

This final report is organized into the following nine documents:

VOL. I Executive Summary (Rev. A)

VOL. II OTV Concept Definition & Evaluation

- Book 1 - Mission Analysis & System Requirements
- Book 2 - Selected OTV Concept Definition - Phase I
- Book 3 - Configuration and Subsystem Trade Studies
- Book 4 - Operations and Propellant Logistics

VOL. III System & Program Trades

VOL. IV Space Station Accommodations

VOL. V WBS & Dictionary

VOL. VI Cost Estimates

VOL. VII Integrated Technology Development Plan

VOL. VIII Environmental Analysis

VOL. IX Implications of Alternate Mission Models and Launch Vehicles

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ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
AFE	Aeroassist Flight Experiment
AGE	Aerospace Ground Equipment
AL	Aluminum
ASE	Airborne Support Equipment
A/T	Acceptance Test, Auxiliary Tank
AUX	Auxiliary
AVG	Average
B/B	Ballute Brake
B/W	Backwall
CDR	Critical Design Review
CPU	Central Processing Unit
CUM	Cumulative
DAK	Double Aluminized Kapton
DDT&E	Design, Development, Test & Evaluation
DELIV	Delivery
DMU	Data Management Unit
DoD	Department of Defense
EPS	Electrical Power System
FACIL	Facility
FFC	First Flight Certification
FLTS	Flights
FOSR	Flexible Optical Surface Reflector
FRCI	Fiber Refractory Composite Insulation
F.S.	Fail Safe
FSI	Flexible Surface Insulation
FTA	Facilities Test Article
GB	Ground Based
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GRD	Ground
IOC	Initial Operational Capability
IRU	Inertial Reference Unit
IUS	Inertial Upper Stage

JSC	Johnson Space Center
L/B	Lifting Brake
LCC	Life Cycle Cost
L/D	Lift to Drag
MGSS	Mobile GEO Service Station
MLI	Multilayer Insulation
MPS	Main Propulsion System
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
OMV	Orbital Maneuvering Vehicle
OPS	Operations
OTV	Orbital Transfer Vehicle
PAM	Payload Assist Module, Propulsion Avionics Module
PDR	Preliminary Design Review
PFC	Preliminary Flight Certification
P/L	Payload
PROD	Production
PROP	Propellant
RCS	Reaction Control System
REF	Reference
RGB	Reusable Ground Based
R&R	Remove & Replace
RSB	Reusable Space Based
RSI	Reusable Surface Insulation
SB	Space Based
S/C	Spacecraft
SCB	Shuttle Cargo Bay
SIL	Systems Integration Laboratory
STA	Structural Test Article
STG	Stage
STS	Space Transportation System
T/D	Turndown
TDRS	Tracking Data Relay Satellite
TPS	Thermal Protection System
TT&C	Telemetry, Tracking and Control
WBS	Work Breakdown Structure

1.0 INTRODUCTION

This section provides a description of the study in terms of background, objectives, issues, organization of study and report, and the content of this specific volume.

Use of trade names, names of manufacturers, or recommendations in this report does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

And finally, it should be recognized that this study was conducted prior to the STS safety review that resulted in an STS position of "no Centaur in Shuttle" and subsequently an indication of no plans to accommodate a cryo OTV or OTV propellant dump/vent. The implications of this decision are briefly addressed in section 2.2 of the Volume I and also in Volume IX reporting the Phase II effort which had the OTV launched by an unmanned cargo launch vehicle. A full assessment of a safety compatible cryo OTV launched by the Shuttle will require analysis in a future study.

1.1 BACKGROUND

Access to GEO and earth escape capability is currently achieved through the use of partially reusable and expendable launch systems and expendable upper stages. Projected mission requirements beyond the mid-1990's indicate durations and payload characteristics in terms of mass and nature (manned missions) that will exceed the capabilities of the existing upper stage fleet. Equally important as the physical shortfalls is the relatively high cost to the payload. Based on STS launch and existing upper stages, the cost of delivering payloads to GEO range from $12,000 to $24,000 per pound.

A significant step in overcoming the above factors would be the development of a new highly efficient upper stage. Numerous studies (ref. 1, 2, 3, 4) have been conducted during the past decade concerning the definition of such a stage and its program. The scope of these investigations have included a wide variety of system-level issues dealing with reusability, the type of propulsion to be used, benefits of aeroassist, ground- and space-basing, and impact of the launch system.

1.2 OBJECTIVES AND ISSUES

The overall objective of this study was to re-examine many of these same issues but within the framework of the most recent projections in technology readiness, realization that a space station is a firm national commitment, and a refinement in mission projections out to 2010.

During the nineteen-month technical effort the specific issues addressed were:

a. What are the driving missions?

b. What are the preferred space-based OTV characteristics in terms of propulsion, aeroassist, staging, and operability features?

c. What are the preferred ground-based OTV characteristics in terms of delivery mode, aeroassist, and ability to satisfy the most demanding missions?

d. How extensive are the orbital support systems in terms of propellant logistics and space station accommodations?

e. Where should the OTV be based?

f. How cost effective is a reusable OTV program?

g. What are the implications of using advanced launch vehicles?

1.3 STUDY AND REPORT ORGANIZATION

Accomplishment of the objectives and investigation of the issues was done considering two basic combinations of mission models and launch systems. Phase I concerned itself with a mission model having 145 OTV flights during the 1995-2010 timeframe (Revision 8 OTV mission model) and relied solely on the Space Shuttle for launching. Phase 2 considered a more ambitious model (Rev. 9) having 442 flights during the same time frame as well as use of a large unmanned cargo launch vehicle and an advanced Space Shuttle (STS II).

The study is reported in nine separate volumes. Volume I presents an overview of the results and findings for the entire study. Volume II through VIII contains material associated only with the Phase I activity. Volume IX presents material unique to the Phase II activity. Phase I involved five quarters of the technical effort and one quarter was associated with the Phase II analyses.

1.4 DOCUMENT CONTENT

This document displays the Work Breakdown Structure (WBS) and describes the program, phase, and hardware elements.

2.0 WORK BREAKDOWN STRUCTURE

2.1 PROGRAM AND PHASE WBS

The Work Breakdown Structure (WBS) for the overall Space Transportation System is summarized in Figure 2.1-1, showing major program elements. The Space Transportation System, as associated with the OTV program, consists of three major program elements: STS/SDV Launch Systems, Orbital Transfer Vehicle, and Space Station Accommodations. The WBS for these elements is shown in Figure 2.1-2. Each program element consists of three phases: DDT & E, Production, and Operations. Each phase is further broken down to major functions and subfunctions, as shown in Table 2.1-1. Subfunctions are at the WBS level 4.

Cost estimates for the OTV program are presented in Volume VI.

2.2 HARDWARE ELEMENT WBS

Each major program element consists of separate hardware elements. Table 2.2-1 includes the hardware element breakdown for the STS/SDV Launch System, Table 2.2-2 gives the breakdown of the Orbital Transfer Vehicle, and Table 2.2-3 gives the breakdown for Space Station Accommodations.

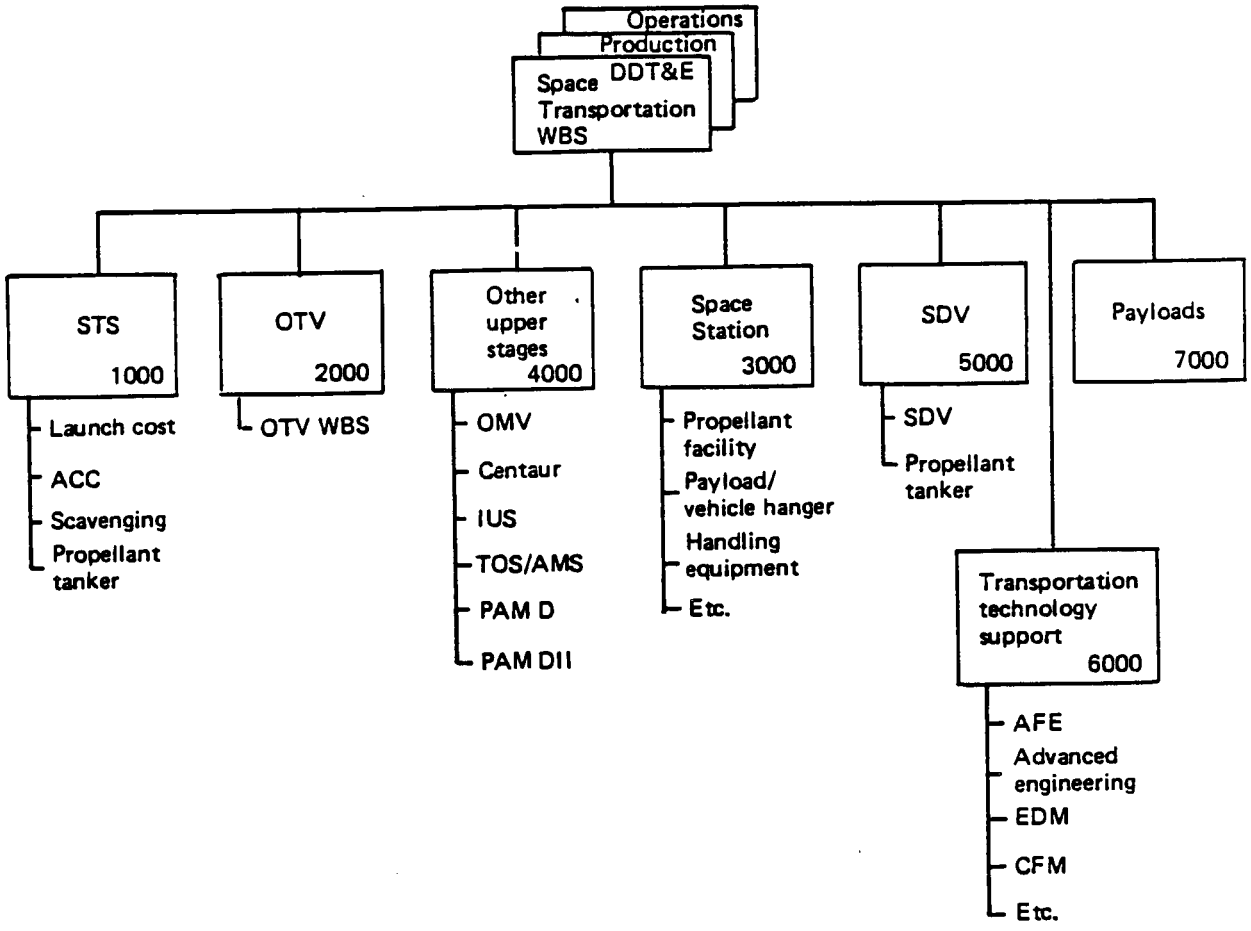

Figure 2.1-1. Space Transportation System WBS

OTV-1749

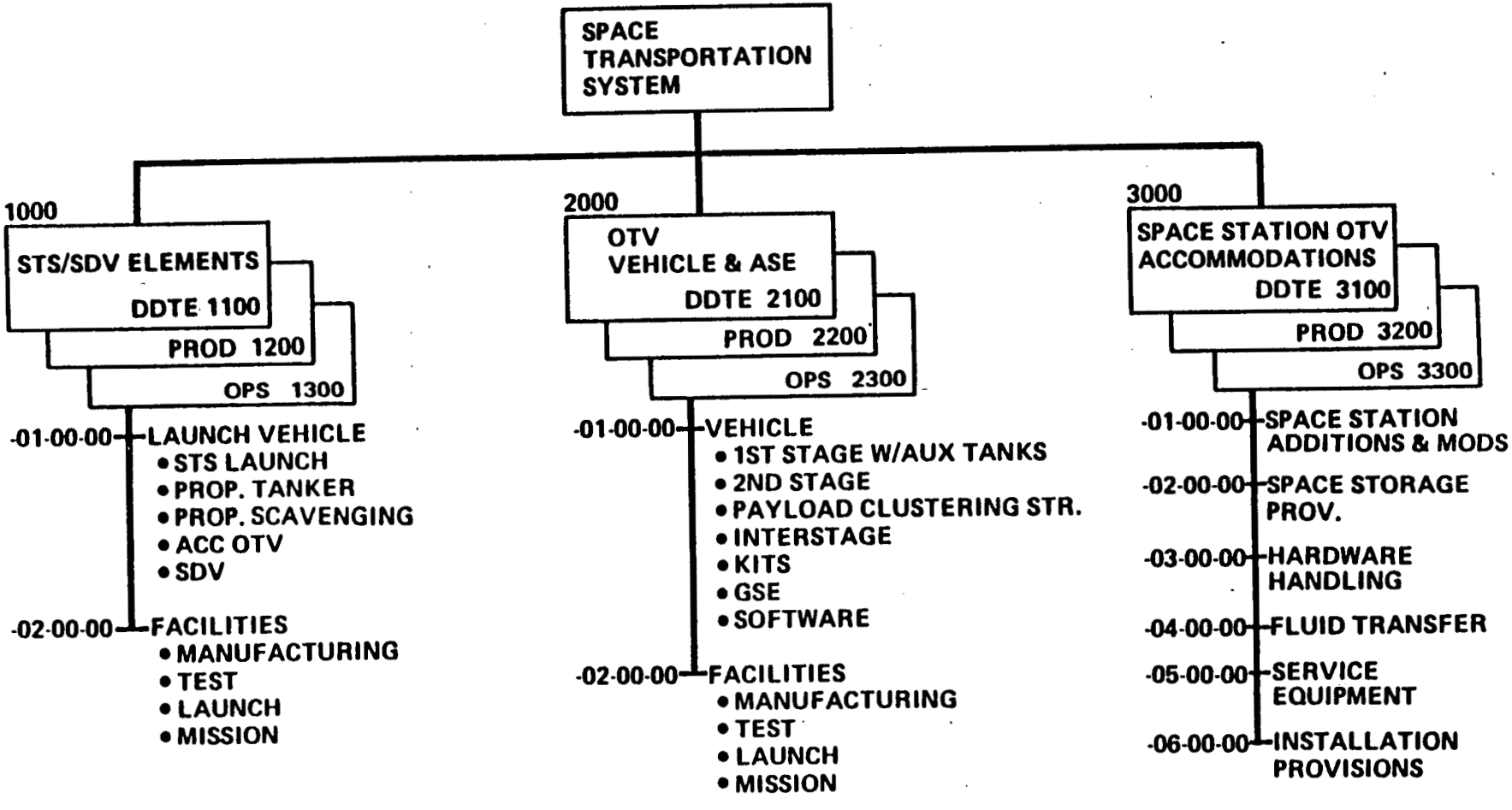

Figure 2.1-2. OTV Top Level WBS

OTV-1750

TABLE 2.1-1 TRANSPORTATION SYSTEM PHASE AND FUNCTIONAL WBS

PHASE FUNCTION SUB-FUNCTION	STS/SDV 1000-	OTV 2000-	SPACE STATION ACCOMM. 3000-
DDT&E	1100	2100	3100
Program Management	1110	2110	3110
Engineering	1120	2120	3120
Systems Eng. & Integ.	1121	2121	3121
Design & Development	1122	2122	3122
Software Eng.	1123	2123	3123
Manufacturing	1130	2130	3130
Tooling & STE	1131	2131	3131
Ground Test Hdware	1132	2132	3132
Flight Test Hdware	1133	2133	3133
Test	1140	2140	3140
Systems Test Operations	1141	2141	3141
Operations	1150	2150	3150
Operations Support	1151	2151	3151
Launch Support	1152	2152	3152
PRODUCTION	1200	2200	3200
Program Management	1210	2210	3210
Engineering	1220	2220	3220
Systems Eng. & Integ.	1221	2221	3221
Design & Development	1222	2222	3222
Manufacturing	1230	2230	3230
Tooling & Ste.	1231	2231	3231
Flight Hardware	1232	2232	3232
OPERATIONS	1300	2300	3300
Operations Support	1310	2310	3310
Program Support	1311	2311	3311
Spares Procurement	1312	2312	3312
Ground-Based Mission Cont.	1313	2313	3313
Space-Based Mission Cont.	1314	2314	3314
Launch Support	1320	2320	3320
Ground-Based Operations	1321	2321	3321
Space-Based Operations	1322	2322	3322
Propellant Operations	1323	2323	3323

TABLE 2.2-1 STS/SDV HARDWARE ELEMENT WBS

HARDWARE ELEMENTS	ELEMENT NO.
LAUNCH VEHICLE	01-00-00
Integration	01-01-00
Shuttle Vehicle System	01-02-00
Prop. Tanker System	01-03-00
Integration	01-03-01
Tanker	01-03-02
ASE	01-03-03
Handling Equipment	01-03-04
Propellant Scavenging System	01-04-00
Aft Cargo Carrier System	01-05-00
FACILITIES	02-00-00
Manufacturing	02-01-00
Test	02-02-00
Launch	02-03-00
Mission	02-04-00

TABLE 2.2-2 ORBITAL TRANSFER VEHICLE HARDWARE ELEMENT WBS

HARDWARE ELEMENTS	ELEMENT NO.
ORBITAL TRANSFER VEHICLE	01-00-00
Vehicle Integration	01-01-00
Stage 1	01-02-00
Integration	01-02-01
Structures	01-02-02
Propellant Tanks	01-02-03
Propulsion, Less Eng.	01-02-04
Main Engines	01-02-05
RCS	01-02-06
G, N, & C	01-02-07
Commun. & Data Handling	01-02-08
Electric Power	01-02-09
Thermal Control	01-02-10
Aerobrake	01-02-11
GSE	01-02-12
ASE	01-02-13
Space Support Equipment	01-02-14
Propellants	01-02-15
Auxiliary Tanks	01-02-16
Stage 2	01-03-16
Space Support Equipment	01-04-00
P/L Clustering Str.	01-05-00
Interstage	01-06-00
Kits	01-07-00
GSE	01-08-00
Software	01-09-00
FACILITIES	02-00-00
Manufacturing	02-01-00
Test	02-02-00
Launch	02-03-00
Mission	02-04-00
Training	02-05-00

TABLE 2.2-3 SPACE STATION ACCOMMODATIONS

HARDWARE ELEMENT WBS

HARDWARE ELEMENTS	ELEMENT NO.
Space Station Additions and Modifications	01-00-00
Independent Platform	01-01-00
Station Modifications	01-02-00
Hangar System	02-00-00
OTV Hangar	02-01-00
Auxiliary Tank Hangar	02-02-00
Storage Provisions	02-03-00
Propellant Supply System	03-00-00
Fluid Storage and Transfer	03-01-00
Gas Storage and Transfer	03-02-00
Handling Equipment	04-00-00
Service Equipment	05-00-00
Storage	06-00-00

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3.0 WBS DICTIONARY

3.1 PROGRAM AND PHASE DICTIONARY

Definitions for the top level WBS programs are presented in Table 3.1-1. Definitions for DDT&E, production, and operations phases, with associated functions are given for the OTV program in Tables 3.1-2 through 3.1-4. Phase and functional definitions for the STS/SDV element and Space Station accommodations element are similar to those of the OTV element.

3.2 HARDWARE ELEMENT DICTIONARY

Definitions for the hardware elements of the three major programs are presented in Tables 3.2-1 through 3.2-3. Table 3.2-1 includes STS/SDV hardware elements. Table 3.2-2 includes OTV hardware elements, and Table 3.2-3 includes Space Station accommodations hardware elements.

Table 3.1-1 SPACE TRANSPORTATION SYSTEM DEFINITIONS

FUNCTION NUMBER	DESIGNATION	DEFINITION
	Space Transportation System	This element is the total cost of the space transportation program associated with launch and support of the OTV. It is the summation of three major project elements. Included is all labor,material, and overhead required for the design, development, fabrication, assembly, testing, and operation of the STS launch system, the Orbital Transfer Vehicle System, and Space Station Accommodations. Each element is further subdivided into lower level cost elements representing program phases, functions, and subfunctions, as well as specific hardware elements.
1000	STS/SDV Launch Systems	This refers to all costs associated with the shuttle and/or shuttle—derived vehicle programs. Included are all functions and subfunctions required for design and development, testing, manufacture, and operations of this program, as well as all hardware elements associated with this program. Required functional elements are similar to those defined for the Orbital Transfer Vehicle in tables 3.1-2 through 3.1-4. Hardware elements are defined in table 3.2-1.
2000	Orbital Transfer Vehicle System	This refers to the total cost of the Orbital Transfer Vehicle Program. Included are all functions and subfunctions required for design, development, testing, manufacture, and operation of this program, as well

Table 3.1-1 SPACE TRANSPORTATION SYSTEM DEFINITIONS (Continued)

FUNCTION NUMBER	DESIGNATION	DEFINITION
		as all hardware elements associated with it. All functional elements are defined in table 3.1-2 through 3.1-4 and hardware elements are defined in Table 3.2-2.
3000	Space Station Accommodations	This refers to the total cost of OTV space station accommodations, including the design, development, testing, manufacture, and operation of all elements associated with accommodating an orbital transfer vehicle and its associated elements at the Space Station, whether it is a space-based or a ground-based vehicle. All phase and functional elements are similar to those defined for the Orbital Transfer Vehicle. Hardware elements are defined in table 3.2-3.

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TABLE 3.1-2 DDT&E PHASE FUNCTIONAL DEFINITIONS

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
2100	DDT&E Phase	This cost element includes the cost to develop the Orbital Transfer Vehicle beginning with the conceptual and definition activities and concluding when the vehicle elements are ready for operational use. Included is the design and development, manufacturing and test of the flight hardware elements and associated ground and airborne support. Tooling, personnel training, systems engineering, facilities, software and program management are also included. It involves the application of scientific and engineering effort to transform an operational need into an operational system possessing the desired performance parameters. An iterative process of definition, synthesis, analysis, design, test and evaluation is utilized. Included in the effort is the integration of related technical parameters to assure compatability of all physical, functional and program interfaces and to optimize the total system definition and design; along with the integration of reliability, maintainability, safety, human and other such factors into the total engineering effort. In addition to design and development of the airborne vehicle elements, costs include the acquisition of all ground equipment, and facilities necessary to support the vehicle development, and tooling necessary for production of test vehicles.

TABLE 3.1-2 DDT&E PHASE FUNCTIONAL DEFINITIONS (Continued)

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
2110	Program Management	Refers to the costs associated with the prime contractor's centralized effort in areas of program planning, control and administration. Includes such tasks as program documentation, financial and manpower control, interfacing with the customer and other contractors and material and project management.
2120	Engineering	Includes the cost of engineering effort that is in direct support of design, development and testing. It involves the coordination of design and development among the various subcontractors and vendors, and includes engineering analysis and integration of tests results, as well as software engineering.
2121	System Engineering and Integration	This is the cost to define the engineering requirements necessary to direct an integrated approach to design, development and operations. Includes requirements definitions, mission payload analyses, preliminary design, design integration, system optimization, interface compatibility, design reviews, technical risk assessment, technical performance assessment, countdown analysis and system engineering data.

TABLE 3.1.-2 DDT&E PHASE FUNCTIONAL DEFINITIONS (Continued)

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
		Integration activities include intersystem engineering interface tasks with contractors and government agencies. Definition of Interface Control Documents, joint operating plans and interface control plans, Also includes development of program plans and analyses for: quality control, reliability, maintainability, producibility, transportability, safety, logistics and mass properties.
2122	Design and Development	This is the cost to design and develop flight hardware in support of the OTV program. It includes test development and integration of test results, as well as analysis of interface compatibility and design of hardware elements.
2123	Software Engineering	This is the cost to develop software in support of OTV operations, including guidance, control, data management, and OTV/Shuttle interface, as well as software for test and launch support operations.
2130	Manufacturing	Includes the cost of manufacturing all items essential for the design and development of the OTV, including initial testing, as well as ground and flight test hardware and fixtures.

TABLE 3.1-2 DDT&E PHASE FUNCTIONAL DEFINITIONS (Continued)

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
2131	Initial Tooling and Special Test Equipment (STE)	Includes the cost of planning, design, fabrication, assembly, installation, and modification, maintenance and rework of all tools and special test equipment including assembly tools, dies, jigs, fixtures, master forms, gauges and handling equipment for use during the manufacture of the Orbital Transfer Vehicle. Includes costs for the determination of tool requirements, planning of fabrication and assembly operations, maintaining tool records, scheduling and controlling all tooling orders, programming and preparation of tapes for numerically controlled machine parts, and preparation of templates and patterns.
2132	Ground Test	Includes the cost of manufacturing major vehicle subsystems and complete vehicle elements needed for structural/dynamic testing, avionics system tests, propulsion system integration testing and all systems testing. Mock-ups and hardware for subsystem test and qualification are excluded from this element but are included with their design and development costs, as are special purpose test rigs. Propellants and gases are to be included with Ground Test Operations and excluded here.
2133	Flight Test	Includes the manufacturing cost of all test articles required for the flight test program such as launch vehicle, drop tanks and airborne support equipment.

TABLE 3.1-2 DDT&E PHASE FUNCTIONAL DEFINITIONS (Continued)

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
2140	System Test	Refers to the cost of performing system development tests of the Orbital Transfer Vehicle. Includes test operations as well as the hardware necessary to perform the tests.
2141	Test Operations	Includes the costs of performing development tests using prototype hardware to acquire engineering data and confirm engineering hypotheses. The test operations include the detail planning, conduct, support, data acquisition and analysis, reports and materials consumed in ground, and flight tests.
2150	Operations	Includes the cost of all operations in support of the design, and development, and testing of the OTV. It involves the operation support for all ground and flight testing, as well as launch support for flight tests.
2151	Operation Support	This subfunction includes the engineering, administrative, planning, and logistics support activities required by the ground and flight test operations. It includes all material, labor and services required to operate and maintain any tools, vehicles, equipment and facilities not directly associated with launch operations.

TABLE 3.1-2 DDT&E PHASE FUNCTIONAL DEFINITIONS (Continued)

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
2152	Launch Support	This subfunction includes all the direct and indirect labor and services required to support the launch of a test vehicle or equipment package, including ground and space assembly and checkout, processing, integration, and recovery activities.

TABLE 3.1-3 PRODUCTION PHASE FUNCTIONAL DEFINITIONS

FUNCTION NUMBER	DESIGNATION	DEFINITION
2200	Production Phase	Refers to that portion of the OTV program that includes reusable flight hardware, excluding first flight units. The facilities, ground equipment, airborne support equipment and tooling are acquired during DDT&E to accommodate all necessary production and operational launch rates. The costs of all reusable orbital transfer vehicles elements required to support the operational fleets are included. The costs of all necessary support and management are also included. Production costs include all direct and indirect labor, material and overhead. Contractor fee is excluded.
2210	Program Management	Refers to prime contractor costs associated with providing a central direction and control of the overall orbital transfer vehicle production program. Includes program planning, scheduling, budgeting, monitoring and control, documentation, coordination and other program management activities.
2220	Engineering Support	Includes the cost of engineering effort that is in direct support of manufacturing. Involves the engineering interface of the various manufacturing activities on an interdepartmental basis and with subcontractors and vendors. Also includes continued engineering analysis of test results and other supporting activities (product improvement).

TABLE 3.1-3 PRODUCTION PHASE FUNCTIONAL DEFINITIONS (Continued)

FUNCTION NUMBER	DESIGNATION	DEFINITION
2221	Integration, Assembly Checkout, and Test	Refers to the contractor activities in integrating and assembling hardware elements and subsystems into an operational system. Includes all system calibration and checkout, as well as necessary acceptance testing.
2222	R&D Vehicle Modifications	Includes the cost to inspect and appropriately modify flight test vehicles or the flight demonstration articles of the orbital transfer vehicle that are to be included in the operational fleet.
2230	Manufacturing	These cost elements refer to the cost of manufacturing new vehicle stages in quantities to support the operations phase of the OTV program. They include the manufacture and assembly of all hardware in the structures, thermal control, avionics, power supply and distribution, propulsion and attitude control subsystems. The integraton of these subsystems into a single entity, checkout and test of the final product is also included.
2231	Sustaining Tooling	Includes the cost of tooling maintenance, replacement, modification and rework needed in support of new vehicle manufacturing.
2232	Flight Hardware	This refers to the cost of manufacturing all reusable flight vehicle hardware, including vehicle stages, auxiliary tanksets, aeroassist devices, as well as all flight support hardware.

TABLE 3.1-4 OPERATIONS PHASE FUNCTIONAL DEFINITION

FUNCTIONAL NUMBER	DESIGNATION	DEFINITION
2300	Operations	This phase covers the operational period of the Orbital Transfer Vehicle program. In this portion of the life cycle the finished product is put into operation and is maintained in an operating condition for the duration of the program, or replaced. It includes all direct and indirect labor, materials (spares), expendable hardware element, and propellant costs required to operate and maintain the vehicles, facilities and equipment developed and produced in the DDT&E and Production Phases. The operations phase is divided into two major functions. Operations Support and Launch Support.
2310	Operations Support	This function includes the sustaining engineering, administration management planning, control and logistics support activities required by the operational program. It includes all material, labor and services required to operate and maintain any vehicles, equipment and facilities not directly associated with launch operations.
2311	Program Support	This subfunction includes all activities associated with the management and control of the operations phase. It includes such items as: (1) program administration and management, including budgeting, monitor, and control; (2) planning and scheduling of flights; (3) financial and administrative support; and (4) sustaining engineering.

TABLE 3.1-4 OPERATIONS PHASE FUNCTIONAL DEFINITION (Continued)

FUNCTIONAL NUMBER	COST ELEMENT DESIGNATION	DEFINITION
2312	Spares Procurement	This subfunction includes all activities associated with the acquisition and stocking of spare parts, expendable hardware elements, and propellants during the operational phase. It does not include maintenance/ refurbishment labor costs. It includes the costs of spare parts and components produced to replenish initial spare stocks in support of OTV maintenance and overhaul, both scheduled and unscheduled, and procurement costs of the expendable hardware items.
2313	Ground Based Mission Control	This subfunction includes all activities associated with ground command, control and tracking from vehicle launch through mission completion and return. Includes such functions as flight control, telemetry communications, data processing and data analysis.
2314	Space Based Mission Control	This subfunction includes all activities associated with space station command, control and tracking from vehicle release through mission completion and vehicle acquisition. It includes such activities as flight control, telemetry communications, data processing and data analysis.
2320	Launch Support	This function includes all the direct and indirect labor and services required to support the launch of an OTV including ground based and space based assembly and checkout, processing, integration, recovery and refurbishment activities. The acquisition of materials (spare parts and propellants) is accomplished as part of function 2310, Operations Support.

TABLE 3.1-4 OPERATIONS PHASE FUNCTIONAL DEFINITION (Continued)

FUNCTIONAL NUMBER	COST ELEMENT DESIGNATION	DEFINITION
2321	Ground Based Operations	This subfunction includes all activities associated with operating and providing the ground based services of: ground assembly and checkout of the OTV, interface verification, integrating the OTV into the Shuttle, and vehicle recovery. It includes the training of replacement personnel, management of the ground based operations and transportation of men and equipment to and from a recovery site.
2322	Space Based Operations	This subfunction includes all activities associated with the operation of an orbital transfer vehicle in space excluding mission control. It includes all refurbishment and maintenance operations. It includes maintenance/refurbishment labor, services and transportation costs including the cost of transporting crews and logistics support to the space station. The acquisition of the logistics support is accomplished as part of function 2310, Operations Support.
2323	Propellant Operations	This subfunction includes all activities associated with transporting and handling propellants and gases used by the OTV from the manufacturer's delivery point to the OTV. It includes the labor and services to process and turnaround propellant tankers. The acquisition of the propellants and gases is accomplished as part of function 2310, Operations Support.

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TABLE 3.2-1 STS/SDV HARDWARE ELEMENT DEFINITIONS
1000 -

NUMBER	DESIGNATION	DEFINITION
01-00-00	Launch Vehicle	This element refers to all of the entities associated with the shuttle, shuttle-derived vehicle, or aft cargo carrier vehicle for launch of the OTV system and its associated support equipment.
01-01-00	Integration	This refers to all elements associated with integration of the shuttle, shuttle-derived vehicle, or aft cargo carrier vehicle with the OTV and OTV-related equipment.
01-02-00	Shuttle Vehicle System	This refers to all elements associated with operation of the shuttle vehicle for launch of the Orbital Transfer Vehicle and its associated support equipment and propellant supply. Associated hardware is either existing or defined elsewhere under OTV and space station accommodations elements.
01-03-00	Propellant Tanker System	This refers to elements associated with the propellant tanker, including tanker, ASE, space and ground handling equipment, and spares.
01-03-01	Integration	This refers to all equipment associated with integration of the propellant tanker system elements.
01-03-02	Tanker	This element is the hardware associated with the propellant tanker vehicle, including structures, thermal control, plumbing, and instrumentation for both ground and space operation.

TABLE 3.2-1 STS/SDV HARDWARE ELEMENT DEFINITIONS (Continued)
1000 -

NUMBER	DESIGNATION	DEFINITION
01-03-03	Tanker ASE	This element refers to the airborne support equipment required for support of the propellant tanker in the shuttle or shuttle-derived vehicle. It includes structure, thermal control, plumbing, and instrumentation necessary for support of the tanker during launch and return.
01-03-04	Handling Equipment	This element refers to all equipment required for handling of the propellant tanker on the ground and at the space station. Included are tools, fixtures, and effectors specifically used to handle the tanker. Not included is equipment defined as part of space station accommodations or standard launch vehicle hardware.
01-04-00	Propellant Scavenging System	This refers to all elements associated with propellant scavenging operations. Included is all hardware and software in the shuttle or shuttle-derived vehicle used specifically for propellant scavenging, as well as ground or space-based hardware or facilities associated with this operation.
01-05-00	Aft Cargo Carrier System	This refers to all elements associated with the operation of the aft cargo carrier for launch of the OTV and supporting equipment. It includes the development, testing, production, and operation of the aft cargo carrier and all associated support equipment and facilities unique to the aft cargo carrier. Not included are elements defined as OTV-related elements.

TABLE 3.2-1 STS/SDV HARDWARE ELEMENT DEFINITIONS (Continued)
1000 -

NUMBER	DESIGNATION	DEFINITION
02-00-00	Facilities	This refers to all facilities necessary for flight test operations, flight operations, and mission operations of the STS/SDV, propellant tanker, and aft cargo carrier systems. These include facilities for manufacturing, testing, launch, and mission control; facilities at the Space Station are included in the Space Station project element.
02-01-00	Manufacturing	This element includes manufacturing facilities for the OTV-related elements of the STS/SDV, propellant tanker, propellant scavenging, and ACC systems.
02-02-00	Test	This element includes test facilities for both ground test and flight test operations of elements of the OTV related elements of STS/SDV, propellant tanker, propellant scavenging, and ACC systems.
02-03-00	Launch	This element refers to all facilities related and unique to the launch of the propellant tanker, propellant scavenging, and ACC systems, and related hardware and consumables. It includes integration and launch facilities.
02-04-00	Mission Control	This refers to all facilities required for mission control and operation of the propellant tanker, propellant scavenging, and ACC systems, and related elements, from launch to retrieve.

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TABLE 3.2-2 OTV ELEMENT DEFINITIONS
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
01-00-00	OTV System	This element refers to all of the entities associated with the OTV, including separate stages, payload support hardware, interstages, kits, ground support equipment, and software. This does not include facilities associated with manufacturing, test, launch or mission of the OTV.
01-01-00	Integration	This refers to all equipment associated with integration of the OTV system elements.
01-02-00	Stage I	This element refers to all of the entities associated with the OTV stage and auxiliary tanks, if any. It includes all hardware associated with the stage and tanks, as well as ground and airborne support equipment, aeroassist device, and propellants.
01-02-01	Integration	This refers to all equipment associated with integration of the OTV stage elements.
01-02-02	Structures	This refers to all primary and secondary load-carrying structural entities on which are mounted the propellant tanks, engines, flight equipment, and peripheral equipment, or which provide vehicle protection. Included in this element are body shell or body support structure, thrust structure (including engine mounting provision), payload interface structure, equipment support structure, meteoroid/debris shielding, as well as

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
		mechanisms and umbilical interfaces associated with operation of the OTV stage.
01-02-03	Propellant Tanks	This element refers to the tankage associated with the OTV stage, including integral or non-integral type tanks as well as any support struts which provide structural support between the propellant tanks and the body structure.
01-02-04	Propulsion Less Engine	This refers to the subsystems required for main engine support, including feed/fill/dump and drain provisions, tank pressurization, engine thrust vector control, and tank vent/relief provisions. It includes plumbing, pressurant tankage, valves, and mechanisms associated with operation of the main engines.
01-02-05	Main Engine	This refers to all elements associated with the main engine as provided by the engine contractor, including valves, pumps, chamber, and nozzle, as well as all mechanisms associated with the desired engine operation. computational and sensing devices are included in the data handling category.

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
01-02-06	Reaction Control System	This refers to elements associated with a reaction control system. Included are thrusters, tankage, pressurization, and feed systems, as well as all other elements associated with the reaction control system. Not included are control computational devices, which are part of the data handling category.
01-02-07	Guidance, Navigation and Control	Includes elements for all sensor and prime reference functions associated with guidance and navigation of the vehicle in flight, as well as during an aeromaneuver. Computational and direct control function elements are included in the data handling category.
01-02-08	Communication and Data Handling	This refers to elements associated with ground/space communications, vehicle self-test capabilities, and computational and control capabilities. Included are RF, optical, or other data links to Shuttle, Space Station, and other spacecraft, ground communications links, data recording, conditioning, and processing elements, as well as sensors, transducers, and circuitry to monitor environmental conditions aboard the OTV.
01-02-09	Electrical Power	This element includes a power source, as well as elements associated with conversion and distribution of power to meet OTV power requirements.

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
01-02-10	Thermal Control	This refers to all elements related to control of heat transfer within the OTV system. Included are elements for thermal control of tankage and associated systems, (insulation, purge, vent), as well as thermal control (both active and passive) of avionics and electrical power packages and devices. Thermal control devices or provisions which are an inherent part of a component of another subsystem are included within that subsystem and are excluded from this element.
-01-02-11	Aeroassist Provisions	This refers to all elements and assemblies of a drag only or drag plus low-lift device used to decelerate the vehicle through the atmosphere. This includes primary and secondary structure and all thermal protection associated with the aeromaneuver, as well as all other mechanisms, provisions, and support associated with the device or aeroassist function. Sensing and/or computational elements associated with aeroassist device are included in the data handling element.
-01-02-12	Ground Support Equipment	Includes all ground-based equipment required to support the handling of the OTV stage during flight test operations, flight operations, or mission operations. Equipment common to other elements of the integrated system is included in the integrated system ground support equipment element. Test equipment common to the test of ground equipment and air vehicle is considered as part of facilities costs.

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
-01-02-13	Airborne Support Equipment	This element includes the equipment required to mate the OTV with the shuttle, link with, and separate from it. Included is the equipment for operational docking/undocking of the OTV and Shuttle, abort provisions, alignment and energy absorption, retraction/extension support, reentry purge, avionics interface, and umbilical disconnects in the fluid/electrical interface.
01-02-14	Space Support Equipment	Includes all elements required to support the OTV stage during on-orbit assembly and operations, excluding those elements defined as airborne support equipment or space station accommodations.
-01-02-15	Propellants	This element includes all propellants and reactants required for the operation of the OTV stage, including main engine propellants, reaction control propellants, and reactants for the electrical power system, as well as pressurants for OTV systems.
-01-02-16	Auxiliary Tanks	This element includes all elements of the auxiliary tank system, including primary and secondary structure, tankage, mechanisms, wiring, instrumentation, and deorbit provisions (if any).
-01-03-00	Stage II	This element refers to all of the entities associated with the second stage of the OTV system. It includes all of the elements as defined by the Stage I integrated system, element -01-02-00.

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
-01-04-00	Space Support Equipment	Includes all elements required to support the OTV integrated vehicle during on-orbit assembly and operations, excluding those elements defined as airborne support equipment or space station accommodations.
-01-05-00	Payload Clustering Structure	This element refers to the structure and system required to launch multiple payloads with the OTV system, and includes structure, mechanisms, wiring, and instrumentation to support the multiple spacecraft payload.
-01-06-00	Interstage	This element refers to the equipment required to mate multiple OTV stages to one another for multi-stage operation. It includes structure, mechanisms, and data/electrical transfer (if any) provisions between stages of the OTV system.
-01-07-00	Kits	This refers to additional components added to the basic OTV system to allow it to meet unique mission requirements beyond its normal design mission capabilities.
-01-08-00	Ground Support Equipment	This refers to elements required to support the handling of the entire OTV integrated system during flight test operations, flight operations, or mission operations. Not included are elements unique to each stage or component of the system.

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
-01-09-00	Software	This element consists of all software required for OTV on-orbit operations, as well as for OTV/Shuttle interface and for aeromaneuver operations.
02-00-00	Facilities	This refers to all facilities necessary for flight test operations, flight operations, and mission operations of the OTV system. These include facilities for manufacturing, testing, launch and mission control, and training. Facilities at the Space Station are included in the Space Station project element.
02-01-00	Manufacturing	This element includes manufacturing facilities for the OTV, auxiliary tanks, ASE and propellants, as well as for OTV related supporting hardware.
02-02-00	Test	This element includes test facilities for both ground test and flight test operations of elements of the OTV, auxiliary tanks, and other OTV-related hardware.
02-03-00	Launch	This element refers to all facilities related and unique to the launch of the OTV and related hardware and consumables. It includes integration and launch facilities.

TABLE 3.2-2 OTV ELEMENT DEFINITIONS (Continued)
2000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
02-04-00	Mission Control	This refers to all facilities required for mission control and operation of the OTV and related elements, from launch to retrieve.
02-05-00	Training	This refers to facilities required specifically for flight crew, ground crew, and mission operator training in support of the OTV missions and operations. This includes simulation facilities, operational and maintenance trainers, mockups, and models.

TABLE 3.2-3 SPACE STATION ACCOMMODATIONS HARDWARE ELEMENT DEFINITION

3000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
01-00-00	Space Station Additions and Modifications	This element refers to all additions to, or modifications of, Space Station and associated hardware already present to provide capability of supporting OTV operations.
01-01-00	Independent Platform	This refers to all elements of a platform separate from a manned Space Station which are necessary for OTV operation.
01-02-00	Station Modifications	Includes modifications and enlargements of Space Station subsystems already present, to make them capable of supporting OTV operations.
02-00-00	Hangar Systems	This refers to hardware associated with hangars at the Space Station for OTV storage, auxiliary tank storage, and storage of other equipment associated with the OTV.
02-01-00	OTV Hangar	This refers to all hardware associated with the hangar designed specifically for storage of the OTV. This includes structure, door, thermal control, debris protection, and OTV attachment mechanisms, but excludes servicing or handling equipment.

TABLE 3.2-3 SPACE STATION ACCOMMODATIONS HARDWARE ELEMENT DEFINITION (Continued)

3000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
02-02-00	Auxiliary Tank Hangar	This includes the hardware associated with storing OTV auxiliary propellant tanks or a tankset. It includes structure, thermal control, and debris protection; but excludes servicing or handling equipment.
02-03-00	Storage Provisions	This refers to all provisions for storage of OTV-related spares and equipment inside hangars as part of the hangar system. Included are provisions for storage of engine spares, aerobrake, orbital replacement units, hardware handling equipment, and flight kits.
03-00-00	Propellant Supply System	This includes all hardware associated with the storage and handling, including transfer, of all OTV-related propellants and gases, including all main, auxiliary, and electrical power propellants and reactants, as well as pressurization gases.
03-01-00	Fluid Storage and transfer	This refers to all hardware associated with storage and transfer of all main, auxiliary and electrical power liquid propellants and reactants. It includes lines, pumps, storage tanks, umbilicals, and interfaces, as well as control and monitoring devices.

TABLE 3.2-3 SPACE STATION ACCOMMODATIONS HARDWARE ELEMENT DEFINITION (Continued)

3000 -

ELEMENT NUMBER	DESIGNATION	DEFINITION
03-02-00	Gas Storage and Transfer	This refers to all hardware associated with storage and transfer of all pressurant and boil-off gases. It includes lines, umbilicals, pumps, and interfaces, as well as control and monitoring devices.
04-00-00	Hardware Handling Equipment	This element refers to all special tools, mechanisms, and structures needed for handling of the OTV and its associated elements at the Space Station. Included are manipulators, end effectors, astronaut restraint devices, control consoles, and all related support hardware. Not included are elements common to non-related Space Station functions.
05-00-00	Service Equipment	This element includes all tools and equipment required for inspection, service, repair, replacement, or refurbishment of the OTV and all related subsystems and hardware. This includes cameras, lighting, and electrical, as well as all hand and remote tools necessary to perform OTV servicing. Not included is equipment common to other Space Station functions.
06-00-00	Storage	This refers to all hardware associated with storage of OTV-related equipment other than that stored in hangars. It includes storage provision for replacement units, spares, tools, and handling equipment outside of hangars.

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