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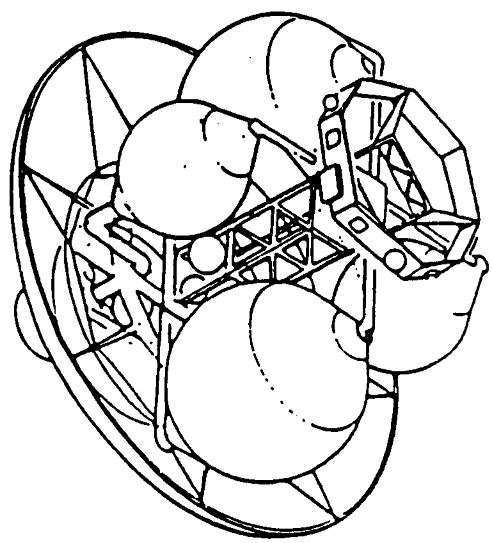
OTV Concept Definition And Evaluation - Operations

Volume II, Book 4

Orbital Transfer Vehicle Concept Definition And System Analysis Study 1985



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MARTIN MARIETTA

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ORBITAL TRANSFER VEHICLE CONCEPT DEFINITION AND SYSTEM ANALYSIS STUDY

VOLUME II
OTV CONCEPT DEFINITION AND EVALUATION
BOOK 4
OPERATIONS

August 1985
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FOREWORD

This final report, Volume III-System and Program Trades, was prepared by Martin Marietta Denver Aerospace for NASA/MSFC in accordance with contract NAS8-36108. The study was conducted under the direction of NASA OTV Study Manager, Mr. Donald R. Saxton, during the period from July 1984 to October 1985. This final report is one of nine documents arranged as follows:

Volume I	Executive Summary		
Volume II	OTV Concept Definition and Evaluation		
		Book 1	Mission and System Requirements
		Book 2	OTV Concept Definition
		Book 3	Subsystem Trade Studies
		Book 4	Operations
Volume III	System and Program Trades		
Volume IV	Space Station Accommodations		
Volume V	Work Breakdown Structure and Dictionary		
Volume VI	Cost Estimates		
Volume VII	Integrated Technology Development Plan		
Volume VIII	Environmental Analyses		
Volume IX	Study Extension Results		

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ACRONYMS

ACC	Aft Cargo Carrier
AFSCF	Air Force Satellite Control Facility
A/G	Air-to-Ground
ASE	Airbourne Support Equipment
BIT	Built in Test
CCTV	Closed Circuit Television
CHSF	Cargo Hazardous Servicing Facility
DACC	Dedicated Aft Cargo Carrier
DRM	Design Reference Mission
DSN	Deep Space Network
EGSE	Electrical Ground Support Equipment
ELS	Eastern Launch Site
ET	External Tank
EVA	Extra Vehicular Activity
FOC	Functional Operational Capability
fps	Feet per Second
GEO	Geosynchronous Equatorial Orbit
GH_2	Gaseous Hydrogen
GPS	Global Positioning System
GN&C	Guidance, Navigation and Control
GSE	Ground Support Equipment
GSFC	Goddard of Space Flight Center
GSTDN	Ground Space Tracking and Data Network
GUCP	Ground Umbilical Carrier Plate
HEO	High Earth Orbit
HPF	Hazardous Processing Facility
HPU	Hydraulic Power Unit
JSC	Johnson Space Center
KSC	Kennedy Space Center
LC	Launch Complex
LCC	Launch Control Center
LEO	Low Earth Orbit
LH_2	Liquid Hydrogen
LM	Logistics Module
LO_2	Liquid Oxygen
LRU	Line Replaceable Unit

ACRONYMS (continued)

MCC	Mission Control Center
MECO	Main Engine Cut-off
MET	Mission Elapsed Time
MGSS	Manned GEO Service Station
MLP	Mobile Launch Platform
MMSE	Multimission Support Equipment
MMU	Manned Maneuvering Unit
MPAD	Mission Planning and Analysis Division
MPS	Main Propulsion System
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NC	Rendezvous Normal Corrective Phasing Maneuver
NH	Rendezvous Normal Height Adjustment Maneuver
O & C	Operations and Checkout
OMI	Operations Maintenance Instruction
OMS	Orbital Maneuvering System
OMV	Orbital Maneuvering Vehicle
OPF	Orbital Processing Facility
ORU	Orbital Replaceable Unit
OTV	Orbital Transfer Vehicle
PAYCOM	Payload Communicator
PCR	Payload Changeout Room
PET	Phase Elapsed Time
PGHM	Payload Ground Handling Mechanism
PI	Payload Integrator
PIDA	Payload Installation/Deployment Aid
PIDM	Payload Interface Deployment Module
PLB	Payload Bay
POCC	Payload Operations Control Center
RAAN	Right Ascension of the Ascending Node
RCS	Reaction Control System
RMS	Remote Manipulator System
RPTF	Remote Propellant Tank Farm
RSS	Rotating Service Structure
RTS	Remote Tracking Station
SAEF-2	
SSSC	Space Station Support Center
SRB	Solid Rocket Booster
STAR	Shuttle Turnaround Analysis Report
STDN	Space Tracking and Data Network
STS	Space Transportation System

ACRONYMS

TDRS	Tracking and Data Relay Satellite
TF	Rendezvous Terminal Phase Final Maneuver
TI	Rendezvous Terminal Phase Initiation Maneuver
TT&C	Tracking, Telemetry and Commanding
UAA	Umbilical Access Arm
VAB	Vehicle Assembly Building
VPF	Vertical Processing Facility

1.0 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The benefits of the reusable Space Shuttle and the advent of the new Space Station hold promise for increasingly effective utilization of space by the scientific and commercial as well as military communities. A high energy reusable orbital transfer vehicle (OTV) represents an additional capability which also exhibits potential for enhancing space access by allowing more ambitious missions and at the same time reducing launch costs when compared to existing upper stages.

The NASA MSFC funded studies of OTV concepts in 1979 through 1980 to investigate ground-based, cargo bay launched, enhanced performance vehicles. In 1984 additional studies were initiated to investigate alternative OTV concepts including the possibility of using the Aft Cargo Carrier for launch of the OTV and the use of the manned Space Station as a transportation node for the OTV. This report presents the findings of the current Martin Marietta Corporation study of OTV concepts.

The NASA stated a number of objectives to be addressed in the current OTV studies. In the operations arena the objective was to "Assess all flight and ground operations associated with candidate OTV concepts and missions to determine impacts, constraints, support requirements, and interfaces as they relate to the STS and or the Space Station".

1.2 CONTENT OF VOLUME

The final report for the Orbital Transfer Vehicle Concept Definition and System Analysis Study is comprised of eight volumes. Volume II, which consists of 4 books, contains the concept definition and evaluation. The main body of Book 4, which covers launch and flight operations, is divided into sections which cover launch operations (Section 2.1) and flight operations (Section 2.2). The Appendices found in Section 3.0 contain detailed launch operations analysis charts (Appendix A) and timelines for flight operations (Appendix B).

The launch operations sections cover analyses of ground-based and space-based vehicles, launch site facilities, logistics requirements, propellant loading, space-based maintenance and ACC access options. The flight operations sections contain summary descriptions of ground-based and space-based OTV missions, operations and support requirements, and a discussion of fleet implications. Also included are discussions of specific operations issues related to operational orbits, tethered operations, and OTV control philosophy.

ORBIT TRANSFER VEHICLE
REUSABLE SPACECRAFT
SYSTEMS ANALYSIS

SPACE COMMERCIALIZATION
" STATION
" TRANSPORTATION SYSTEM
" MAINTENANCE
SPACECRAFT LAUNCHING

2.0 LAUNCH AND FLIGHT OPERATIONS

2.1 LAUNCH OPERATIONS

2.1.1 Introduction

Launch operations activities and requirements for high potential candidate Orbital Transfer Vehicles (OTV) processing are defined in this section. The scope of the tasks involved in our analysis included development of launch site (ground and space) operations scenarios, and waterfall timelines, identification of facilities, Ground Support Equipment (GSE), logistics requirements and services necessary to support OTV prelaunch processing activities and post launch landing activity required for OTV turnaround, refurbishment or storage. Also as a part of the task, NASA/KSC facilities/services capabilities were reviewed against identified OTV requirements to determine incompatibilities either from a flight or ground hardware interface with NASA institutional capabilities or from a facility deficiency standpoint. In those cases where hardware design change would eliminate interface problems the design team was advised. Our study also investigated Dedicated Aft Cargo Carrier access requirements, Space Station and ground logistics requirements, maintenance options and automated processing concepts.

2.1.2 Objectives

The objective of the launch operations study was to identify, in depth, the ground operations requirements for high potential OTV candidates processing activities for the following OTV categories:

1) Ground based, cryogenic and storable propellant, Dedicated Aft Cargo Carrier (DACC) launched, recovered in the Orbiter payload bay.

2) Ground based, storable propellant, Orbiter payload bay launched and recovered.

3) Space based, cryogenic and storable propellant, Orbiter payload bay launched and recovered.

4) Space based, cryogenic and storable propellant, Space Station launch operations.

2.1.3 Ground Rules

General ground rules established for the launch operations study are as follows:

1) Maximum utilization must be made of applicable data and results from prior or current projects and government studies.

2) Primary OTV launch mode is the STS with a Dedicated Aft Cargo Carrier (DACC) capability.

3) The Launch Site Accommodations Handbook for STS payloads, K-STSM-12.1 Rev B, is to be used as a guide.

4) The Shuttle Turnaround Analysis Reports (STAR) 025 and 027 are to be used as guides.

5) OTV ground process impacts on launch site capabilities shall be minimal.

2.1.4 LAUNCH OPERATIONS ANALYSES

Launch site operations scenarios were developed for each high potential candidate OTVs identified in paragraph 2.1.2. Operations analyses were then accomplished against the scenarios in order to determine detail for timeline development and processing requirements such as GSE, facilities, support requirements, and related data. The following paragraphs summarize the output of the individual analyses.

2.1.4.1 Ground-Based OTVs - DACC Launched

One ground operations scenario shown in Figure 2.1.4-1 basically satisfies the ground processing flow for either the cryogenic or storable propellant OTV candidates launched in the DACC since the only apparent variables are OTV size/weight and fuel type and volume. The detailed operations scenario is provided in Appendix B. The processing activity, including loading location are the same for each OTV. In the case of DACC launched OTV's, all RCS/MPS loading and pressurization is planned to be accomplished at the launch complex, using available STS equipment as applicable.

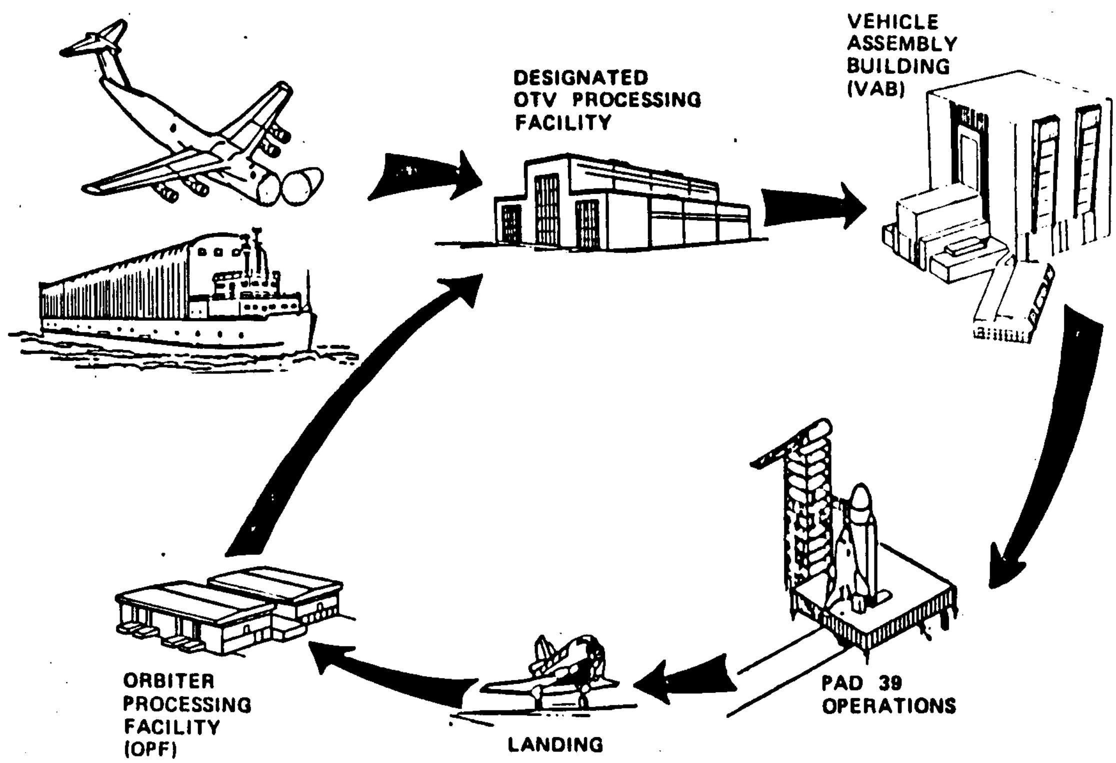

Figure 2.1.4-1 Ground-Based DACC OTV Ground Processing

These OTV's present a deviation from the existing KSC norm for that type of flight hardware from integration as well as a propellant loading standpoint, and as such drive the need for additional facilities, primarily in the VAB for OTV/DACC integration. Initial build-up and test activity in the KSC industrial area and OTV recovery in the OPF appear to cause no impact to existing KSC capabilities. However, high volume processing of STS vertical cargo in the OTV era may drive the need for a dedicated OTV facility. The timeline in Figure 2.1.4-2 developed for this OTV version is a best estimate based on the maturity of the program at this time. STAR 025 and 027 were used in the development of the on-line STS flow, i.e. VAB through launch. Times derived for OTV processing were: 86 serial hours for OTV standalone operations; 51 serial hours for OTV/ET/DACC integration; 63 hours serial time after DACC integration to launch and a total time (including Orbiter time) of 729 hours from initial OTV receipt to launch. For turnaround between OTV flights, the estimated procesing time is 743 serial hours.

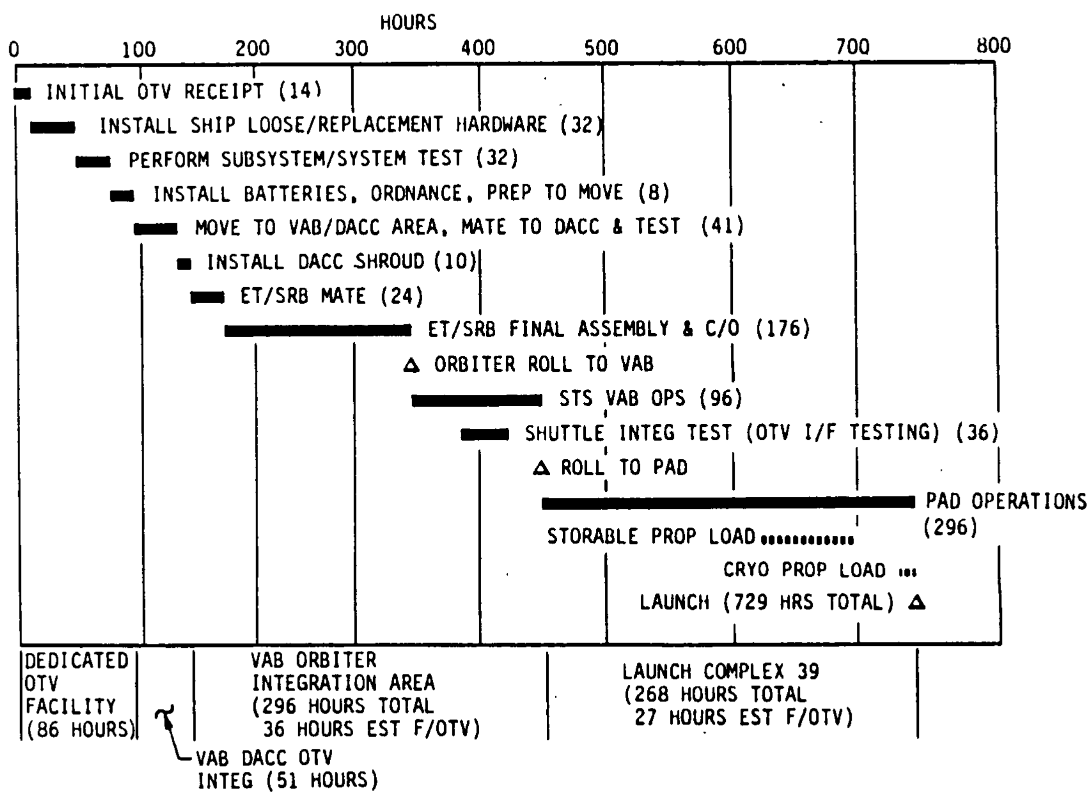

Figure 2.1.4-2 Ground-Based DACC OTV Ground Processing Summary Timeline

2.1.4.2 Ground-Based OTV - Payload Bay (PLB) Launched

As shown in Figure 2.1.4-3, the ground operations scenario for the Orbiter PLB launched, storable propellant OTV will follow the generic flow established at KSC for automated payload processing.

This scenario involves preparation, build-up, test and propellant loading in an assigned Hazardous Processing Facility (HPF), moving to the Vertical Processing Facility (VPF) for cargo integration and transfer to Launch Complex 39 (RSS/PCR) in the Canister for installation into the Orbiter PLB for launch.

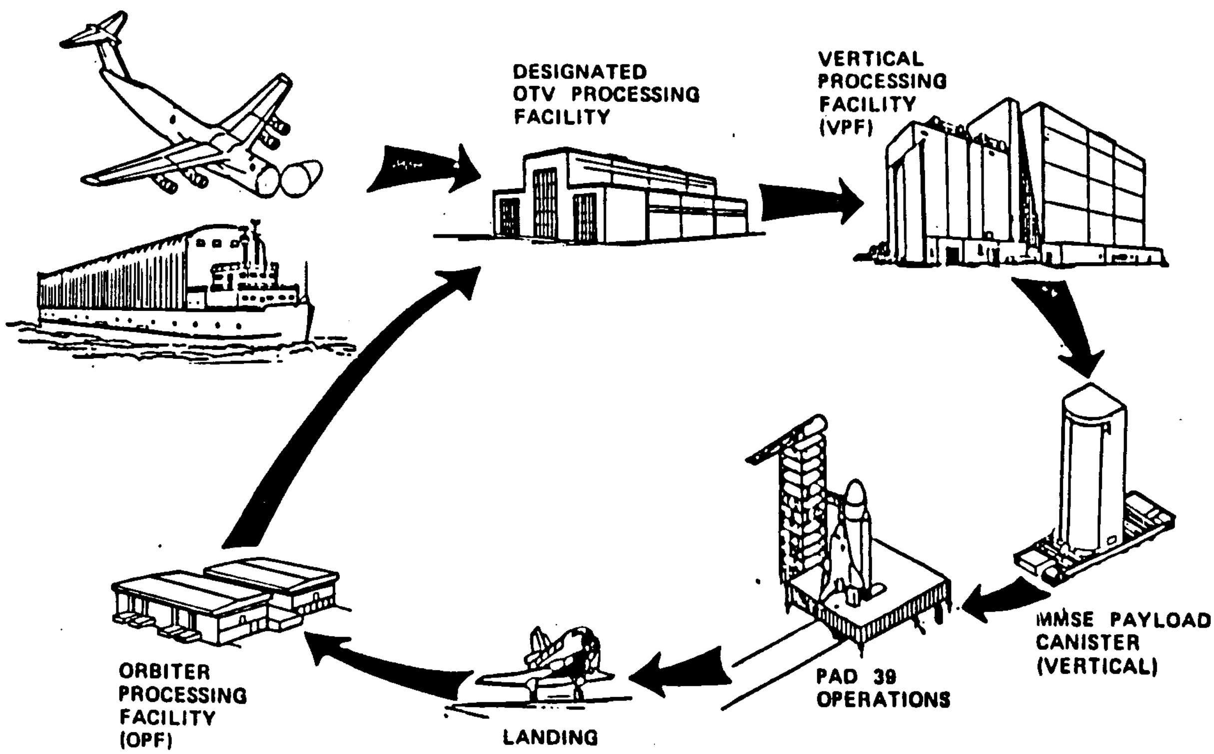

Figure 2.1.4-3 Ground-Based PLB OTV Ground Processing

This version drives the dedicated OTV facility to provide the capabilities for prelaunch fuel and oxidizer loading and pressurization and offloading after OTV recovery. However, the facility requirement may be avoided if existing KSC Hazardous Processing Facilities such as SAEF-2 or the new Cargo Hazardous Servicing Facility (CHSF) are not saturated during the OTV operational time frame and can be scheduled for fueling/defueling activities. Since this OTV is being sized for the Orbiter PLB, the design will be driven to assure compatibility with existing KSC ground handling capabilities including the Vertical Processing Facility (VPF) mechanical stand, the Canister and the Payload Ground Handling Mechanism (PGHM) in the Payload Changeout Room.

The estimated receipt to launch processing time for this high potential candidate OTV as indicated in Figure 2.1.4-2, if loading is accomplished in a dedicated facility, is estimated to be 184 serial hours of actual hands on activity and a total of 492 hours when integrated into the STS flow. If loading is done in a HPF, serial time is increased, because of the move requirement, to 193 hours and 501 hours when integrated with the STS. OTV return ground operations are estimated at 52 hours of serial time. The turnaround time for the next flight would be 228 hours of serial time and 536 hours when integrated with the Orbiter.

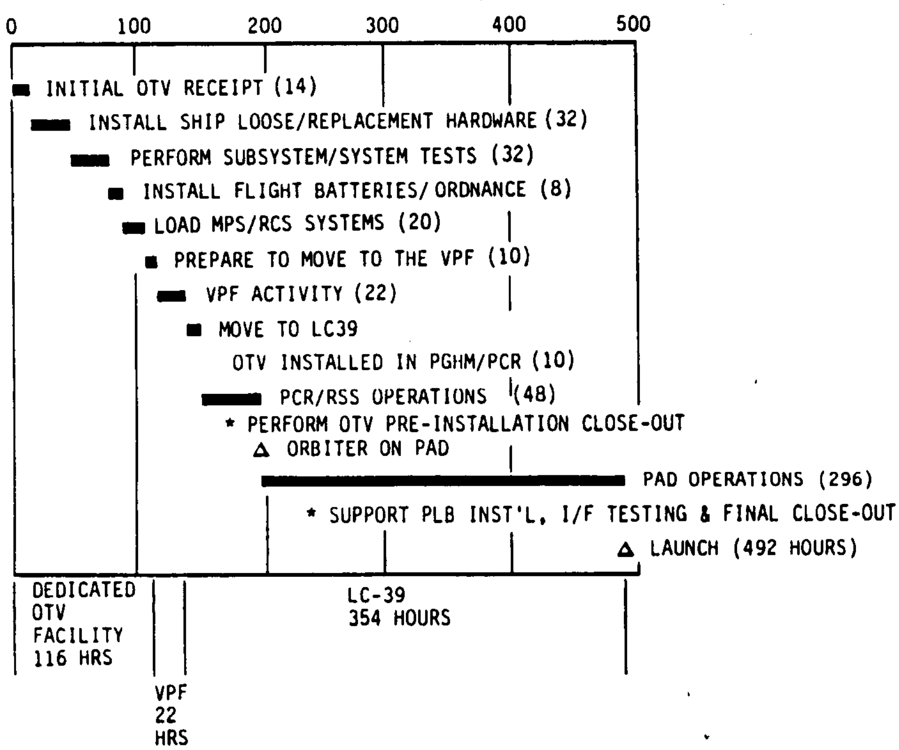

Figure 2.1.4-4 Ground-Based PLB OTV Ground Processing - Summary Timeline

2.1.4.3 Space-Based OTV - Ground Operations

2.1.4.3.1 Storable Propellant OTV

Initial preparation for ground processing of the space based storable propellant OTV will be accomplished in a dedicated off-line facility. For the purpose of this analysis, integration with the Orbiter is planned to be at the Pad following the vertical cargo integration process, since that approach minimizes the time required in the on-line STS flow. It should be noted, however, that since the OTV is essentially dormant, it could be integrated into the Orbiter horizontally in the OPF. The OTV, as shown in Figure 2.1.4-5, will be received from the factory assembled with the exception of the aerobrake installation, and will be retested if required to verify system integrity. It will then be processed from its facility to the VPF for cargo integration and then to the Pad for insertion into the Orbiter. The aerobrake will be processed separately for the same cargo.

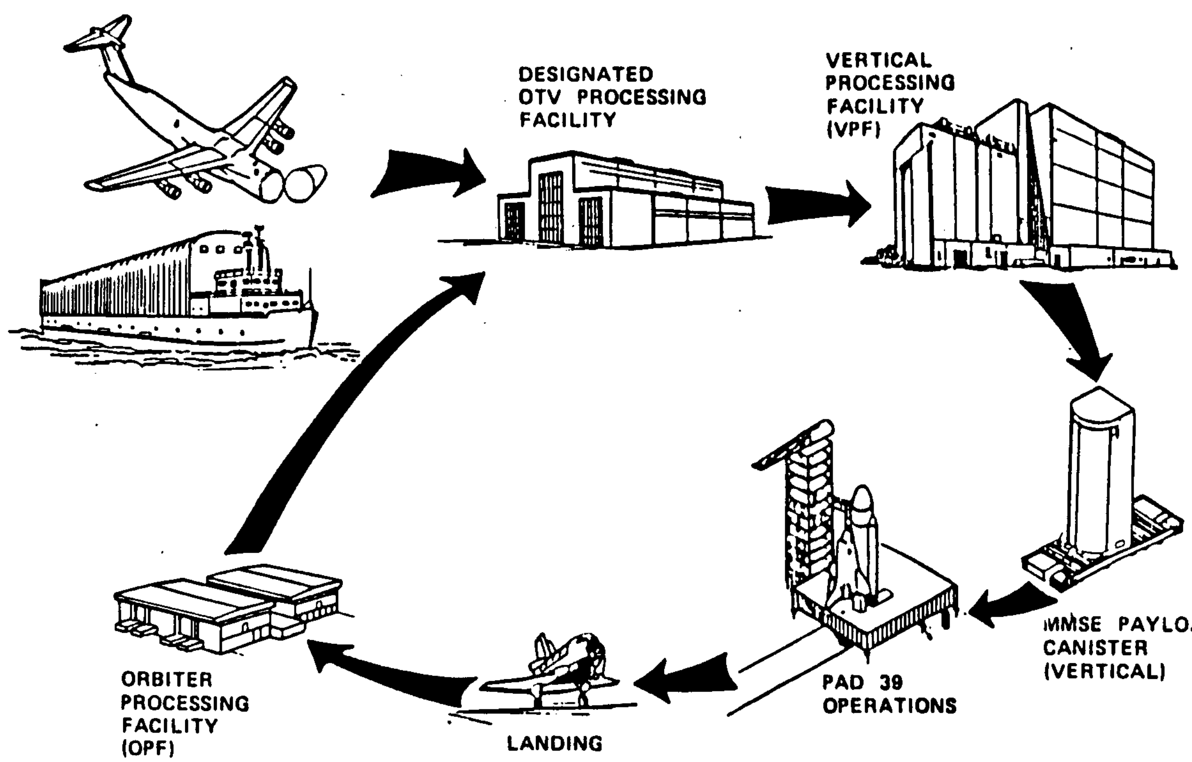

Figure 2.1.4-5 Space-Based OTV Ground Processing - Vertical

Recovery of the space based storable OTV if returned from the Space Station will occur in the OPF. Once safed and recovered from the Orbiter PLB, the OTV will be moved to the dedicated facility for refurbishment, testing and transfer via the Orbiter back to the Space Station. Time from initial OTV receipt through launch has been estimated at 117 serial hours and 477 hours when integrated into the Orbiter flow (See Figure 2.1.4-6).

There is no impact to on-line STS processing of the space based storable OTV since there is no propellant loading on the ground and the vehicle is passive in the payload bay.

2.1.4.3.2 Cryogenic Propellant OTV

Ground processing of the cryogenic propellant OTV parallels that of the storable type as defined in paragraph 2.1.4.3.1 above, with the following exception. Due to its size this OTV will be packaged by major components which fit in the Orbiter PLB. Final assembly and system tests will be accomplished in the OTV hangar at the Space Station. Time from initial cryogenic OTV receipt through launch as indicated in Figure 2.1.4-7, has been estimated at 120 serial hours and 484 serial hours when integrated into the STS flow.

2.1.4.4 Space-Based OTV - Launch Operations

An initial concept for space-based operations from a KSC perspective was developed to serve as a benchmark for the Space Station Accommodations task found in Volume IV. The proposed cryogenic or storable propellant OTV launch operations flow at the Space Station is satisfied by one scenario (See Appendix A, Figure 2.1.4-8). This is assumed since the only variables identified during this study are OTV weight, size, fuel type and volume. Ground rules considered for this analysis were: The OTV hanger will be unpressurized; EVA required for OTV launch operations will be on a contingency basis only; and propellant and pressurization loading systems are considered to be a Space Station provided capability, not OTV unique and may be located in the OTV hanger proximity or remote to the Space Station. The size of the OTV hangar will be dictated by final OTV design criteria, however, support equipment and facility requirements identified in Table 2.1.4-1 and 2.1.4-2, should basically remain constant. The timeline shown in hours (Figure 2.1.4-8) applies to either the cryogenic or storable fueled OTV due to system similarities. The variable considered was propellant loading at either the Space Station or at a Remote Propellant Tank Farm (RPTF). Times applied to each major task were a best estimate based on the maturity of the technical data available at the time. Time allocated for maintenance and mission reconfiguration was arbitrarily set at 16 hours, however this allocation will have to be addressed as designs mature, since it is directly proportional to component life cycles and types of flight kits applicable to OTV operations. Further it was assumed that all testing will be automated and initiated/controlled from the Space Station and that OTV design will accommodate ORU and kit removal/installation and will be accomplished using RMS type equipment. Results of the timeline development are as follows:

Space based OTV turnaround time for a satellite delivery mission with propellant loading at the Space Station is 44 hours of serial time with a total potential of 84 manhours excluding EVA for contingencies.

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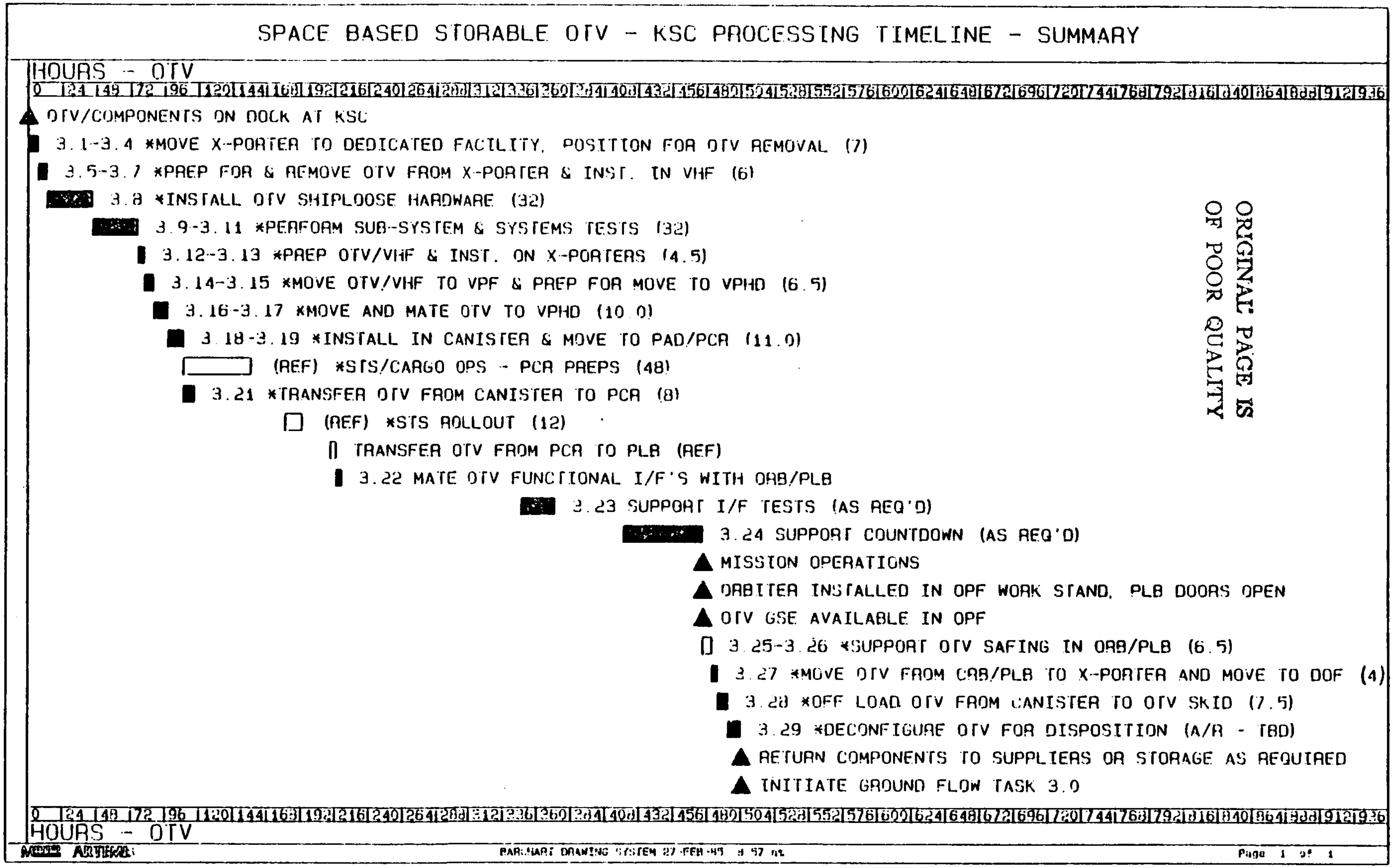

Figure 2.1.4-6 Space-Based Storable OTV - KSC Processing Timeline Summary

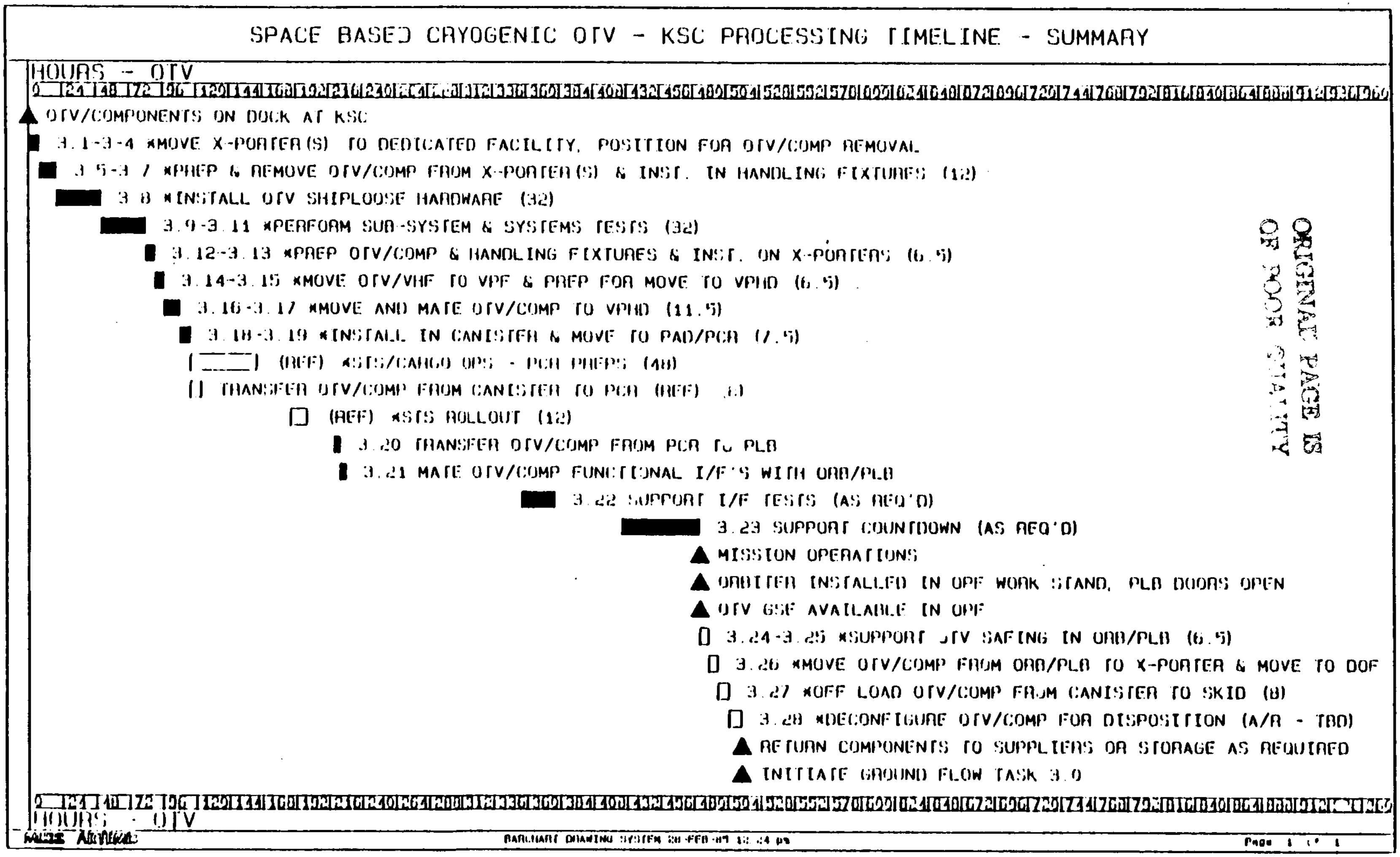

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Figure 2.1.4-7 Space-Based Cryogenic OTV - KSC Processing Timeline - Summary

Table 2.1.4-1 Space-Based OTV Support Equipment Requirements

1. *OTV Systems Test and Checkout Console
2. Airborne Support Equipment (For use inside the Hanger)
3. OTV to Hangar Mechanical Restraints
4. CCTV Monitor and Control Console
5. Video Recorder
6. Propellant System Control and Checkout Console
7. OTV Peculiar, RMS Compatible, ORU Removal/Installation Tools
8. OTV/ORU Checkout Console (ORU in Storage, in Hangar)
9. RMS Manipulator Control Console

* As a minimum this console should control/monitor the following functions:

- o Space Station to OTV power
- o Command and Data (OTV, Space Station and Ground)
- o Active ORU Test/Monitoring
- o OTV Safing
- o OTV System Health/Status (incl. propellant tanks, fuel cells)
- o Umbilical Engage/Disengage indication
- o OMV/Spacecraft to OTV I/F checkout monitoring/test

Table 2.1.4-2 Space-Based OTV Facility & Utility Requirements

REQUIREMENT	NEED LOCATION			COMMENTS
	HANGAR	SPACE STATION INTERIOR/ OTV - SS I/F	REMOTE PROP TANK FARM (RPTF)	
1. CLOSED CIRCUIT TELEVISION	6 REMOTE CONTROLLED CAMERAS	CAMERA CONTROLS & VIDEO RECORDER	TBD REMOTE CONTROLLED CAMERAS	
2. OTV SYSTEM COMPATIBLE POWER		X	X	
3. LIGHTING		LIGHT CONTROLS		
a. FIXED	X		X	
b. REMOTE CONTROLLED FLOOD/SPOT LIGHTS	X			
4. VAPOR DETECTION EQUIPMENT	X	VAPOR DETECTOR READOUT	X	
5. REMOTE MANIPULATOR SYSTEM	X	RMS CONTROL	X	
6. GROUNDING	X	GROUNDING INDICATOR	X	
7. COMMUNICATIONS W/ OMV OPERATIONS		X		
8. EVA PLATFORMS/AIDS		MOVEABLE PLATFORM CONTROLS		
a. FIXED	X		X	
b. MOVEABLE	X			DUAL CONTROLS IN HANGER & OTV CONTROL STATION.
9. PROPELLANT TRANSFER SYSTEM INCLUDING: a. TRANSFER PUMPS b. METERS c. STORAGE TANKS d. PRESSURIZATION SYSTEM e. COMPUTER (AUTOMATED LOADING PROGRAM) f. UMBILICAL SYSTEMS g. OTHER TBD		X	X	
10. COMMUNICATION SYSTEM WITH EVA PERSONNEL		X		

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Table 2.1.4-2 Space-Based OTV Facility & Utility Requirements (continued)

REQUIREMENT	NEED LOCATION			COMMENTS
	HANGAR	SPACE STATION INTERIOR/ OTV - SS I/F	REMOTE PROP TANK FARM (RPTF)	
CONTINUED				
11. BERTHING PROVISIONS F/OTV		X	X	MECHANICAL DOCKING PORT, COMM., POWER ETC. UMBILICALS
12. STORAGE POSITIONS F/ORUs (INCL. THERMAL CONTROL IF REQD)	X			
13. DESIGN FEATURES FOR METEROID PROTECTION	X			
14. TETHER SYSTEM	X		X	FOR TETHERING HAND HELD EVA TOOLS, ORUs ETC.
15. TOOL STORAGE/CONTAINMENT SYSTEM	X			FOR STORAGE OF EVA AND/OR RMS APPLICABLE MAINTENANCE TOOLS
16. OTV CONTROL STATION/S.S. SYSTEM INTERFACE a. POWER b. ENVIRONMENTAL CONTROL c. COMM & DATA MANAGEMENT d. TELEMETRY/TRACKING e. HAZARD WARNING f. OTHER TBD		X		

NOTE: REMOTE PROPELLANT TANK FARM (RPTF) IS AN ALTERNATIVE TO PROPELLANT STORAGE AS PART OF THE SPACE STATION CONFIGURATION.

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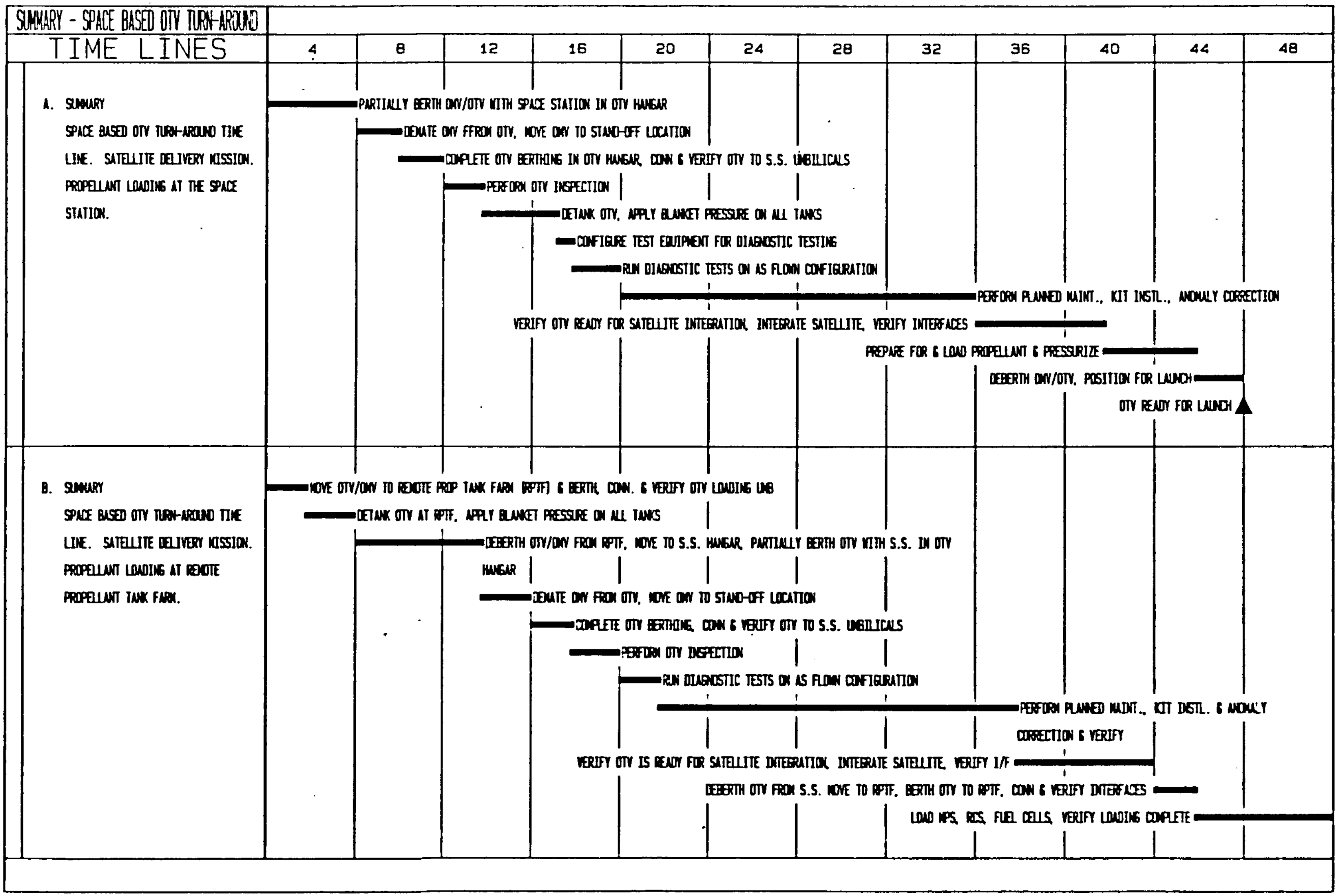

Figure 2.1.4-8 Summary - Space-Based OTV Turnaround Timelines

Space based OTV turnaround time for satellite recovery,OTV/satellite deintegration and reconfiguration for a delivery mission with propellant loading at the Space Station is 50 hours of serial time. Total potential manhours is 100 excluding EVA for contingency activity.

Space based OTV turnaround time for a satellite delivery mission with propellant loading at a Remote Propellant Tank Farm (RPTF) is 48 hours of serial time. Total potential manhours is 101 excluding EVA for contingency activity.

Space based OTV turnaround time for satellite recovery,OTV/satellite deintegration and reconfiguration for a delivery mission with propellant loading at a RPTF is 54 hours of serial time. Total potential manhours is 111 excluding EVA for contingency activity.

2.1.5 Launch Site Facilities/Capabilities Compatibility Analyses

As a function of the analyses accomplished against the high potential candidate OTV ground operations scenarios, facility requirements for each type OTV were identified, i.e. ground based and space based, cryogenic and storable versions. This data was then compared to existing and/or approved new NASA/KSC facilities to 1) identify potential OTV flight and ground support hardware design drivers to assure compatibility with KSC capabilities and 2) to identify anticipated incompatibilities so that necessary planning may be started to assure resources are in place to support the program when it is implemented. Existing and approved new facilities are suitable for OTV build-up prior to integration with the Shuttle, and for vertical STS cargo integration of the storable PLB launched OTV and initial space based OTV delivery to the Space Station.

The need for additional facilities for the above OTV activity would be brought about by existing facility saturation due to STS cargo operations in the OTV era. Based upon the facility capability assessment the following potential incompatibilities have been identified.

1) There is a high probability of the need for a dedicated OTV facility for ground based OTV versions, i.e. Dedicated Aft Cargo Carrier (DACC) and Orbiter Payload Bay (PLB) launched. Furthermore, this facility may require the capability for hazardous operations.

2) An External Tank/OTV integration cell will be required for DACC launched OTV's in the Vehicle Assembly Building (VAB).

3) Modifications will be required at Launch Complex 39 to accommodate storable propellant DACC type OTV reaction control and cryogenic main propulsion systems loading for the recommended OTV configuration.

4) Anticipated support requirements for OTV ground processing such as component cleaning, environmental health, microchemical analysis and various analysis laboratories were reviewed against NASA/KSC capabilities as outlined in the Support Services Handbook KHB 8610.1D and the O&C Building Payload Processing and Support Capabilities Handbook K-STSM-14.1.14. No incompatibilities for OTV ground processing support were identified.

2.1.6 Ground to Orbit Logistics Requirements

Implementation of the OTV as a space based upper stage requires determination of logistics requirements at both the Space Station and at the launch site. This is necessary in order to plan for spares storage accommodations during OTV Space Station hangar definition, identify launch site OTV spare storage and handling requirements and for projecting OTV non-recurring/recurring logistics costs. The approach taken for this analysis was based on the following guidelines:

1) Spares types and quantities to be located at the Space Station are based on establishment of critical or insurance quantities. These space based spares would be used to satisfy contingency replacement of any one OTV Orbital Replacement Unit (ORU) at any time between normal maintenance cycles.

2) OTV maintenance spares are planned to be maintained in ground storage and shipped to the Space Station to satisfy planned maintenance cycles based upon life expectancy/reliability data, or to replenish critical spares.

These spares would be transported to the Space Station via the Logistics Module (LM) and, in the case of large units such as tanks and aerobrakes, in the Orbiter payload bay. Ground storage spare quantities proposed would equal the OTV total operating quantity, considering pipeline time and trend data.

Results of the analysis are as follows:

Proposed OTV spares (weight) to be located at the Space Station are summarized on Table 2.1.6-1 for the current MMC high potential candidate OTV's. Projected spares total weights at the Space Station range from 2,149 pounds for the 27K propellant load storable OTV to 3,392 pounds for the 84K propellant load cryogenic OTV. It should be noted that the avionics systems for all OTV's for this analysis were assumed to be identical. In case more than one OTV is operating from the Space Station, total critical spares at the Space Station would be adjusted following the rationale that common items, i.e., avionics, engines, etc., would be spared for one unit replacement only. Obviously, spares peculiar to OTV configurations, such as tanks and aerobrakes, would be spared for each OTV configuration. Table 2.1.6-2 outlines preliminary ground storage facility requirements for OTV spares receiving, handling, and storage. The size of the facility ultimately must accommodate spares for all OTV's based at the Space Station. Spares will be processed for delivery to the Space Station in the OTV Logistics Facility.

Large components, such as fuel and oxidizer tanks and aerobrakes, will be mounted on STS compatible cradles (ASE) and processed for delivery to the Orbiter for integration either in the Orbiter Processing Facility (OPF) as horizontally integrated cargo, or through the Vertical Processing Facility (VPF) to be integrated into the Orbiter vertically at the launch complex. Small components will be processed to the Logistics Module (LM) facility for incorporation into the LM, delivery to the Space Station, and subsequent transfer to the OTV hangar for planned maintenance activities.

Table 2.1.6-1 Space-Based OTV Space Station Located Spares

SYSTEM	STORABLE OTV 27 KLb APOGEE STG	STORABLE OTV 51 KLb PERIGEE STG	STORABLE OTV 51 KLb APOGEE STG	STORABLE OTV 97 KLb STG	CRYO OTV 58 KLb STG	CRYO OTV 84 KLb STG
1. Structure	106	157	157	266	323	394
2. Aerobrakes	887	590	1343	887	1407	1489
3. Environmental Control	60	63	64	39	33	41
4. Main Propulsion System	570	570	570	509	632	642
5. Orientation Control	58	58	58	64	95	95
6. Electrical Power	296	296	310	191	203	203
7. Avionics	220	220	220	220	220	220
Subtotal Spares Weight	2197	1954	2722	2176	2913	3084
Contingency 10%	220	195	272	218	291	308
Total Spares Projected Weight	2427	2149	2994	2394	3204	3392

Note: Figures represent pounds

Table 2.1.6-2 Space-Based OTV Ground Logistics Storage Facility Requirements (Preliminary)

1. Facility	
a. Main entrance door	30 ft. wide x 25 ft. high
b. Facility size	80 ft. long, 50 ft. wide 40 ft. high
c. Crane	5 ton capacity
d. Temperature	70 deg. ± 5 deg. F.
e. Relative humidity	50%
f. Cleanliness	Orbiter compatible
2. Standard commercial power	
3. Potable water	
4. Vacuum system	
5. Commercial telephones	
6. Paging	
7. GN_2 supply	
8. Shop pneumatics	

Notes:

1 Facility should be in close proximity to the Logistics Module facility since many OTV routine maintenance ORUs may be shipped to the Space Station via the LM.

2. Replacement fuel and oxidizer tanks, aerobrakes, and other large structural items will be transitioned to the Space Station via the STS (Cargo Bay).

3. This facility sizing considers total maintenance spares for two OTVs, i.e., 84K cryogenic version.

2.1.7 Ground-Based OTV Storable Propellant Loading Alternatives

In order to accomplish the ground process planning for the storable propellant OTV to be launched via the Dedicated Aft Cargo Carrier it was necessary to determine where propellant loading should occur. Three options were considered for this activity: an existing Hazardous Processing Facility in the Industrial Area; the OTV dedicated processing facility; or Launch Complex-39 after the STS has been positioned for launch. Based on the analysis (See summary in Table 2.1.7-1) the optimum location is to load/pressurize the DACC OTV at LC-39 in parallel or serial to similar STS loading activity. This recommendation should provide economic benefits from the standpoint of both non-recurring costs in regard to facility and ground support equipment acquisition and maintenance. This approach should also be beneficial relative to safety/handling during ground transport from the KSC Industrial Area to the Vehicle Assembly Building (VAB), integration with the ET/DACC and subsequent STS activities prior to Pad operations. If for some reason as OTV designs mature, problems relating to safety, impact to STS on-Pad time due to loading schedule conflicts or loading access occur, the use of a KSC HPF should be considered as a secondary location.

Table 2.1.7-1 Storable Propellant Loading Options Comparison

OPTION	ADVANTAGES	DISADVANTAGES
OTV DEDICATED FACILITY	NO IMPACT TO STS OR CARGO PROCESSING NO IMPACT TO KSC HPF UTILIZATION ACCESS TO OTV SYSTEMS (CONTINGENCY)	MONITORING REQ'D APPROX. 24 DAYS SAFETY PROBLEMS (MOVEMENT/HANDLING/INTEGRATION) INCREASED FACILITY COSTS INCREASED EQUIPMENT COSTS (TO SUPPORT LOADING & HANDLE LOADED OTV)
DESIGNATED HAZARDOUS PROCESSING FACILITY (SAEF-2,CHSF)	NO IMPACT TO STS PROCESSING EXISTING FACILITY CAPABILITY REDUCES COST OF OTV DEDICATED FACILITY ACCESS TO OTV SYSTEMS (CONTINGENCY)	MONITORING REQ'D APPROX. 24 DAYS SAFETY PROBLEMS (MOVEMENT/HANDLING/INTEGRATION) INCREASED EQUIPMENT COSTS TO HANDLE LOADED OTV PROBABLE FUELING EQUIPMENT COSTS MAY IMPACT CARGO PROCESSING (CONTINGENCY)
PAD	LIGHTER DESIGNED HANDLING EQUIP UTILIZE STS FUELING EQUIPMENT REDUCED COST OF OTV DEDICATED FACILITY REDUCED MONITOR TIME CROSS UTILIZATION OF SUPPORT POTENTIAL CROSS UTILIZATION OF STS FUELING PERSONNEL LIGHTER OTV STRUCTURE SAFER MOVEMENT/HANDLING/INTEGRATION	MAY IMPACT STS PROCESSING (PROBLEMS OR NON-PARALLEL) CONTINGENCY ACCESS PROBLEMS PAD MODIFICATIONS REQ'D

2.1.8 Space-Based OTV Maintenance Options

Maintenance policy/planning for high potential candidate, Space Station based OTV's cannot be definitized at this time due to the immaturity of the program. Therefore we established groundrules and recommendations to be considered as design drivers in an attempt to maximize the capabilities to maintain the OTV with a minimum amount of EVA. Recommended groundrules to be considered are: A limited number of personnel will be available for maintenance; as a goal, previously qualified components should be used; hardware commonality/standardization with the Space Station and OMV should be considered; space based OTV design must be considered in ground based design concepts, use the ground based OTV as a test bed. Preliminary recommendations for OTV design consideration were developed/tailored to coincide with those identified for Space Station design and maintainability as follows:

1) Onboard Space Station systems should be provided for OTV checkout, monitoring, warning, and fault isolation to a level consistent with safety and with the in-orbit maintenance and repair approach selected. Loss of redundancy for critical functions being accomplished during OTV operations at the Space Station should be detectable automatically by the Space Station management subsystem and the crew alerted through caution and warning system signals.

2) Applicable OTV subsystems, such as avionics GN&C, should provide for fault isolation and subsystem checkout. Subsystem design should include a Built-In-Test (BIT) capability, if applicable, to facilitate detection and reporting of functional discrepancies. BIT should be provided for all time-critical equipment.

3) Subsystems equipment should be removable or replaceable by use of installation handling devices or an onboard set of standardized tools. Interconnecting plumbing and wire runs should have suitable attachment, length, and mounting characteristics to facilitate removal/replacement. These subsystems should be further subdivided into sub-module units which can be isolated and replaced at the ORU level.

4) As a goal, all failures or damage should be repairable.

5) All critical, life-limited components and subsystems should be designed to allow on-orbit inspection/monitoring for determination of remaining useful life.

6) The design requirement is to provide a minimum set of onboard spares and hardware/software maintenance capability for subsystems expected to experience occasional failures or needing refurbishment and maintenance.

7) All applicable systems should be capable of fault isolation to the ORU level while docked with the Space Station.

8) Redundant functional paths should be designed so that their status can be verified without removal or ORU's.

9) ORU's should be designed to allow refurbishment or repair by exchange of replaceable equipment modules. Equipment design should allow for required diagnostics and isolation to a faulty module and should provide for periodic or on-demand system checkout to allow early detection and maintenance of faulty equipment.

10) Replacement of subsystem equipment should not require the removal or disconnection of other subsystem equipment, nor should replacement of an equipment module require the removal or disconnection of other equipment modules. Further, system design should provide interfaces that prevent mislocation of equipment modules or intermixing of equipment interface connectors.

ORU's should be designed for ease of on-orbit replacement. The hardware should be designed to use common type fasteners, connectors, and tools, and to use the same packaging as appropriate. In addition, all connections should be designed and labeled to preclude improper mating.

11) Removal of ORU's for maintenance action shall not introduce a hazardous condition.

12) Adequate clearance shall be provided during service and maintenance activities to prevent interference with other Space Station operations and to avoid creating a safety hazard.

2.1.9 Dedicated Aft Cargo Carrier/OTV Access

A study was performed concerning access for OTV LRU replacement at the launch pad considering both ground based cryogenic and storable OTV's installed in the Dedicated Aft Cargo Carrier (DACC).

The identified Pad access options for DACC/OTV LRU replacement and inspection are summarized in Table 2.1.9-1 for the cryogenic configuration and in Table 2.1.9-2 for the storable configuration.

The candidate solutions investigated included DACC design changes, OTV design changes, LC-39 GSE modifications, internal access kit configurations and various combinations of the aforementioned.

After investigation of the various options, the following was recommended for the ground based cryogenic OTV:

1) Locate skirt access door adjacent to the Ground Umbilical Carrier Plate (GUCP) location.

2) Locate the shroud access door below the skirt access door adjacent to the GUCP.

Recommendations for the storable OTV DACC Pad access are as follows:

1) Reduce the DACC shroud access door height and width from existing design to 30"H X 40"W. (This will minimize potential OTV aerobrake damage during entry operations by not exposing its leading edge to the door passage).

2) Determine high probability failure components (LRU's) and relocate installation near the DACC shroud access door(s). This would reduce timeline impact due to failed component replacement.

3) Provide three additional doors 90 degrees apart for a total of 4 shroud doors and 1 skirt door.

Table 2.1.9-1 ACC/OTV Ground-Based Cryo Configuration - Pad Access Options

OPTION	ADVANTAGES	DISADVANTAGES
BASELINE ACC ACCESS ICD 80900000025	- UTILIZES GUCP ACCESS ARM WITH MINOR MODIFICATION	- LIMITED WORKING AREA - ROTATION OF OTV 15° CCW - HIGH PROBABILITY OF OTV/ACC DAMAGE - COMPLEX INTERNAL ACCESS KIT DESIGN - DIFFICULT/TIME CONSUMING INTERNAL ACCESS KIT INST'L - INTERFERENCES WITH INTERNAL UMBILICAL LINES
RELOCATE EXISTING DOORS CENTERLINES TO 225° AND 15° Xt = 2211 AND Xt = 2121	- UTILIZES GUCP ACCESS ARM	- LIMITED WORKING AREA - HIGH PROBABILITY OF OTV/ACC DAMAGE - COMPLEX INTERNAL ACCESS KIT DESIGN - DIFFICULT/TIME CONSUMING ACCESS KIT INST'L
PROVIDE THREE ADDITIONAL ACCESS DOORS ON SHROUD AT 45°, 135° AND 315°	- UTILIZES GUCP ACCESS ARM - ALLOWS SELECTIVE ENTRY - DIMINISHES TIMELINE IMPACT	- NEED FOR ADDITIONAL EXTERIOR ACCESS STANDS/SCAFFOLDING - INCREASED WEIGHT
RELOCATION OF HIGH FAILURE PROBABILITY COMPONENTS	- MINIMIUM INTERNAL ACCESS KIT - UTILIZES GUCP ACCESS ARM - DIMINISHES TIMELINE IMPACT	- ADVERSELY AFFECTS MASS PROPERTIES CONSIDERATIONS - IMPACTS AVIONICS PACKAGE COOLING METHOD - DETERMINATION OF HIGH PROBABILITY COMPONENTS IS DIFFICULT
PROVIDE AN ADDITIONAL DOOR LOCATION IN THE AFT DOME	- ACCESS FROM MLP DECK - SIMPLIFIED GROUND OPERATIONS/PREPARATIONS - SELECTIVE ACCESS KIT INST'L OPTION	- AEROBRAKE RELOCATION OR PERSONNEL ACCESS THRU IS REQUIRED - DOOR LOCATION IN HIGH HEAT AREA AND REQUIRES COMPLEX TPS CLOSEOUT

Table 2.1.9-2 ACC/OTV Ground-Based Storable Configuration - Pad Access Options

OPTION	ADVANTAGES	DISADVANTAGES
BASELINE ACC (ICD 80900000025)	- UTILIZES GUCP ACCESS ARM WITH MINOR MODIFICATION - AMPLE WORK AREA INTERNALLY	- AEROBRAKE REQUIRED RELOCATION OR PERSONNEL ACCESS THRU PROVISION - FULL 360° COVERAGE INTERNAL ACCESS KIT REQUIRED
PROVIDE THREE ADDITIONAL ACCESS DOORS ON SHROUD AT 45°, 135° AND 315°	- SAME AS BASELINE - ALLOWS SELECTIVE ENTRY - DIMINISHES TIMELINE IMPACT	- AEROBRAKE INTERFERENCE - INCREASED WEIGHT
PROVIDE AN ADDITIONAL AFT DOME ACCESS DOOR AT 225° Xt 2400	- SIMPLE ACCESS KIT DESIGN - SIMPLIFIES GROUND OPERATIONS/PREPARATION - SELECTIVE ACCESS KIT INSTALLATIONS - DIMINISHES TIMELINE IMPACT	- ACCESS DOOR IS LOCATED IN HIGH HEAT AERA
REDUCED DOOR DIMENSIONS	- PROVIDES AEROBRAKE CLEARANCE	- REDUCED ENTRY SPACE

4) Locate the skirt access door adjacent to the GUCP location.

5) Provide a shroud access door on the aft dome.

6) Incorporate access kit attach points in the OTV/DACC design.

2.1.10 Automated Versus Manual Ground Checkout

This study was performed to investigate automated versus manual checkout of the ground based OTV in an effort to: 1) Identify ways to minimize the number of personnel required for turnaround maintenance on the ground; 2) To drive OTV design to accommodate Space Station requirements; and 3) To ascertain if it would be practical to simulate Space Station operations with robotics during ground processing. The approach used in performing this study was as follows:

1) Develop and analyze a generic OTV ground operations turnaround scenario to determine tasks which could be accomplished using robotics.

2) Consider alternatives to current ground processing approaches (Figure 2.1.10-1). It is assumed that OTV electrical and electronic systems and corresponding EGSE initial design will incorporate a single umbilical interface, i.e. OTV to checkout console, and that systems test will be accomplished by one person at the console.

3) Analysis of the generic scenario indicated that the only viable area for the use of robotics in the generic flow appears to be activity involving Orbital Replacement Unit (ORU) removal/replacement when the OTV is in the dedicated facility. While the use of robotics to accomplish this activity would be "new and different", the cost of development of specialized equipment for demonstration purposes at the launch site may not be justifiable. This type of demonstration should be accomplished in a test bed during space based OTV design to prove maintainability concepts driven by Space Station criteria.

4) Consideration was given to alternative ground processing approaches for both Dedicated Aft Cargo Carrier (DACC) and Orbiter payload bay launched OTV's. No attempt was made to recommend deviations to proposed KSC OTV flows commencing with either OTV delivery to the VAB for integration with the DACC or to the VPF for transfer to LC-39 with the Canister. The possibility for change does exist in the area of GSE which could incorporate automatic checkout equipment and robotics as an integral part of the GSE. The concept drives design of a Transporter (Table 2.1.10-2) for use at the launch site which would also serve as a universal work stand for the OTV. The OTV would be safed and recovered from the Orbiter in the Transporter, moved to its dedicated facility, defueled/decontaminated, inspected, reconfigured and retested in the Transporter and then moved to its point in the flow (either the VAB or VPF) for Orbiter integration. As a part of the Transporter or as a separate fixed unit, a robotics system could be provided with appropriate computer programming for use on interconnecting GSE/OTV cables/lines mating/demating and ORU replacement. This obviously would require fixed exact positions for both the GSE and the OTV since it is assumed that the robotics operation should be primarily automatic. Due to the size, the aerobrake would probably be installed manually as the last operation prior to movement to the VAB or Pad. This approach drives to a Space Station OTV ground maintenance simulator.

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Table 2.1.10-1 Ground-Based OTV Automation Opportunities

OTV Turn-around Task	Ground Turn-around Activity	Space Station Turn-around Activity	Ground Processing Approach	Space Station Processing Approach	Launch Site Simulation Applicability	Simulator Requirement	OTV Design Requirement (Ground Based)
1. OTV SAFING	Safe OTV while in the orbiter payload bay. Disconnect firing circuits, verify gas pressures, verify that no hazardous vapor is present.	Safe OTV while in the hanger, if ordnance is used, disarm circuits, verify tank pressures, verify no hazardous vapor is present.	Manual - Activity using technicians, safety engineers	Automated - initiated by control console in the S.S.	None - activity takes place in the OPF	N/A	N/A
2. OTV VISUAL INSPECTION	Inspect OTV in the Orbiter Payload Bay for damage.	Inspect OTV after installation in the hanger for damage.	Manual - activity using Quality inspection and system engineers	Remote using closed circuit television (CCTV) EVA if required in case of extensive damage	None - activity takes place in the OPF	N/A	N/A
3. CONFIGURE OTV & GSE FOR DEFUELING/ DECONFIGURATION	Set-up propellant loading and press equipment, install interconnecting lines to OTV fuel, oxidizer and RCS bulkhead fittings Install GSE lines to facility systems	Detank OTV fuel system. Install lines (umbilical) to S.S. provided system, verify system is mated and ready for operation	Manually configure for defueling/ decontamination	Mate system automatically using probe type umbilicals extending to the fixed OTV from the Space Station	Possibility of mating GSE lines to the OTV using an articulating arm with electronics to verify hard connection has been made	Articulating arm with capability to grasp GSE connectors and mate with OTV control console with hard mate indicator	1. GSE connectors designed to accommodate robotic manipulator 2. OTV and GSE connectors designed for guided mate
4. PREPARE FOR FLIGHT SYSTEM TESTS, I.E. SUBSYSTEMS AND SYSTEMS RUN TESTS	Set-up EGSE & verify. Connect I/F cables between EGSE and OTV Systems Test Points, Perform Systems Test(s), Review Test Data	Engage S.S. to OTV power/ electronics system umbilical, activate OTV control console for OTV system self test. Record out of tolerance parameters	Manual configure EGSE/OTV for Test, verify ready for test, perform testing	Mate system automatically, verify I/F has been established via control console, run test from test console	1. Use articulating arm to mate EGSE to OTV connectors 2. Build S.S. type expendable umbilical simulator 3. In either case, use control console for test	Same as above	Same as above

Table 2.1.10-1 Ground-Based OTV Automation Opportunities (continued)

OTV Turn-around Task	Ground Turn-around Activity	Space Station Turn-around Activity	Ground Processing Approach	Space Station Processing Approach	Launch Site Simulation Applicability	Simulator Requirement	OTV Design Requirement (Ground Based)
5. RECONFIGURE OTV, I.E. REPLACE ORUs, INSTALL KITS, ETC.	Stage ORUs and kits, remove and replace ORUs, install kits	Replace ORUs while OTV is in the hanger using articulating arm. Install kits in the same manner	Manual	Remote operation using articulating arm. Kits and spare ORUs stored in the close proximity with the OTV. Electronic feedback for confirmation of operational mate to control console	Simulator with robotics capability and control Console interface. ORU and kit storage rack mock-up. Remove and replace hardware using articulating arm.	1. Articulating arm with capability to interface with ORUs and kits. 2. ORU and kit storage rack mock-up. 3. Control console	1. ORU placement on OTV for articulating arm access. 2. ORU compatibility with ORU end effector. 3. Electronics to verify operational ORU mate.

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Table 2.1.10-2 OTV Transporter Requirements (Preliminary)

OTV TRANSPORTER REQUIREMENTS (PRELIMINARY)

1. Length: To be determined based on final OTV design
2. Width: To conform to either DACC or PLB envelope, whichever applies
3. Height: Same as 2. above
4. Capacity: Mounted GSE plus OTV (not fueled if CRYO version, fueled if storable version
5. Cover: Removable to allow total OTV access using facility crane
6. Transporter to facility interfaces (I/F plates)
    a. Grounding System
    b. Lightning Protection System
    c. Pneumatic System
    d. Scrubber/Vent Systems (if storable)
7. Transporter Systems
    a. Environmental Control
    b. Air Ride
    c. Outriggers
    d. OTV Support Fixture
    e. Vapor Detectors (if required)
8. Transporter to Control Console I/F (with I/F to OTV)
    a. Guidance, Navigation and Control Systems
    b. Data Management System
    c. Telemetry and Command System
    d. Communications and Tracking System
    e. Power
    f. Other

Tractor/tug should be gasoline or diesel with electric motor for movement into/out of the OTV facility.

Airbearing pallets should be considered for the transporter.

In summary, automated checkout of the ground based OTV is a desired approach, using a test and checkout console with a single OTV umbilical interface. This assumes that OTV subsystem design includes a built-in test capability, as is recommended for the Space Station, to facilitate detection and reporting of functional discrepancies.

The simulation of Space Station operations during ground based OTV turnaround activities has been investigated. It has been concluded that only activity concerning subsystem/system test set-up and component changeout occurring in the designated OTV facility are candidate activities. It has further been determined that it is not practical to do simulation at the launch site since it would require additional, specialized GSE, which could not effectively replace or eliminate the generic approach to ground processing. Simulations should be conducted with scaled model equipment, both Space Station and OTV, in a factory test bed such as the Denver Division Space Operations Simulations Laboratory.

2.1.11 Dedicated Aft Cargo Carrier Launched OTV - STS Launch Rate

Conclusions reached on our analyses of the high potential OTV candidates ground processing timelines indicated no impact in any case to the STS turnaround flows projected in STAR 027. The following, provided as information applicable to OTV/DACC operations, has been extracted from the "Advanced Space Transportation System Ground Operations (ASTG/GO) Study Extension" final report, NAS10-10572, SA#6, May 1985 and provides detail relative to launch rate impact during the DACC facility modification implementation period. In the referenced study, operational timelines were developed that integrated the STS and DACC ground operations. The timelines (Figures 2.1.11-1 and -2) demonstrate that the ground operations required to process a DACC and integrate the STS and DACC can be performed in parallel with STS operations without serial impact. The STS can be augmented by a DACC for delivery of the ground based OTV without operational impacts or increases to top level STS processing times.

Based on the STAR 027, the timelines developed considered the STS/DACC common facility use and determined the time requirements for DACC processing events. The operational timeline reflects serial ET checkout and ET/OTV/DACC integration prior to ET/SRB mate. The upper region of the timeline (Figure 2.1.11-1) summarizes the standard STS ET checkout cell processing time at 200 hours, followed by a 16-hour operation that transfers the ET/DACC skirt to the ET/OTV integration cell. The DACC skirt processing requires 48 hours and is performed in parallel with OTV transfer to the ET/OTV integration cell and final OTV preparations for mate. (Receiving and inspection tasks were performed in parallel with the ET receiving and inspection tasks.) The OTV/skirt mate and closeout operations require 48 hours.

The DACC shroud standalone operations are performed in parallel to the ET skirt and OTV checkout and integration tasks. Shroud mate and ET/OTV/DACC interface verification tasks require 16 hours.

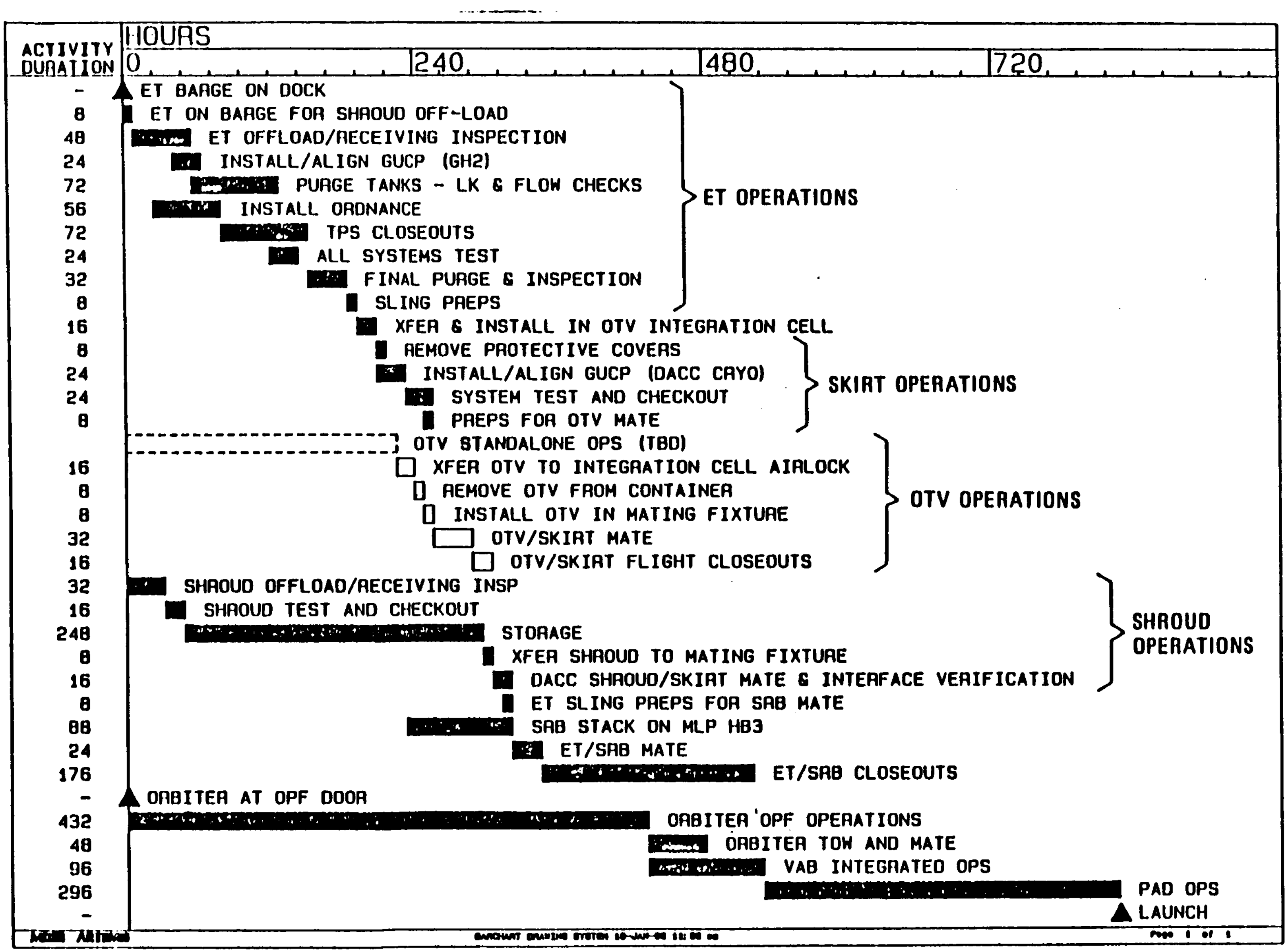

Figure 2.1.11-1 DACC Operations - Pre-ET/SRB Mate

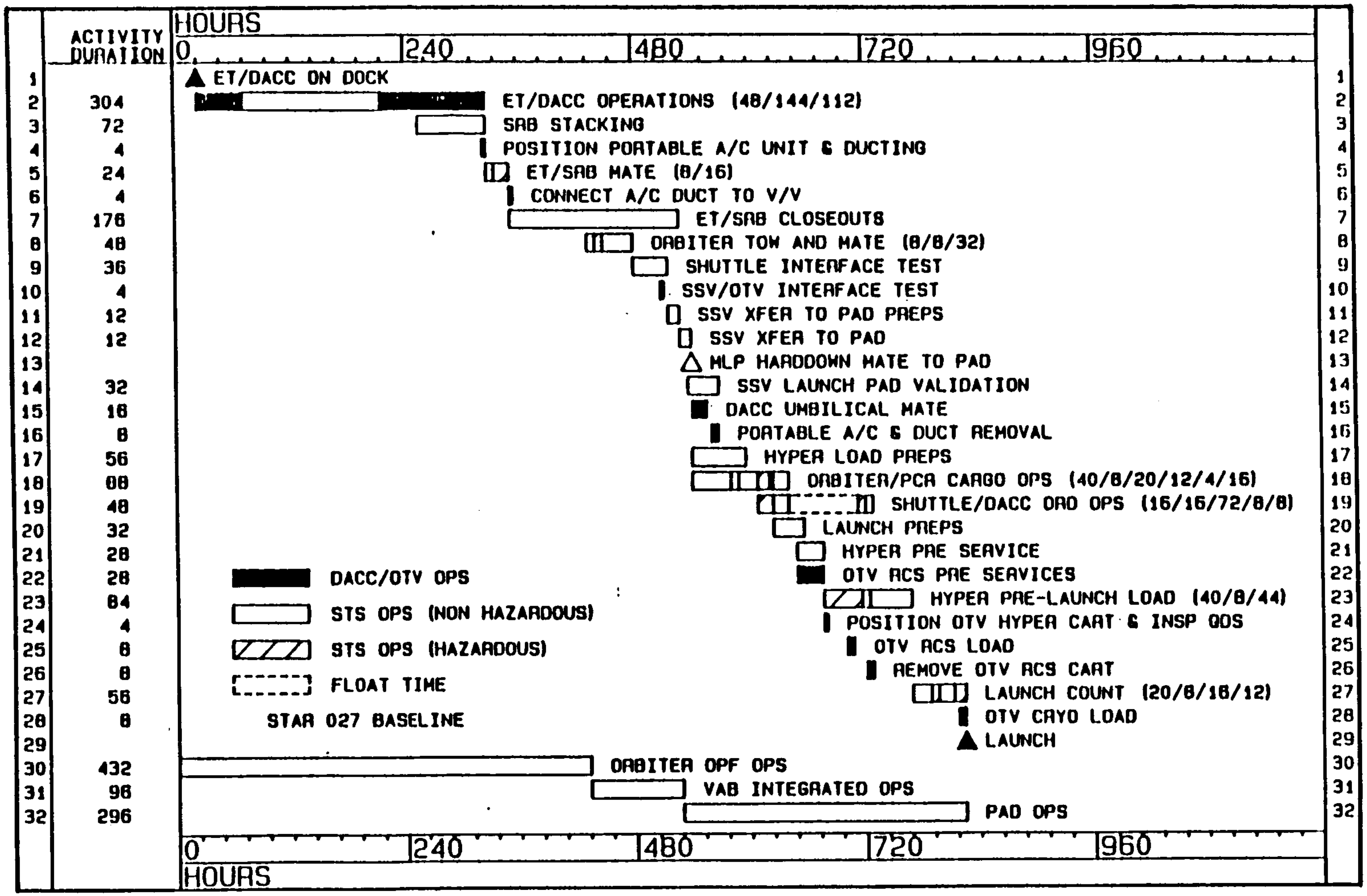

Figure 2.1.11-2 DACC/STS Operations - Post-ET/SRB Mate

The DACC/OTV operations have a 112 hour serial impact on ET processing. In particular, the STAR 027 assessment of the standard STS pre-ET/SRB mate operations is 192 hours. Additional DACC/OTV operations increase the time from ET on dock to ET/SRB mate to 304 hours. Although this represents an impact to the ET processing timeline, there is no impact to the STS critical path. The critical STS path from the STAR 027 is basically the same as Orbiter processing (shown at the bottom of Figure 2.1.11-1 for reference).

Immediately after the ET/SRB mechanical mate and in parallel with initial ET/SRB closeout operations, a portable air conditioning unit is positioned beneath the ET on the MLP "0" Deck. The unit is connected through portable ducting to the DACC vent valve on the aft end of the DACC shroud. This unit provides environmental conditioning for the DACC interior through the remaining STS VAB integration cell operations and during rollout to the launch pad. After connection of the DACC umbilical at the launch pad during OMI S0009, SSV Launch Pad Validation, the air conditioning unit and ducting are disconnected and removed from the MLP "0" Deck.

During OMI S0008, Shuttle Interface Test, additional sequences are performed to verify all SSV-to-OTV interfaces. These sequences reverify the previously verified ET/DACC/OTV interfaces and provide functional verification of the Orbiter/ET interfaces to the OTV and DACC.

The DACC cryogenic umbilical mate operations are performed in parallel with ET GH2 vent and intertank umbilical mate (subtask to OMI S0009, SSV Launch Pad Validation). The time estimate of 16 hours for this operation was based on the operational times for the ET GH2 vent and intertank umbilical mate procedures.

The OTV RCS hydrazine loading operations were scheduled in parallel with the SRB Hydraulic Power Unit (HPU) hydrazine loading operations (Figure 2.1.11-2). Preservice operations are included, e.g., requirements for equipment preparation, sampling and analysis, and scupper and line support installations. In parallel with SRB HPU cart positioning, the OTV RCS cart is positioned followed by inspection of the GSE and flight disconnects. Drag-on umbilicals are connected via disconnects on the cart and the DACC skirt near the DACC Umbilical Access Arm (UAA). The OTV RCS loading and cart removal are also planned in parallel with analagous booster HPU loading and cart operations.

Final preparations for launch include changing over from GN2 to GHe purge of the DACC interior in parallel with ET LH2 fill operations and loading the OTV liquid hydrogen (LH2) and liquid oxygen (LO2) tanks in parallel with ET propellant tank loading procedures.

After ET/SRB mate, all DACC and known/anticipated OTV operational requirements are scheduled in parallel with analogous STS operations. No serial impact to the STS operational timeline is projected.

However, there are some potential impacts to the projected STS launch rate during the DACC facility modification implementation period. Figure 2.1.11-3 shows the MSFC Nominal Mission Model projected flight rate and the projected flight rate derived from the STAR 027. The bottom row of figures indicates the projected launch rate factoring in facility modification downtimes based on the STAR 027 flight rate. Figure 2.1.11-4 provides the backup analysis for the STAR 027 launch rate data.

	FISCAL YEAR									
	90	91	92	93	94	95	96	97	98	99
Nom. Mission Model (Rev. 7) Flights/FY*	15	31	30	37	48	39	40	48	43	46
STAR 027 Flight Rate Projection**	22.7	22.7	22.7	22.7	22.7	22.7				
Implementation Plan/STAR 027 Derived Flight Rate	22.7	22.7	22.1 ***	19.2 ****	22.7	22.7				

* Data Extracted from MSFC, Nominal Mission Model (FY 1983-2000), Rev. 7(SS), Space Station Advocacy, July 1984, Page VI-B1-1.

** STAR 027 Assumptions:
-6 day/3 shift work week
-3 orbiters - orbiter limited
-3 MLPs, 2 Pads, 2 VAB integ. cells, 2 OPF bays
-No modification/maintenance specific periods
-No ET/SRB limitations

*** Launch rate limited by 2 operational MLPs (Ref. Figure 2.1.11-4)

**** Launch rate limited by 1 operational Pad (Ref. Figure 2.1.11-4)

Figure 2.1.11-3 DACC Implementation Period Potential Launch Rate Impact

	STAR 027 OPERATIONS ASSESSMENT (HOURS)								
Facility/Element	ORB SLF 4	ORB OPF 432	ORB VAB 96	STS VAB 288	STS PAD 296	PAD RFRB 77	MLP RFRB 64	ORB MISS. 120	Turnaround Hours
Orbiter	X	X	X		X			X	948
MLP				X	X		X		648
VAB (HB-1/3)				X					288
PAD (39 A/B)					X	X			373
OPF		X							432

Launch Rate Capability Assumptions

6 day/3 shift work week
14 holidays
Derived total yearly operations time = 7176 hours

Launch Rate Capability

ORB $\frac{7176}{948}$ = 7.5(+) launches/yr/ORB

MLP $\frac{7176}{648}$ = 11.1(-) launches/yr/MLP

VAB (HB) $\frac{7176}{288}$ = 24.9(+) launches/yr/cell

PAD $\frac{7176}{373}$ = 19.2(+) launches/yr/pad

OPF $\frac{7176}{432}$ = 16.6(+) launches/yr/bay

Figure 2.1.11-4 KSC Launch Rate Capabilities

Although the analysis shows that implementation can be accomplished with a relatively minor impact to the STS operational launch rate, it would be undesirable to have both a Pad and a MLP out of service for an extended period of time. A more detailed analysis could better correlate and interleave the STS operations and the activation activities to reduce the potential for impact discussed below.

The three-one year MLP (1,2,3) modification timelines begin in the middle of FY 1991 and continues through the middle of FY 1994. Although the STS launch rate is limited by two operational MLP's during the second half of FY 1991 and the first half of 1994, the launch rate during these fiscal years remains Orbiter limited. Therefore, no impact to the STAR 027 projected flight rate is indicated for these years. During the entire FY 1992, the STS flight rate is limited by the two operational MLP's to 22.1 flights/year based on the Figure 2.1.11-4 analysis.

The DACC required modifications of Launch Pads 39A and 39B mandate that each facility be offline for 10 months. These modifications are performed serially at the two facilities, resulting in a 20 month period. This period goes from the last quarter of FY 1992 through the first half of FY 1994. During this time, the STS flight rate is limited by one operational Pad to 19.2 flights/year. As with the MLP modifications, during FY's 1992 and 1994, the projected STAR 027 launch rate can be achieved because both launch pads will be operational at least one-half of these fiscal years. Based on an analysis of the FY 1993, the STS launch rate is limited by one operational launch pad to 19.2 flights.

Detailed scheduling of these modifications can help reduce the potential impacts during FY's 1992 and 1993. As indicated by the projected launch rates in the mission model for later years, a slip of the DACC IOC date to the out years could result in a more significant STS launch rate impact. However, earlier starts resulting in FY 1988 - 1990 modification periods could completely eliminate these potential impacts.

2.1.12 Conclusions and Recommendations

2.1.12.1 Conclusions

1) A review of the high potential OTV's ground processing scenarios and timelines indicates that no on-line impact should be experienced by the STS as a result of the addition of the OTV(s) as a cargo element.

2) OTV processing demands may impact existing NASA/KSC off-line facilities depending on OTV launch rate and the density of other Shuttle manifested cargo. There is a high probability that a dedicated OTV processing facility will be required to handle OTV build-up requirements. This facility could however be transitioned to support OTV logistics and turnaround maintenance/repair activities or shared with other users once the stage is space based.

3) A new integration area will be required at the Vehicle Assembly Building (VAB) to support OTV/DACC integration.

4) DACC/OTV propellant loading (either cryogenic or storable) should be accomplished at the Pad in conjunction with applicable Orbiter systems loading. This would require modifications at the Pad.

5) Initial space based OTV packaging for ground to Space Station transfer and system testing should be accomplished at the factory. Ground processing activity at the launch site should be minimized.

2.1.12.2 Recommendations

For the selected OTV configurations, i.e. ground based, DACC launched cryogenic and space based cryogenic, the following should be considered for future study, using Phase A final configuration data:

1) Review and update applicable ground operations scenarios and operations analyses.

2) Definitize detail requirements i.e. ground support equipment, support requirements. Provide GSE design recommendations/concepts.

3) Update detail ground flows and timelines. Provide manpower loading and processing procedure requirements.

4) Develop detailed facility requirements to support each selected OTV configuration including processing facilities, logistics facility, labs/shops etc. Provide facility layouts and estimated cost for new facility construction and/or existing facility modification. Provide detail for Complex 39 modifications required for ground based OTV cryogenic loading, and OTV/DACC integration facility requirements in the VAB.

5) Consider incorporation of an additional field joint in the DACC skirt above the OTV support structure.

6) Provide a master plan/schedule to be implemented for OTV launch site ground processing planning and readiness activities leading up to launch capability.

2.1.13 <u>References</u>

a. K-DPM-10.1.5, February 1983, Rev. A, Facility and Equipment Requirements Documentation for Cargo Hazardous Servicing Facility.

b. K-STSM-14.1. Space Transportation System Launch Site Accommodations Handbook for STS Payloads.

c. K-STSM-14.1.7, Facilities Handbook for SAEF-2.

d. Modification Package for SAEF-2.

e. K-STSM-14.1.11, Facilities Handbook for Payload Ordnance Processing Area at CCAFS.

f. K-STSM-14.1.12, Facilities Handbook for Vertical Processing Facility.

g. K-STSM-14.1.13, Orbiter Processing Facility Payload Processing and Support Capabilities.

h. K-STSM-14.1.14, O&C Building Payload Processing and Support Capabilities.

i. KHB 8610.1D, Support Services Handbook.

j. Martin Marietta Progress Review, Feb. 1985, Advanced Space Transportation System Ground Operations Study Extension (Contract NAS10-10572).

k. Standard Interface Documents (SID)

   1) 79K12170 Payload Canister

   2) 79K16210 Vertical Processing Facility

   3) 79K18218 Launch Pad-39A

   4) 79K18745 Orbiter Processing Facility

l. Shuttle Turnaround Analyses Reports 025 and 027.

m. Boeing Aerospace Operations Orbital Transfer Vehicle Launch Operations Study, Midterm Report, August 15, 1985.

n. NAS10-10572, SA#6, Martin Marietta Advanced Space Transportation System Ground Operations Study Extension, Final Report, Vol. II, May 1985.

o. Aft Cargo Carrier and Shuttle Derived Cargo Vehicle Definition Study, Vol. II, MMC-SDV-DR-6-3, February, 1983.

2.2 FLIGHT OPERATIONS

2.2.1 Introduction - Flight operations analysis requirements and associated support requirements are presented in the following sections. The tasks undertaken sought to develop and assess the operations for the various candidate OTV configurations and missions. Specifically, the intent was to influence the designs so that they meet mission objectives and are cost effective and easy to operate, i.e., there are no design features that cause operations problems and complexity.

This was accomplished by developing mission plans for design reference missions. These mission plans define baseline launch, onorbit, and retrieval operations scenarios for ground-based and space-based OTVs in both storable and cryogenic propellant configurations. These plans provided the basis for requirements on OTV operational characteristics such as mission durations, communications capabilities, grappling and mounting fixtures, and delta-v capabilities. Tasks were also performed to develop operations concepts for flight operations support and for OTV fleet operations. The results of these tasks are also presented here.

2.2.2 Objectives - The objective of the flight operations tasks was to define the flight phases of OTV operations to a sufficient level of detail to allow conceptual design of various OTV configurations which would meet the mission model requirements. Definition of the flight operations included identification of operations support activities so that costing data for trade studies could be developed for the various configurations and operating modes. The operations analyses also would serve to insure that OTV concepts were indeed capable of being operated in the environment and at the flight rates called for by the mission model.

2.2.3 Ground Rules - The set of ground rules adhered to in the completion of flight operations tasks are as follows:

a) Operations scenarios are based on the concept of a reusable OTV employing aeroassist for return to LEO and evolving to space-based operations as the FOC Space Station becomes available as called for in the mission model.

b) Mission durations are based on requirements for dwell time at the mission orbit.
   GEO delivery - 1 day
   Unmanned GEO Servicing Demonstration - 10 days
   Manned GEO Sortie - 18 days
   Unmanned Lunar Delivery - 7 days
   Manned Lunar Sortie - 16 days
   DOD - 1 day

c) Precise longitude placement will be achieved by 12 hours coast in LEO to select the appropriate burn node and by an intermediate phasing orbit with a period of between 1.5 and 3.0 hours as necessary.

d) Planetary missions will utilize OTV retrieval whenever possible. The use of expendable planetary inject stages will be considered to achieve this end.

e) Any OTV hardware jettisoned during a mission shall be disposed of through controlled deorbit or other acceptable noninterference modes.

f) The OTV and payloads will be launched to orbit in the STS, either in the cargo bay of the orbiter or in the aft cargo compartment. OTV and payload launch by the Shuttle Derived Vehicle or other new launch vehicles will not be considered.

g) Rendezvous and proximity operations maneuvers are performed by the STS or OMV with the OTV in a passive role.

h) OTV operations will be designed for minimum impact to current STS operating procedures and to currently understood Space Station operation philosophy.

i) The Space Station orbit is 270 n mi circular at 28.5 deg inclination.

2.2.4 Flight Operations Analyses

Analysis of OTV flight operations was directed at the set of design reference missions (DRMs) which were identified early in the study as being the missions in the model which would be vehicle performance and systems design drivers. Mission plans were developed for each DRM using the high potential candidate cryogenic and storable propellant OTV configurations. The DRMs encompass both ground-based and space-based missions for each propellant type.

Some of the missions characteristics such as payload weight and dwell at mission orbit were modified between the Revision 7 and Revision 8 models. Although the original analyses were performed against the Revision 7 model, the mission plans summarized here reflect Revision 8 modifications where applicable. Detailed timelines for the DRMs are provided in Appendix B. Ground-based and space-based missions were subdivided into mission phases.

The following conventions are used in the timelines:

1. Times are in Phased Elapsed Time (PET)
2. Each phase begins with a phase title and the corresponding Mission Elapsed Time (MET)
3. Each phase ends with a phase title and the MET
4. Main Engine delta-V is indicated in fps, and RCS burns are indicated within the event.

Ground-based GEO delivery timelines are based only on MET

2.2.4.1 Ground-Based OTV Missions

Three missions were analyzed for ground-based operations. GEO Delivery, Planetary, and High Inclination (Molniya and GPS) are the driver missions, based on the mission model, to be accomplished using ground-based OTV.

For ground-based OTV, two storable stage configurations were analyzed. The timelines generated depict the PLB configuration, which rides already attached to the payload in the orbiter cargo bay. This configuration has the advantage of not requiring OTV/orbiter initial rendezvous and subsequent payload mating operations. The other configuration utilized the ACC. The operations and corresponding timelines for this configuration during launch, rendezvous, payload mating and orbiter separation are identical to the Cryo ACC stage, and increase mission duration by 22.1 hours. A single timeline GEO Delivery, was generated for the storable ACC configuration to demonstrate this likeness. All cyro timelines reflect the ACC configuration.

The planetary and High Inclination missions utilize most of an orbiter's capability to stay on orbit. The storable mission timelines in Appendix B are shorter in duration than the cryo since:

1. The In-bay configuration was used in developing storable stage high inclination and planetary timelines, and time for OTV/Orbiter ascent rendezvous and payload mating was not required.

2. The Storable GEO Delivery mission performs a perigee burn only; no time is spent at GEO.

The timelines were developed with the goal of minimizing operational complexity within a given mission, and maximizing the use of standard operations phases between all missions. With this as a goal, all ground-based missions share common mission phases. For ACC configurations these phases are Launch, Orbiter Operations and Separation, OTV Delivery and Return, and Orbiter Rendezvous and Retrieval. In-Bay (storable only) configurations use a subset of ACC phases. The only mission to mission unique operations involve the OTV Delivery and Return phase.

2.2.4.1.1 Launch Phase

The launch phase for the ACC OTV consists of orbiter ascent, orbiter separation, and the independent achievement of park orbit by the OTV and Orbiter prior to rendezvous initiation.

The ACC launched OTV ascent is based on a standard STS trajectory leaving the External Tank (ET) suborbital at Main Engine Cut Off (MECO). The OTV is protected from ascent atmospheric environment effects by the ACC shroud which is jettisoned shortly after Solid Rocket Boosters (SRB) separation.

The OTV deployment sequence begins at STS MECO. The STS and attached OTV are in a 16 x 80 n mi suborbital trajectory designed to accommodate ET disposal. A coasting delay follows while the STS nulls out shutdown attitude transients. Downward firing aft Reaction Control System (RCS) jets are

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inhibited until after the OTV is separated in order to prevent plume impingement on the exposed the OTV located directly beneath the orbiter boattail. The OTV is separated by springs which provide a 2 feet per second (fps) retrograde, relative separation velocity. After 30 seconds of coast, sufficient clearance exists to re-enable the inhibited orbiter RCS jets. A normal ET separation sequence follows with ET impact occurring safely downrange.

A multibody 3 degree of freedom simulation produced the relative motion plot shown in Figure 2.2.4-1. Due to the low altitude at MECO, atmospheric drag significantly affects the separation dynamics and was therefore included in the simulation. The ET forms the center of coordinates for the local vertical, local horizontal reference frame. The orbiter and OTV were assumed to have fixed attitudes whereas the ET was assumed to have a tipoff rotation rate of 0.5 deg/sec at orbiter separation. The combination of orbital mechanics and drag causes the orbiter and OTV to move in arcs which carry them below and ahead of the ET.

OTV attitude control jets are enabled at T = 90 sec after MECO at a distance of 370 ft. An attitude maneuver is initiated to orient the deployed aeroshield forward to provide plume contamination protection from the upcoming orbiter OMS-1 burn at T = 240 sec after MECO. The distance between the Orbiter and OTV is 1600 ft at an angle to the OMS engine centerline of 28 deg. The orbiter OMS-2 burn circularizes the orbiter at 130 nmi.

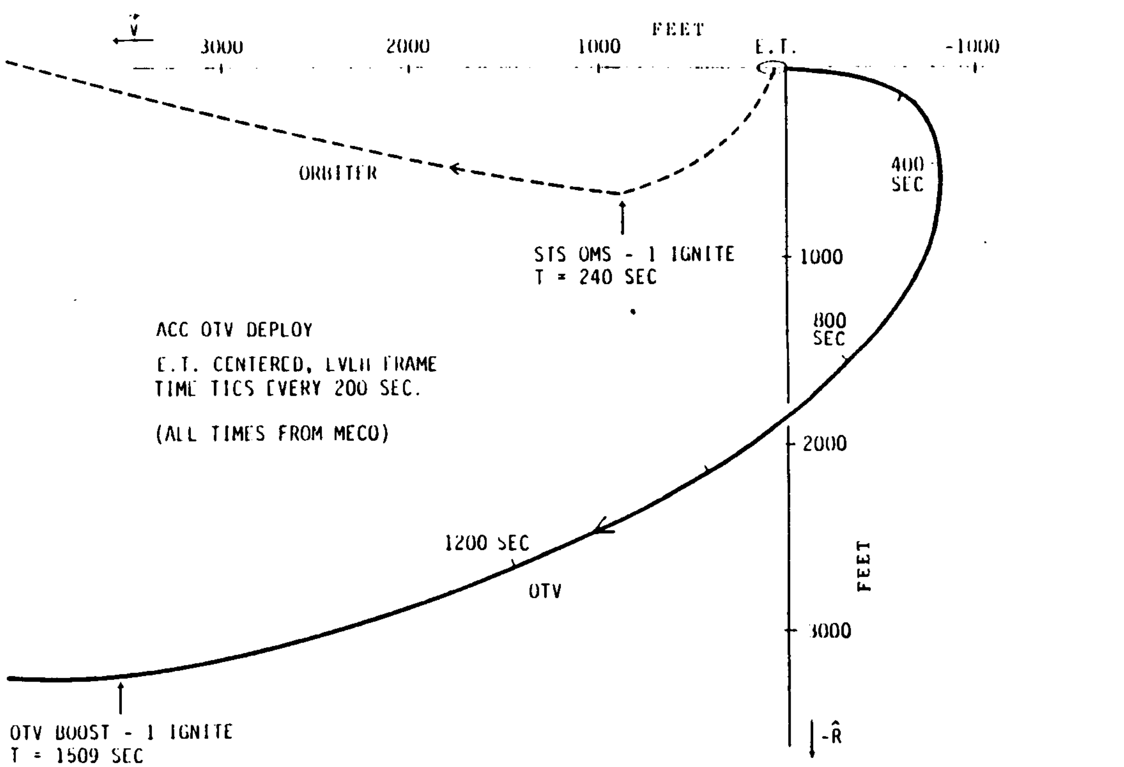

Figure 2.2.4-1 Orbiter-ET-OTV Relative Motion

The OTV coasts away from the immediate vicinity of the ET. Following a navigation update using the Global Positioning System (GPS) and stellar attitude update, the OTV performs a park orbit insertion burn at T = 1509 sec after MECO. The timing of this, and the circularization burn one half revolution later, is to establish a rendezvous initiation time four hours after liftoff. The OTV park orbit is 140 nmi, 10 nmi above that of the orbiter. Figure 2.2.4-2 shows the launch phase events.

The launch phase for the payload bay OTV is simplified from the above scenario as no rendezvous with the orbiter is required. Following the standard ascent and MECO, the STS perform two OMS burns to place it in a 130 n mi circular orbit.

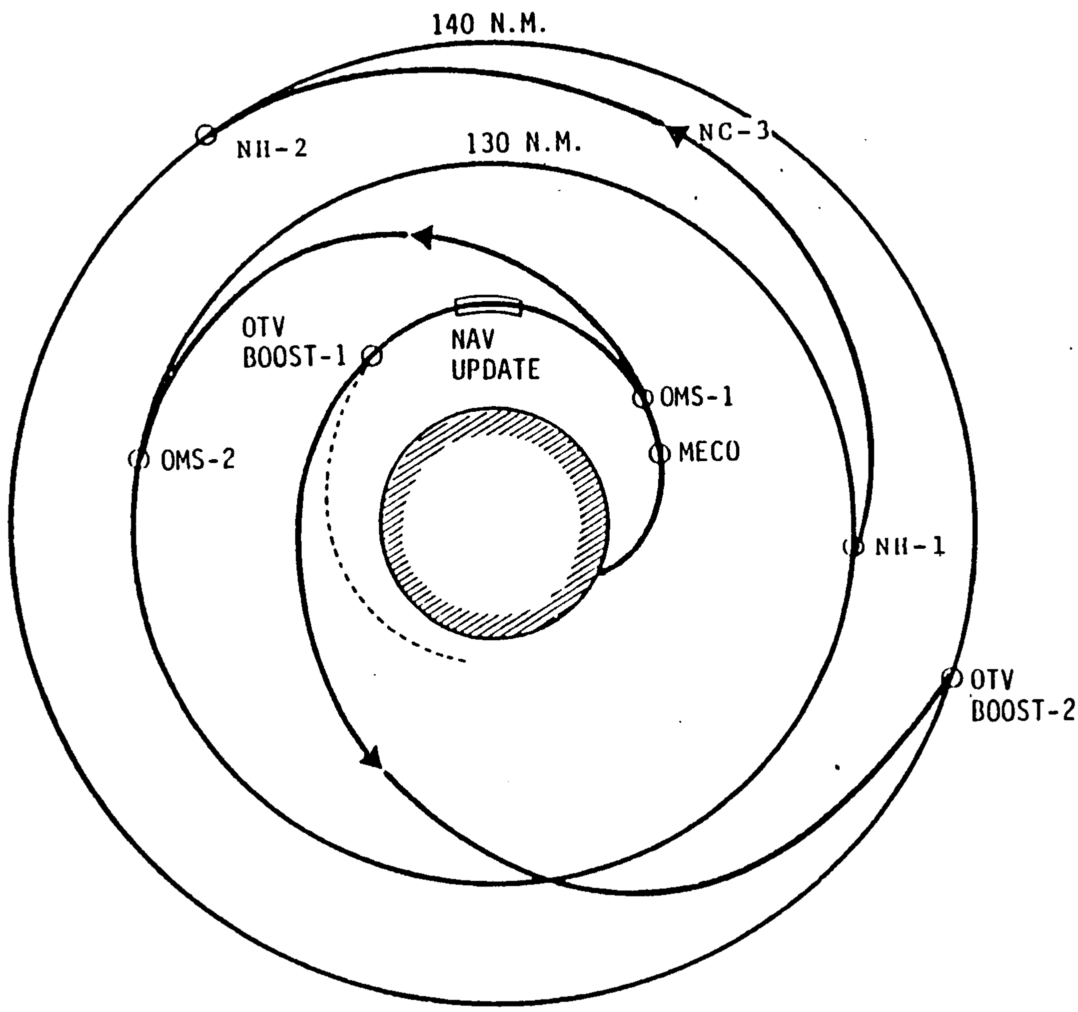

Figure 2.2.4-2 OTV/Orbiter Park Orbit Trajectory

2.2.4.1.2 Orbiter Operations and Separation Phase

This phase of the ground-based ACC OTV consists of operations required to perform rendezvous and payload mating prior to deployment by the orbiter.

The orbiter initiates rendezvous with a height maneuver (NH-1). Next, the orbiter performs a phasing burn (NC-3) designed to place the orbiter 10 nmi behind the OTV one revolution later, where its orbit is circularized at 140 nmi. The orbiter, now on the Velocity Vector (V-bar) and in a stable position with respect to the OTV, and the crew prepare for a sleep period since there is insufficient time for rendezvous, mating, and deployment operations. Early the next crew day, the orbiter performs a burn, terminal phase initiation (TI), designed to bring the orbiter to a point 1000 ft ahead of the OTV one revolution later. The OTV must disable/safe its 15,000 lb thrust main engine at 10,000 ft due to orbiter safety considerations. A terminal phase final (TF) burn stabilizes and nulls the relative rates at the +1000 ft position. Using its RCS engines, the orbiter moves toward the OTV on the velocity vector at 1 fps to grapple distance where the OTV is commanded via ground control to disable its RCS. After receiving telemetry confirmation from the ground, the crew grapples the OTV at a phase elapsed time of 20:50:00. (HH:MM:SS)

A standard grapple fixture on the OTV is utilized for Remote Manipulator System (RMS) operations. Computer generated views of the grapple, payload mating and deployment operations are shown in Figures 2.2.4-3 through 2.2.4-7 In Figure 2.2.4-3 following grapple, the OTV is translated to a position above the payload installation and deployment aid (PIDA) which is mounted on the starboard payload bay sill. Following a rotation of 90°, the OTV is mated with the PIDA. Figure 2.2.4-4 shows a computer generated representation of a closed-circuit television (CCTV) view available to the crew on the aft flight deck during mating with the PIDA. The payload, using the RMS, is removed from the payload bay and mated to the OTV. Latches are used in the mating process. These operations are depicted in Figures 2.2.4-5 and 2.2.4-6. The mated OTV and payload are then grappled using the OTV graple fixture and released by the RMS as shown in Figure 2.2.4-7.

The orbiter utilizes a combination of +X an -X primary RCS thruster firings to achieve a "low Z" thrust separation maneuver. This is caused by the canting of the ±X RCS nozzles. When fired together, the X thrust is zeroed and a small or low Z thrust remains. This technique permits separation with minimum plume impingement. A 1 fps maneuver increases the separation velocity after reaching a safe distance. The OTV must be visible to the crew out to 1000 ft. At 400 ft the orbiter crew will notify the OTV ground control (via air-to-ground (A/G) voice) to activate the OTV RCS. The OTV must wait until 10,000 ft to activate its main engines. During this time, the OTV performs an attitude and state vector update in preparation for Boost-1.

The payload bay launched OTV operations during this phase involve only predeployment checks of payload and OTV systems and the deployment and separation activities described above.

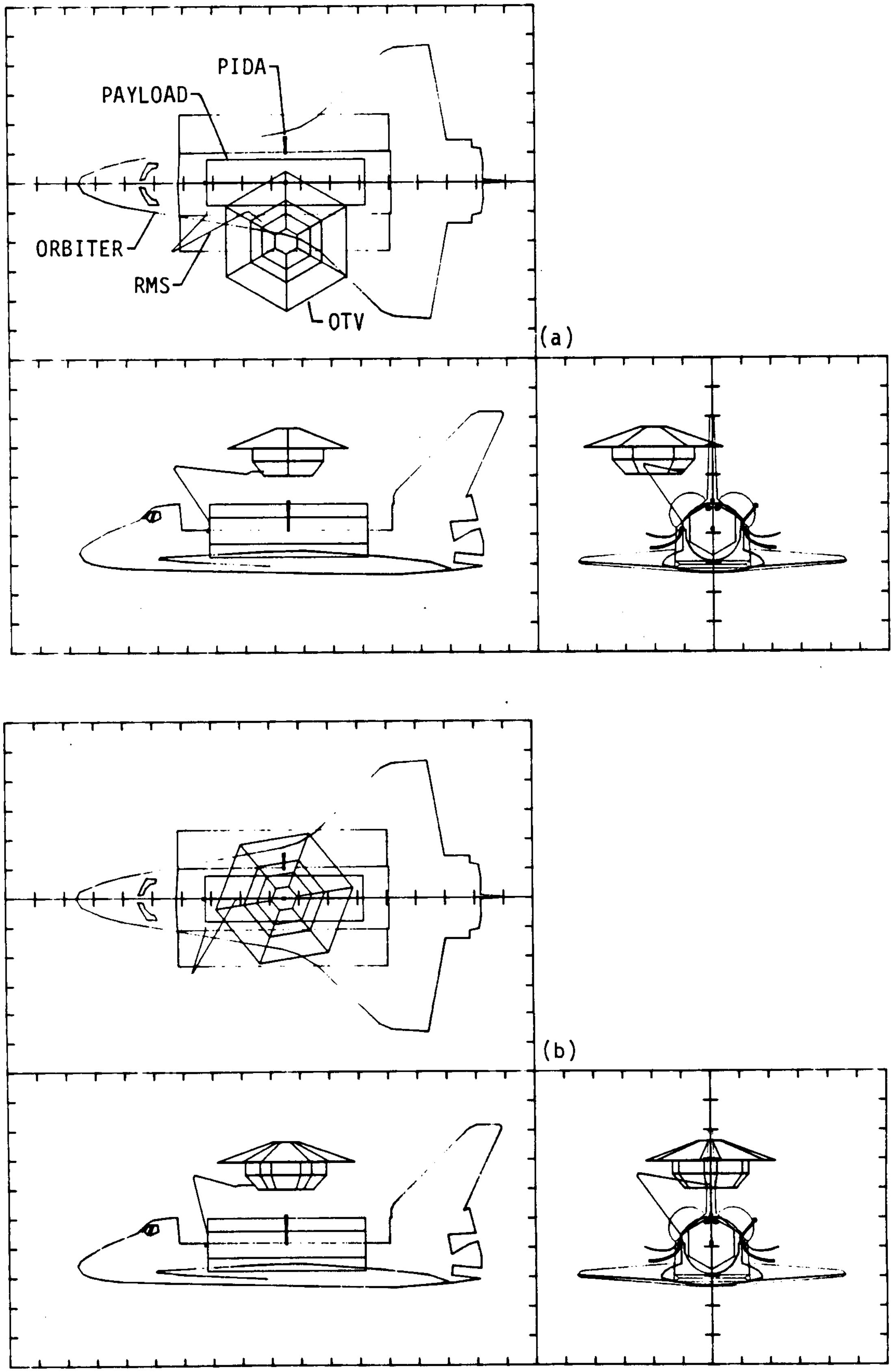

FIGURE 2.2.4-3
RMS OPERATIONS - GRAPPLE AND ATTACH OTV TO PIDA

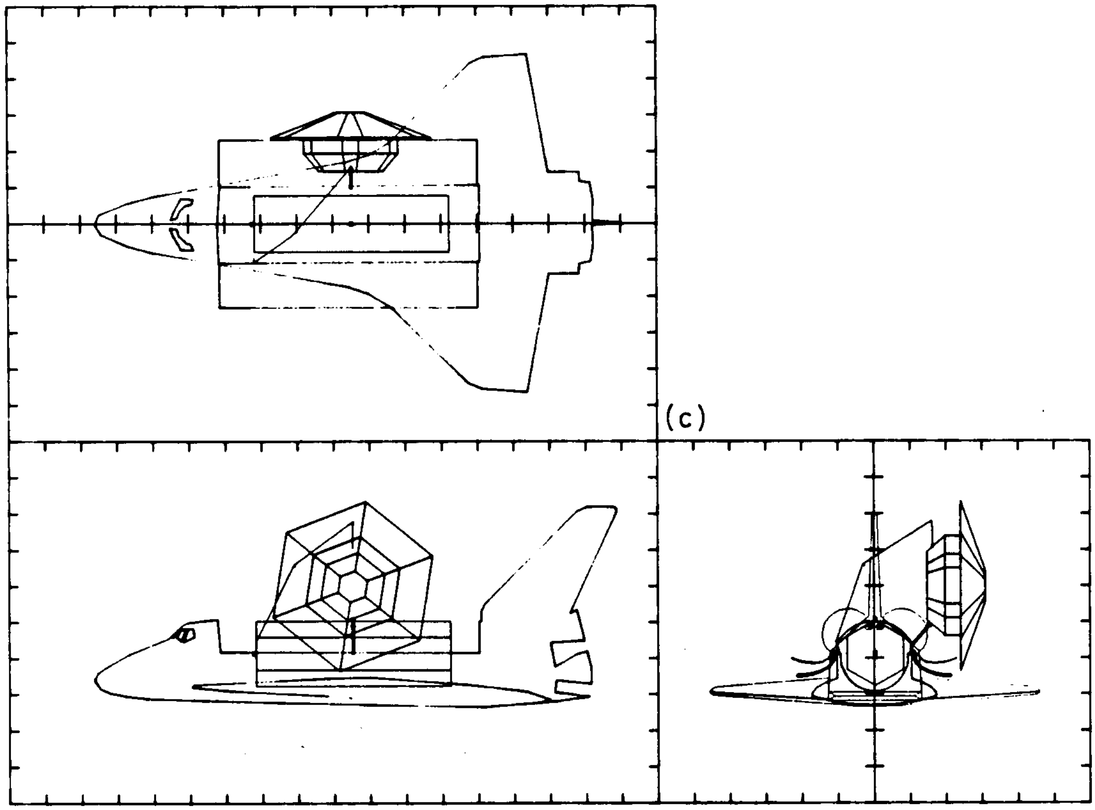

Figure 2.2.4-3 (Cont.)
RMS OPERATIONS - GRAPPLE AND ATTACH OTV TO PIDA

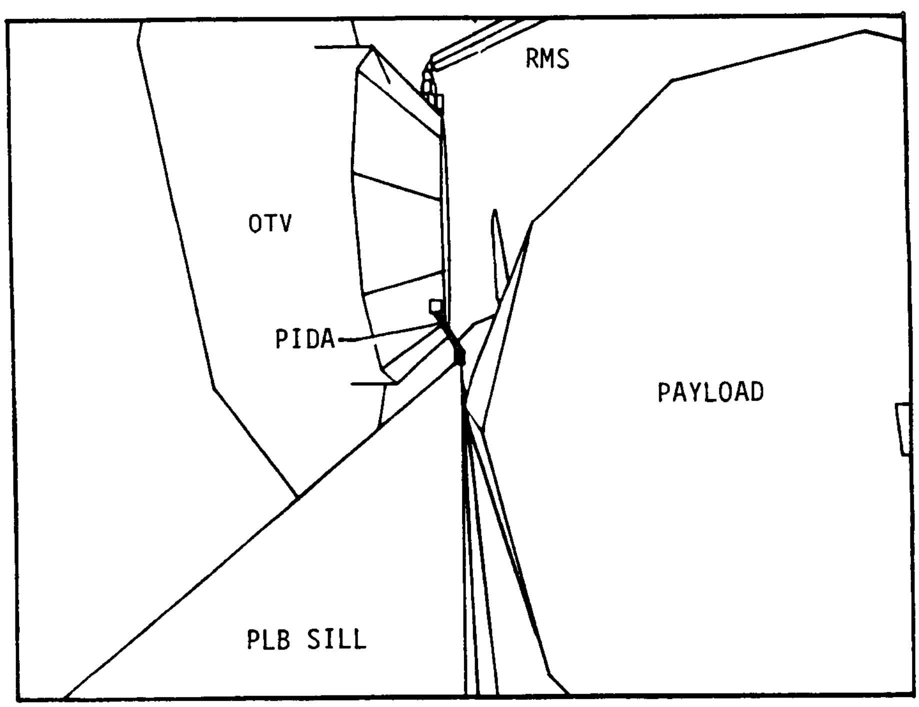

Figure 2.2.4-4
CCTV VIEW - OTV ON PIDA

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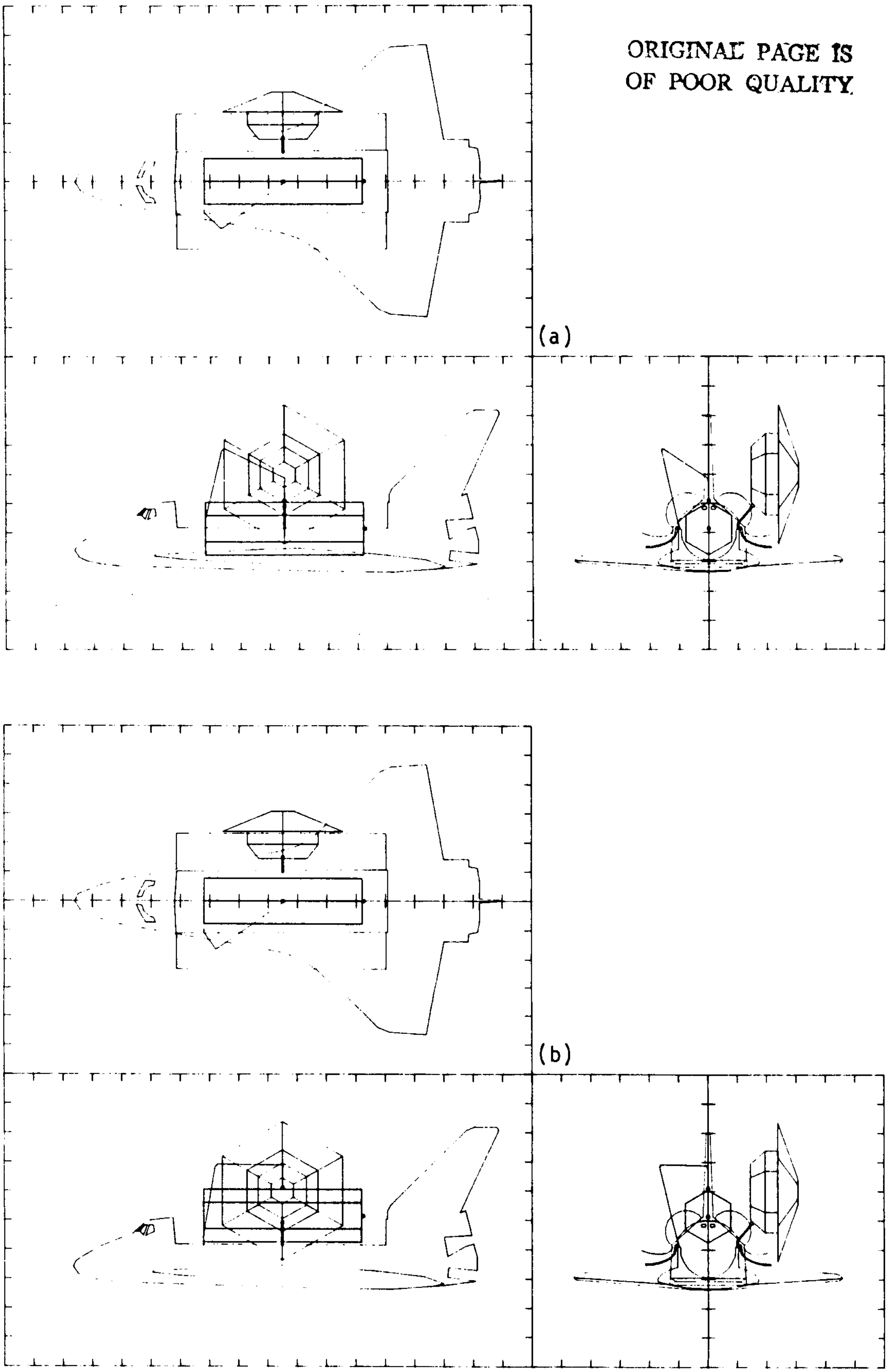

Figure 2.2.4-5
RMS OPERATIONS - MATE PAYLOAD TO OTV

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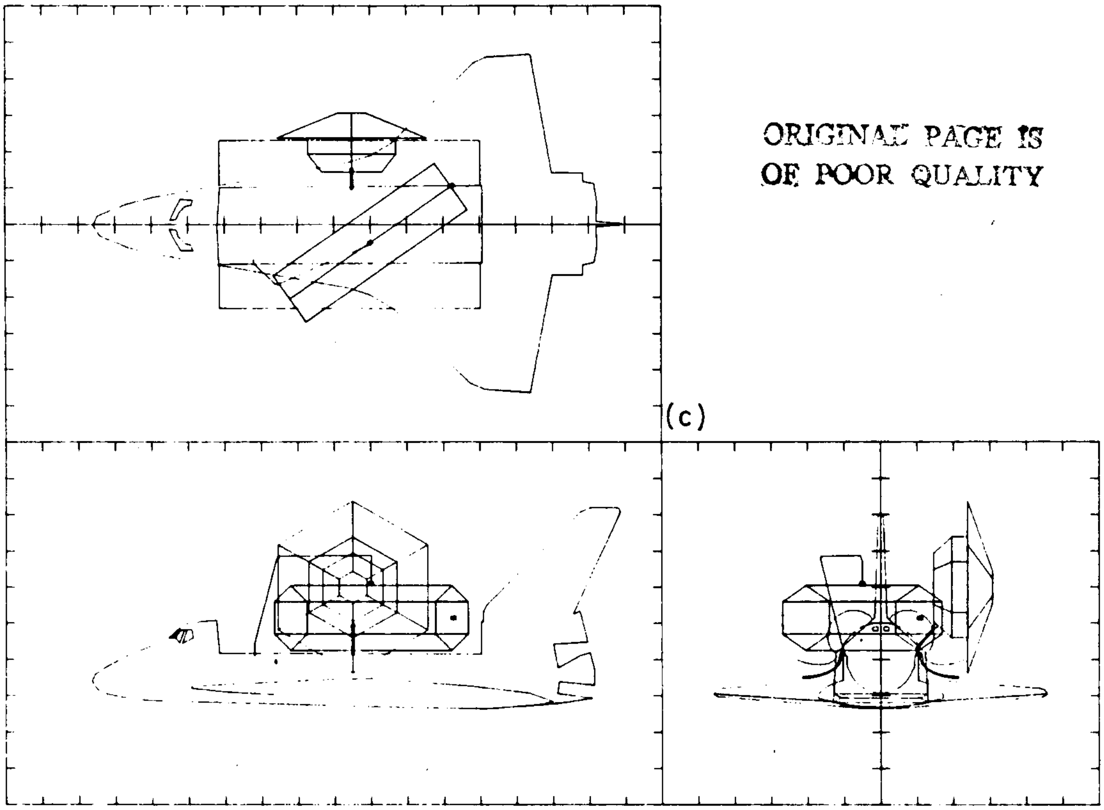

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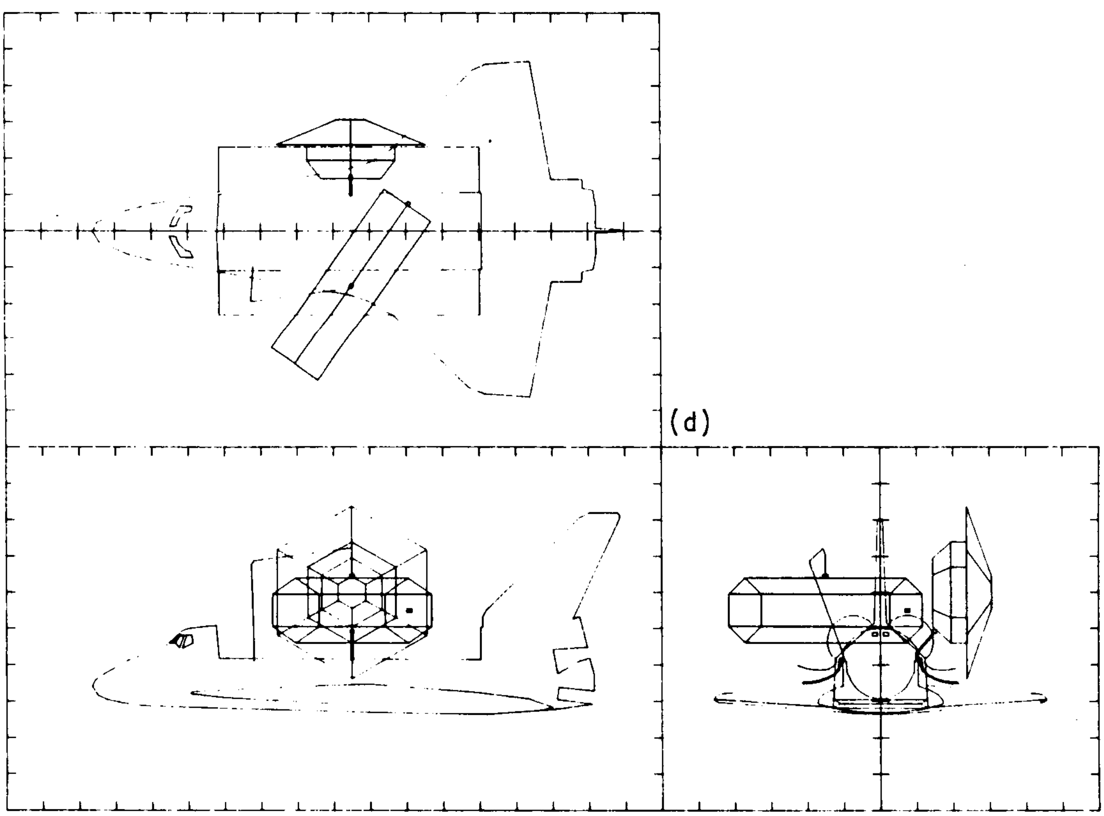

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Figure 2.2.4-5 (Cont.)
RMS OPERATIONS - MATE PAYLOAD TO OTV

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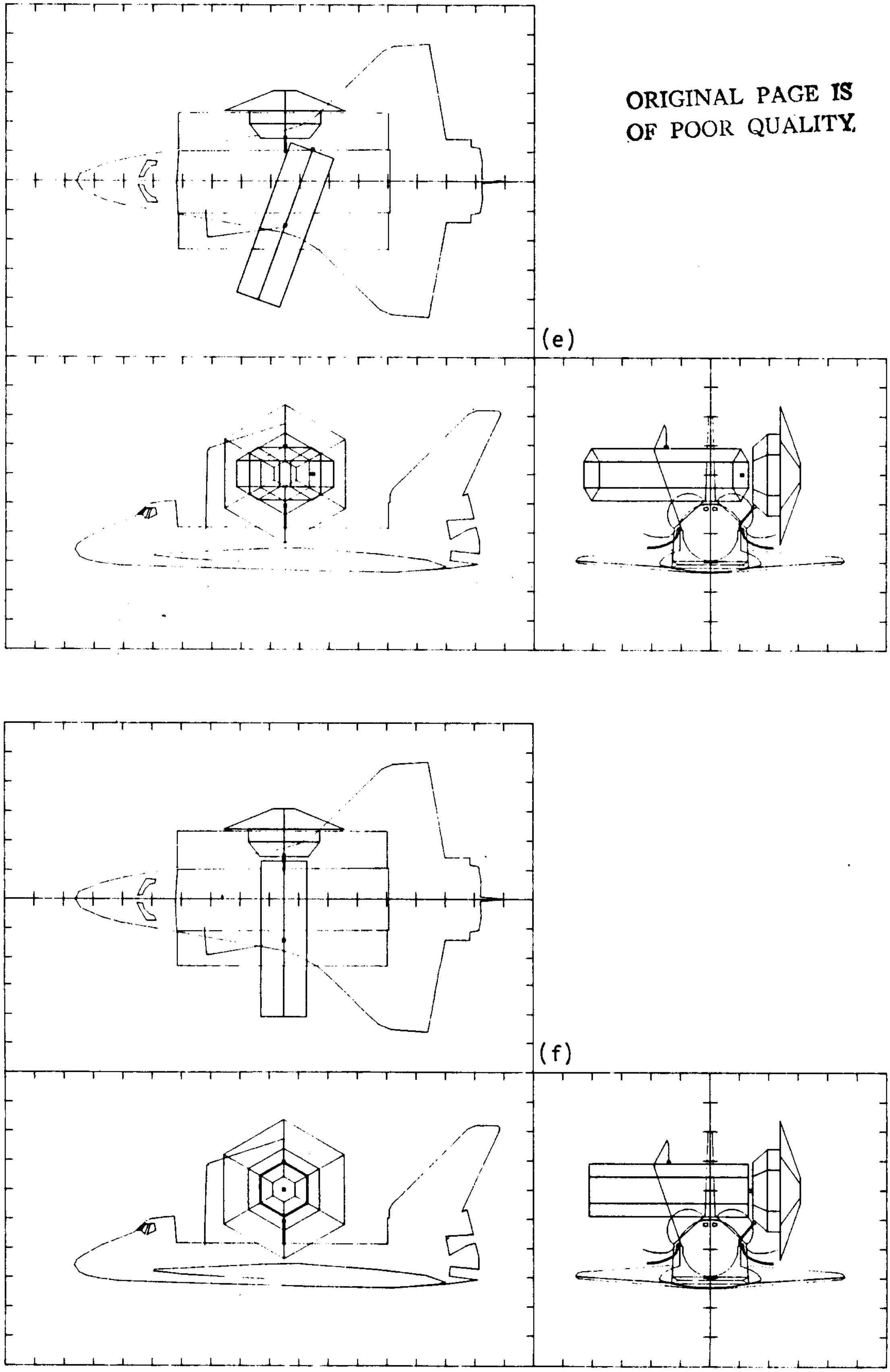

Figure 2.2.4-5 (Cont.)
RMS OPERATIONS - MATE PAYLOAD TO OTV

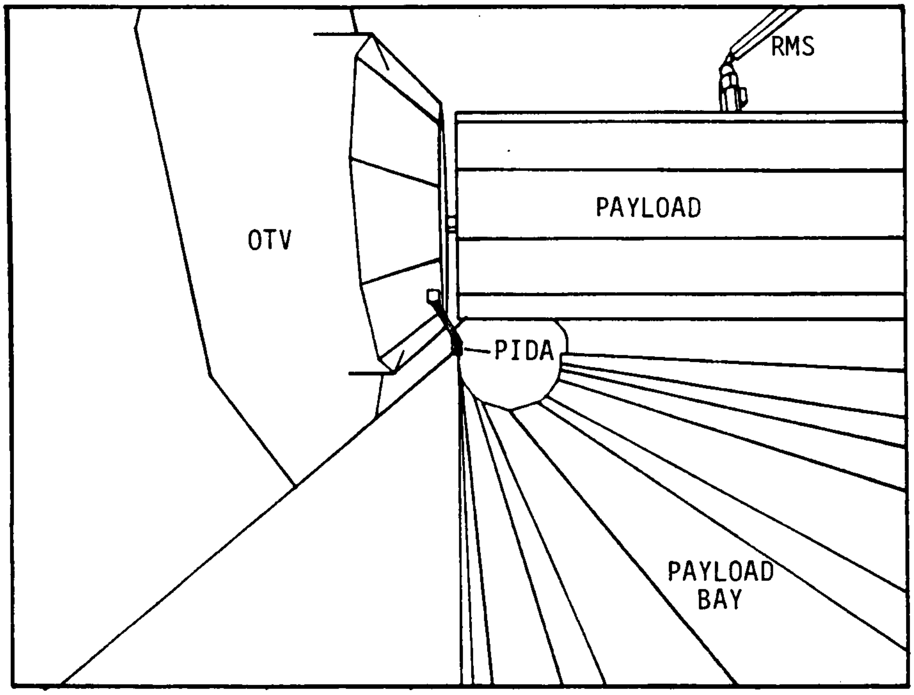

Figure 2.2.4-6
CCTV - PAYLOAD TO OTV MATING

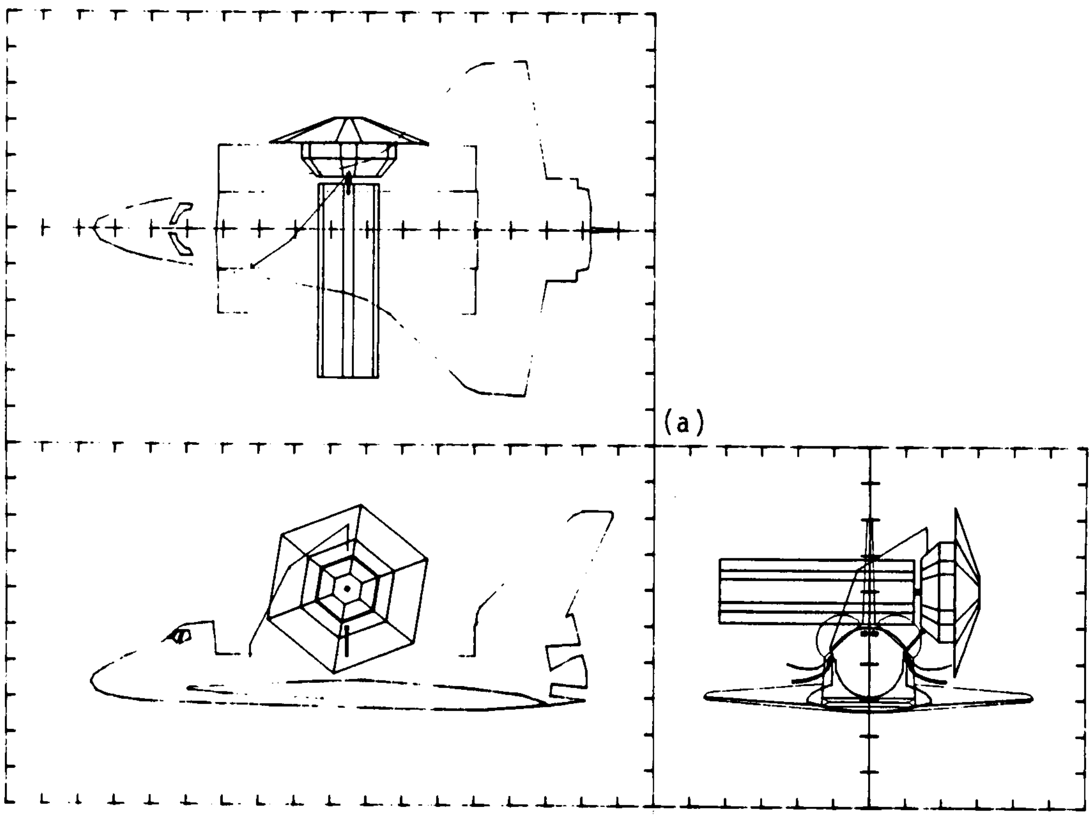

Figure 2.2.4-7
RMS OPERATIONS - DEPLOY OTV AND PAYLOAD

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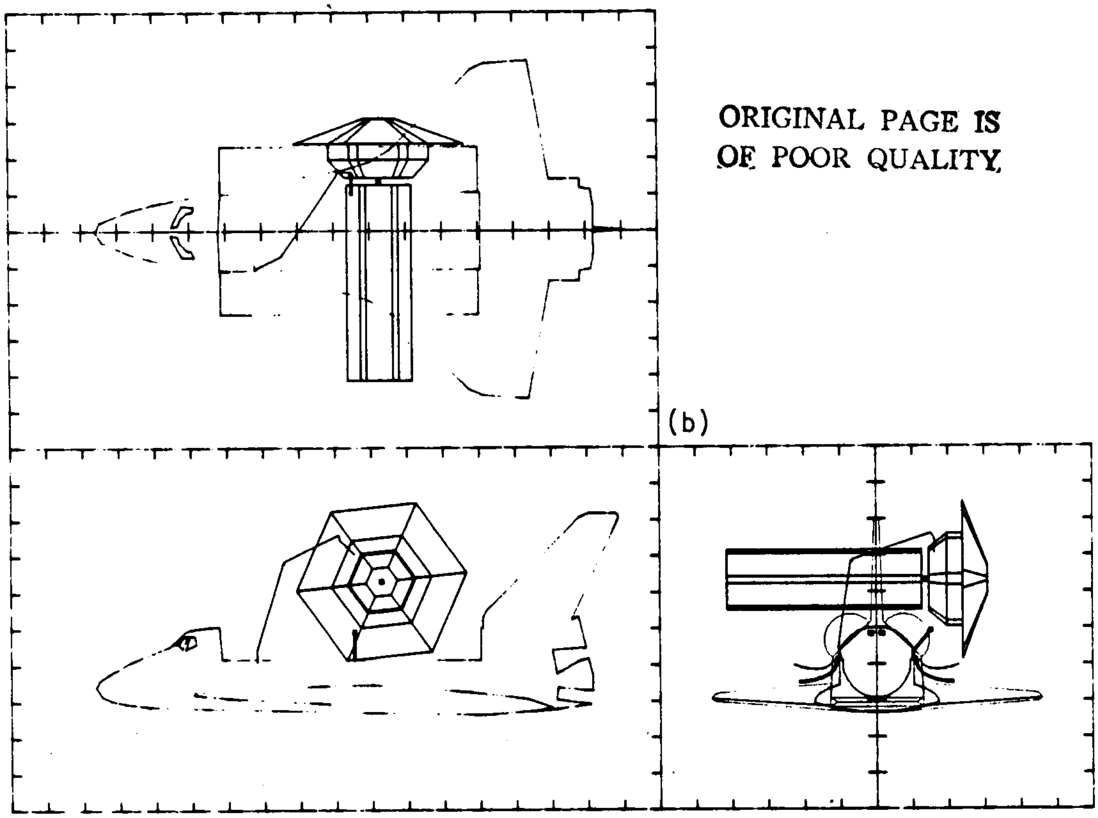

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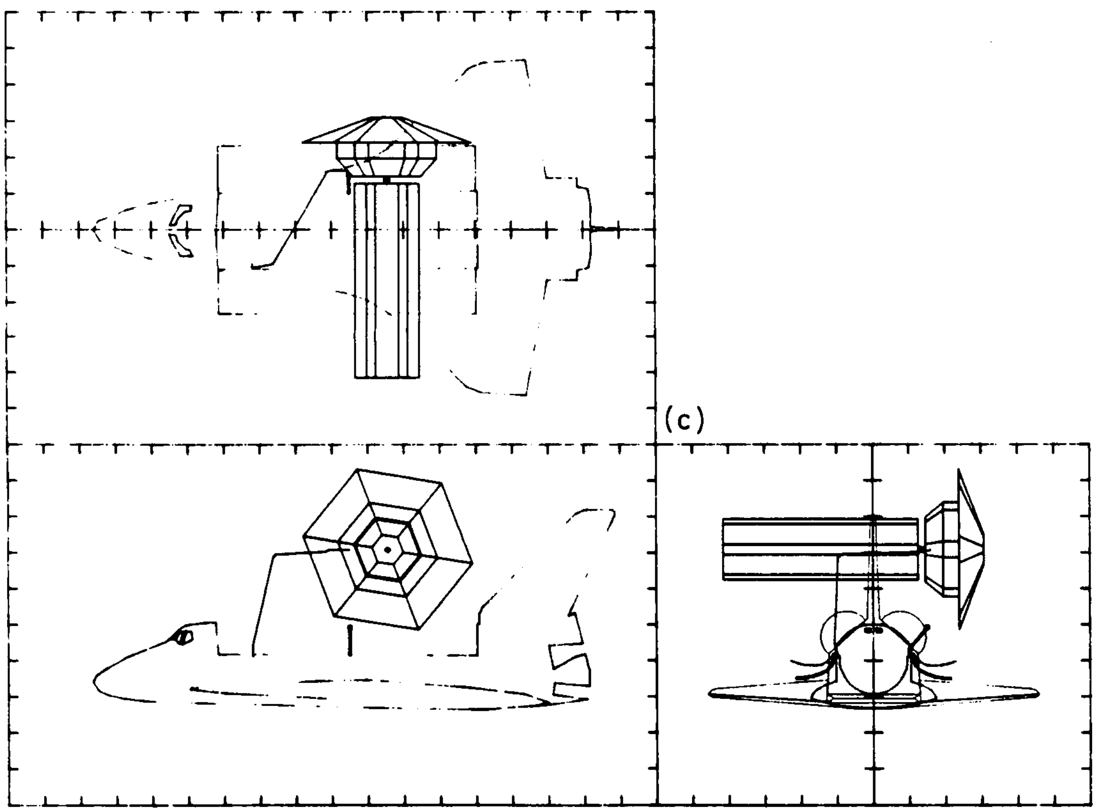
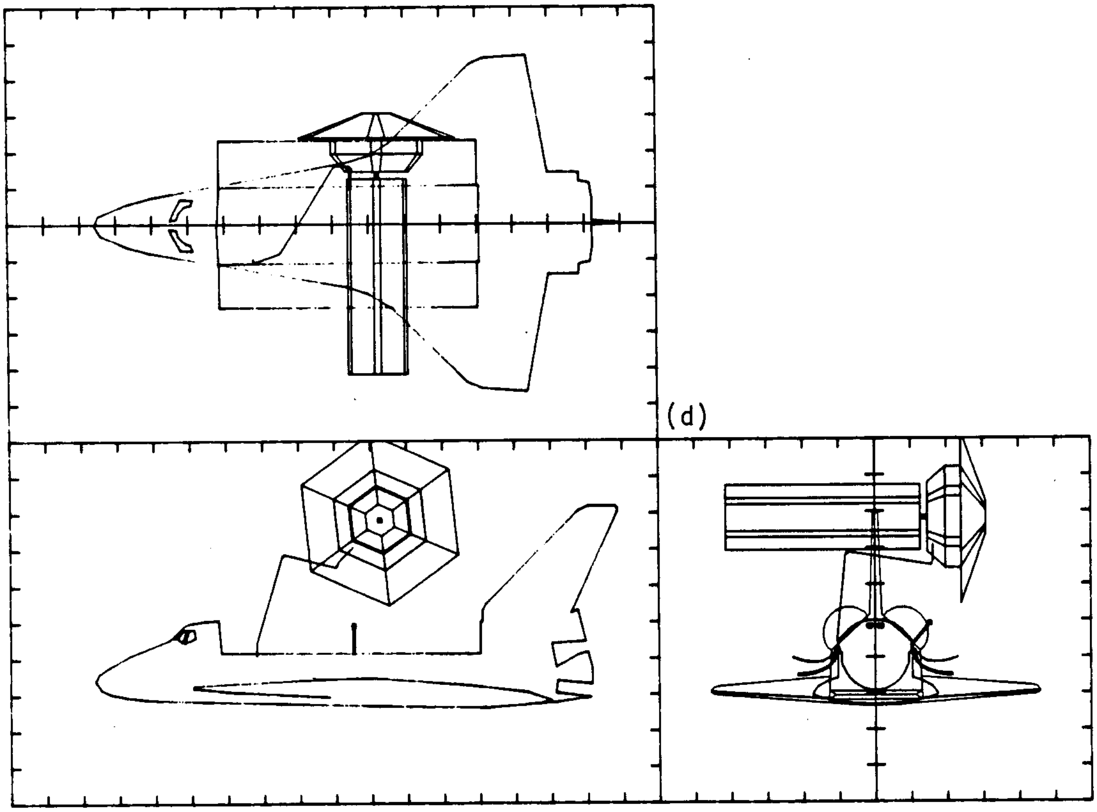


Figure 2.2.4-7 (Cont.)
RMS OPERATIONS - DEPLOY OTV AND PAYLOAD



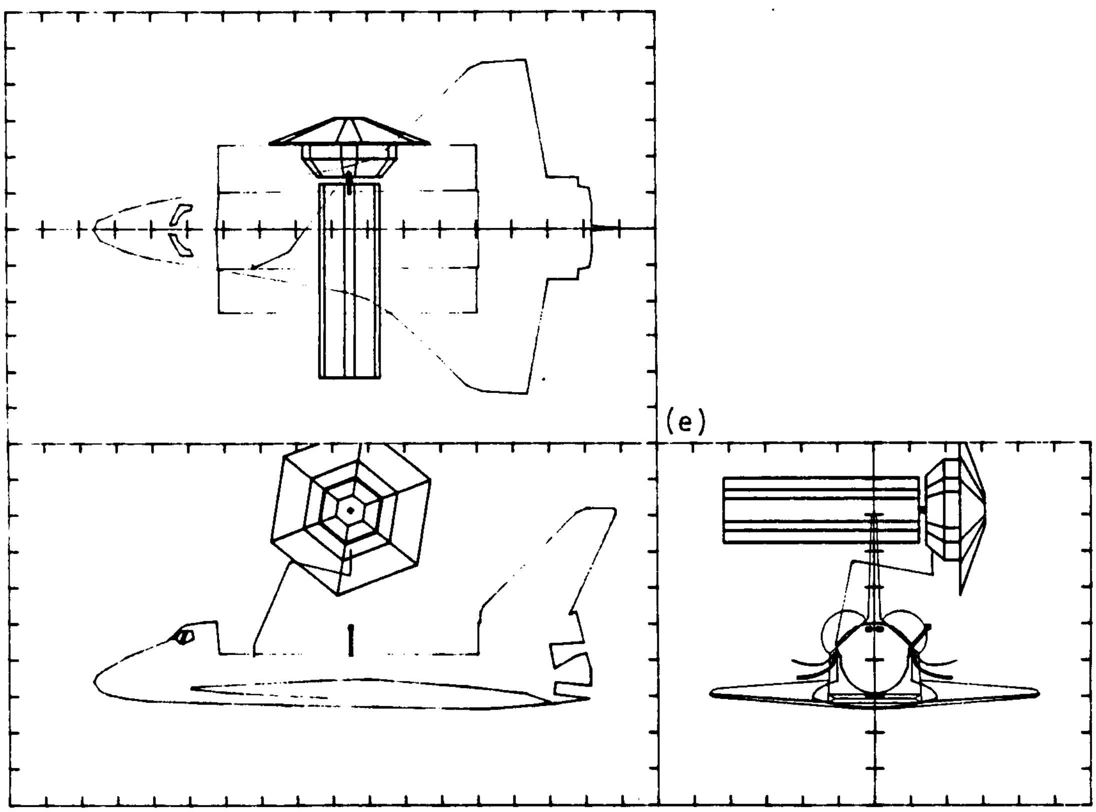


Figure 2.2.4-7 (Cont.)
RMS OPERATIONS - DEPLOY OTV AND PAYLOAD

2.2.4.1.3 OTV Delivery and Return Phase

This phase of the ground-based OTV mission consists of operations required to deliver the payload to its operational orbit, extended onorbit operations if required, and deorbit, aeropass and rendezvous operations.

All ground-based OTV missions begin this phase with a major OTV burn, followed by two orbiter burns at a phase elapsed time of 1:00:00 (H:MM:SS). These are designed to return the orbiter to a 130 x 130 nmi park orbit as required to setup OTV retrieval at the end of mission. This phase requires unique operations planning to accommodate the different operational orbits of the baseline reference missions. Deorbit, aeropass and rendezvous operations are discussed following the unique operations which are described for each mission below.

2.2.4.1.3.1 Ground-Based GEO Delivery

After the orbiter has established a safe separation distance, the OTV prepares for its transfer orbit burn by updating navigation and attitude information. The burn occurs about 1 hr 20 min after release by the RMS. For a geosynchronous equatorial orbit mission, the perigee burn is followed by a coast to apogee. The OTV provides a thermal roll during this period. Figure 2.2.4-8 graphically shows the operations of this mission.

The single stage (cryo propellant) and perigee stage (storable propellant) scenarios are different from this point until the return phase. The single stage OTV performs a navigation update prior to an apogee burn which circularizes the OTV and payload in GEO orbit. The payload(s) is (are) separated followed by a collision avoidance maneuver. The OTV must remain at GEO until the proper orbital alignment occurs for return (approximately 12 hr intervals). Again the navigation and attitude information are updated prior to the deorbit burn. During the return transfer to low earth orbit, attitude and navigation data are updated twice more; once prior to a midcourse maneuver and once just before the aeropass.

Perigee stage missions (storable) eliminate the circularization burn at GEO altitude. Instead the payload is separated from the OTV soon after the perigee burn. A small RCS burn is performed to provide relative separation between the payload and OTV. Near apogee the OTV performs a burn to lower perigee and change plane slightly to align the return leg of the transfer orbit with the orbiter rendezvous orbit. In the meantime, the payload burns its apogee kick stage to circularize in GEO. The remainder of the OTV's return leg is similar to the single stage mission.

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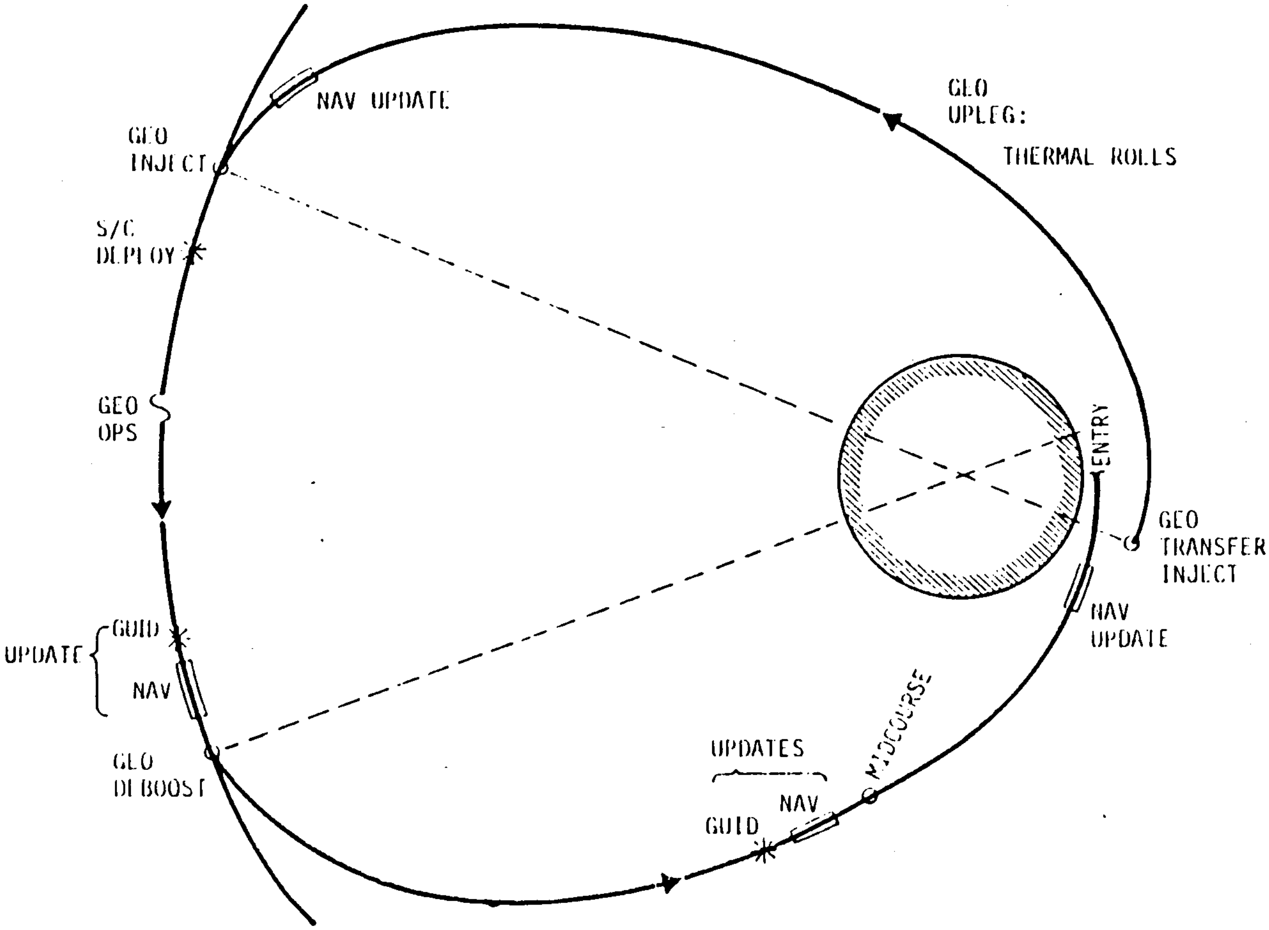

Figure 2.2.4-8 Geosynchronous Equatorial Mission

2.2.4.1.3.2 Ground-Based Planetary

Planetary missions flown by the OTV in a ground-based mode will begin from an orbit with an inclination and launch window optimized to achieve the desired hyperbolic velocity vector. After deployment and separation from the orbiter, the OTV main engine burn places the OTV and spacecraft on a hyperbolic escape trajectory. Figure 2.2.4-9 shows the burn sequence for a planetary mission. The OTV then separates from the spacecraft and increases the separation rate by performing a small RCS burn. About 15 minutes after separation, the OTV performs another burn to place itself in a highly elliptical orbit. Three additional burns are performed on this ellipse prior to the aerobraking maneuver. Two of these burns accomplish a plane change to align the OTV's trajectory with the orbiter rendezvous plane which is regressing relative to the OTV orbit. The third burn (actually the second burn in sequence) lowers the perigee of the ellipse to the appropriate altitude for the aerobraking maneuver. The plane change maneuvers are designed to minimize the energy required to transfer to the rendezvous plane.

2.2.4.1.3.3 Ground-Based High Inclination

Although not explicitly identified in the mission model, this DRM was developed to identify techniques and approximate mission times associated with the delivery of payloads to high inclination, 12-hour period orbits. The mission analyzed delivers two payloads to 12 hour circular orbits inclined 55 degrees. The payloads are to be delivered to different right ascension of the ascending node (RAAN) planes separated by 60 deg. Figure 2.2.4-10 illustrates this mission. A separate timeline for the cryogenic configuration was not generated due to the similarity with the storable configuration

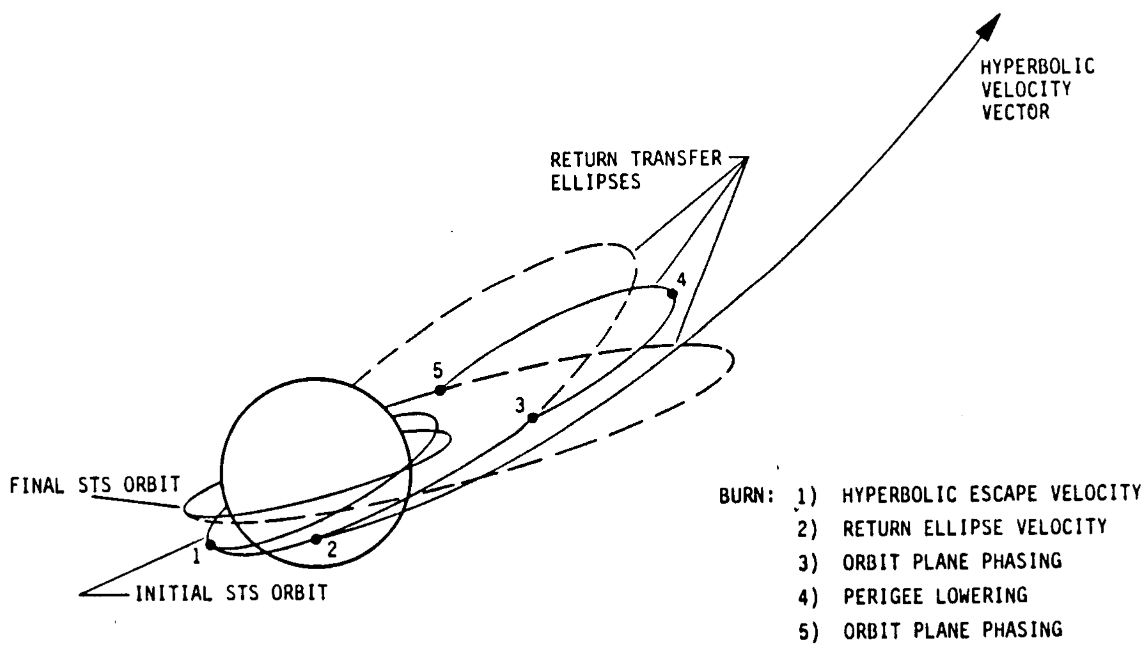

Figure 2.2.4-9 Ground-Based Planetary Mission

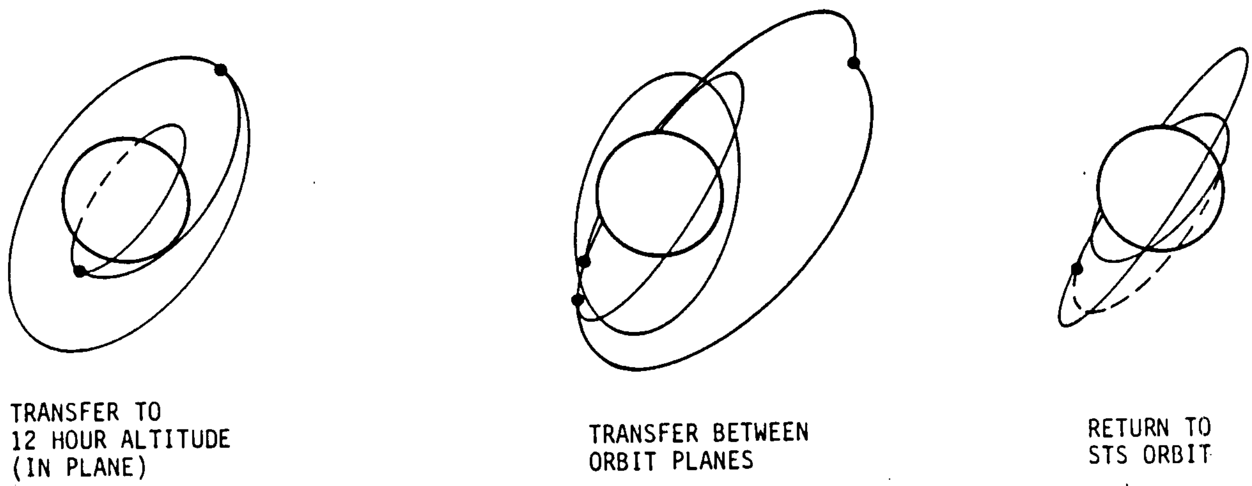

Figure 2.2.4-10 Ground-Based - High Inclination Mission

The orbiter is launched at the proper time into the 55 deg inclination so that the OTV makes an in plane transfer to the first payload (most easterly) plane. The burns are summarized in Table 2.2.4-1. The OTV then separates from the first payload. A 1 fps spring was used in separation for analysis purposes. At 400 ft the OTV performs a 20 fps RCS burn to increase the separation velocity. The next objective is to make a 60 RAAN plane change. The plane change is optimized by employing a three burn strategy. The first burn raises apogee to 22,148 n mi, and changes the plane by 4.9 deg. This is followed by a burn at apogee to change the plane an additional 38.6 deg. Finally, the third burn lowers the apogee back to 10,898 n mi and completes the plane change with a delta of 4.9 deg. A plane change of 48.4 deg is required to change the RAAN by 60 deg due to the geometry of the intersection of the orbits. The second payload is now deployed in the same fashion as the first but with a 10 fps separation maneuver, reduced from 20 fps due to the time available.

Table 2.2.4-1 Ground-Based High Inclination Mission Burn Sequence

OTV BURN #	MANEUVER (NMI)	DELTA-V (FPS)
1	Park Orbit Perigee MECO to 84.6 x 140	249
2	Park Orbit Apogee 84.6 x 140 to 140 x 140	96
3	Mission Orbit Perigee 140 x 140 to 140 x 10898	6737
4	Mission Orbit Apogee 140 x 10898 to 10898 x 10898	4673
-	Deploy Payload #1	-
5	RAAN Plane Change 10898 x 10898 to 10898 x 22148 4.9 deg Plane Change	2032
6	RAAN Plane Change 38.7 deg Plane Change at Apogee	5338
7	RAAN Plane Change 10898 x 22148 to 10898 x 10898 4.9 deg Plane Change	2032
-	Deploy Payload #2	-
8	Deorbit to Aeropass 10898 x 10898 to 10898 x 40	7643
9	Phasing Orbit 4 x 115 to 115 x 140	203
10	Rendezvous Orbit 115 x 140 to 140 x 140	42
		29045 Total

The final objective is to rendezvous with the orbiter. To do this, the OTV uses time in the higher orbit, with less regression than the orbiter, to reduce the RAAN plane change required by 13.6 deg. Figure 2.2.4-11 shows how the plane changes are managed and the advantage of launching into the easterly orbit first and then waiting as long as possible before rendezvousing with the orbiter. The final plane change of 34.8 deg to match the plane of the orbiter is accomplished coincidently with lowering perigee to 40 n mi.

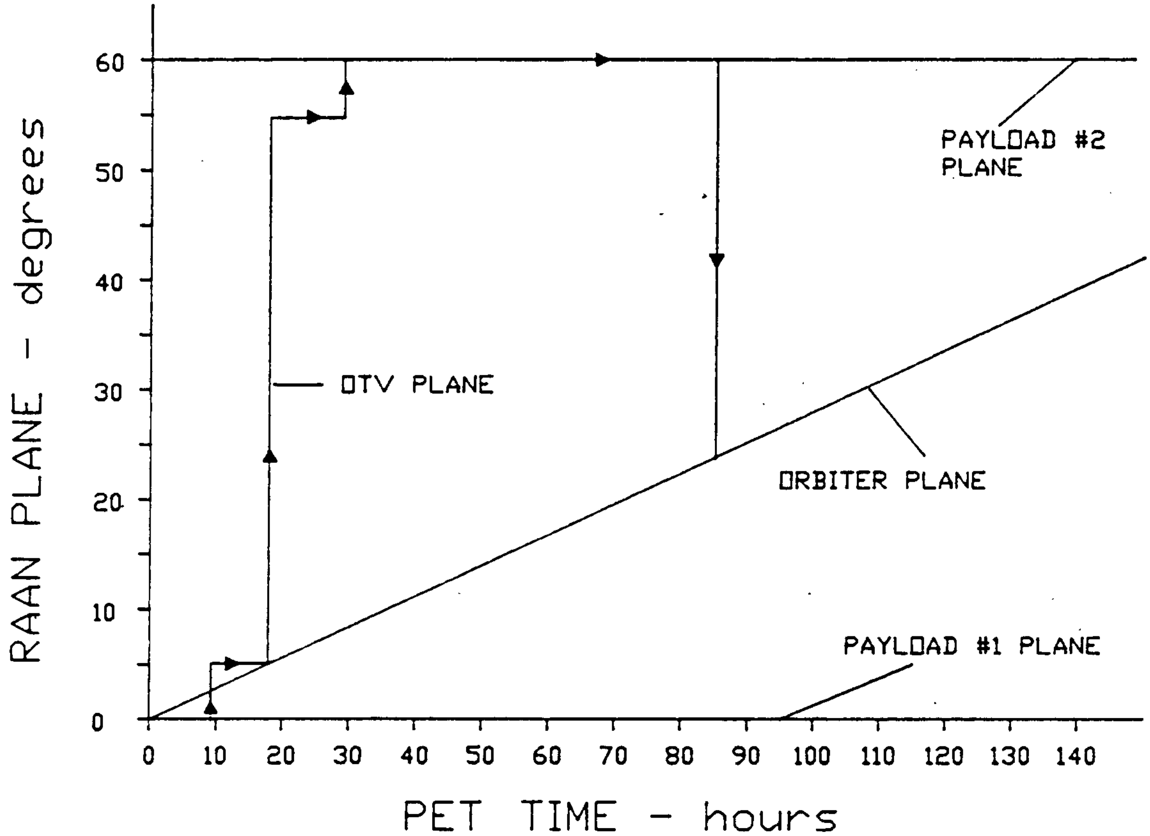

Figure 2.2.4-11 High Inclination Mission RAAN Plane Changes

2.2.4.1.3.4 Aeropass and Reboost Operations

Common to all ground-based OTV design reference missions is the aeropass and reboost operations. Figure 2.2.4-12 graphically shows these operations. The OTV is targeted for a 4 x 140 nmi orbit at aeropass exit. This requires at least one midcourse maneuver after the deorbit burn (or apogee). Prior to midcourse and the aeropass operations, the attitude and state vector are updated to maximize accuracy. GPS is utilized for state vector updates. Cryo and ACC storable configurations require the aerobrake to be jettisoned after the aeropass, as it will not fit in the orbiter bay for return. Next, the OTV reboosts up to the orbiter retrieval orbit. Gross phasing relative to the orbiter can be accomplished in one of two ways. In the first method, depicted in Figure 2.2.4-13a, a direct descent is used and the size of the downleg orbit (apogee altitude) is varied to change the time of aeroentry. To accommodate the full range of relative phasing requires this orbit's timing shift be adjustable between +.8 to -.7 hours. A velocity penalty of up to 170 ft/sec is incurred on the deorbit burn for this method of phase adjustment. Figure 2.2.4-13b shows an alternate approach where phasing is accomplished by first raising the apogee of the GEO orbit half of a revolution prior to the deorbit point. A Hohman transfer is used for the downleg to the LEO aeropass. Since both segments require more time to traverse, a net delay in the entry time is accomplished which produces the phasing shift. The deorbit burn occurs at a higher altitude (about 2000 nmi for the 90 minute delay case); hence, less velocity is required to accomplish it. The maximum delay situation of 90 minutes actually requires 129 ft/sec less velocity than a normal deorbit from GEO. Thus, the second method is more optimum than the first from a propellant standpoint (12 hours worth of additional consumables is more than offset by the velocity reduction). However, missions which cannot afford the added 12 hours at GEO can use the first method.

Minor phasing adjustments to account for uncertainties in the aeropass are accomplished by separating the return to retrieval orbit into two steps. The first orbit is 115 x 140 nmi. The perigee can be adjusted as necessary for phasing. The final orbit is 140 x 140 nmi, where the orbiter will retrieve the OTV. Attitude and state vector updates using GPS are scheduled prior to all main engine burns.

OTV cryo stages require the propellant tanks to be removed prior to stowage in the orbiter bay. All propellants must be removed prior to tank removal. This is achieved in conjunction with a RCS trim maneuver. The acceleration induced by the RCS trim is used to purge cryo propellant from the tanks at the end of this phase in preparation for disassembly and stowage in the orbiter cargo bay.

2.2.4.1.4 Orbiter Rendezvous and Retrieval Phase

The orbiter initiates final rendezvous operations with a height maneuver, NH, to raise its apogee to 140 nmi. A phasing burn, NC, is then performed at a range of about 40 nmi to the OTV. It adjusts the phasing so that one revolution later the orbiter is 8 nmi behind the OTV at TI. All orbiter burns from this point on use onboard targeting, are performed with closed-loop lambert guidance, and utilize the rendezvous radar. The next orbiter milestone is TI. This burn results in a direct transfer to the OTV on 320 deg of OTV travel, which allows margin for an orbiter dispersed low energy transfer trajectory. The OTV main engine must be inhibited/safed prior to a distance of 10,000 ft. One revolution after TI, terminal phase final (TF) is initiated to null the orbiter/OTV relative rates. The orbiter is now 1000 ft ahead of the OTV on the V-bar. When lighting conditions are correct, the orbiter moves in to the OTV on the V-bar at 1 fps. The RMS and CCTVs are powered up in preparation for grapple. When in position to grapple the OTV, the crew will send a command directly to the OTV via the payload interogator or request the OTV ground control to disable/safe its RCS. After receiving confirmation of a safe vehicle, the OTV is grappled. The storable OTV can be immediately stowed in the orbiter bay. The cryo OTV must be placed on the PIDA for tank removal and stowage before being stowed in the orbiter bay.

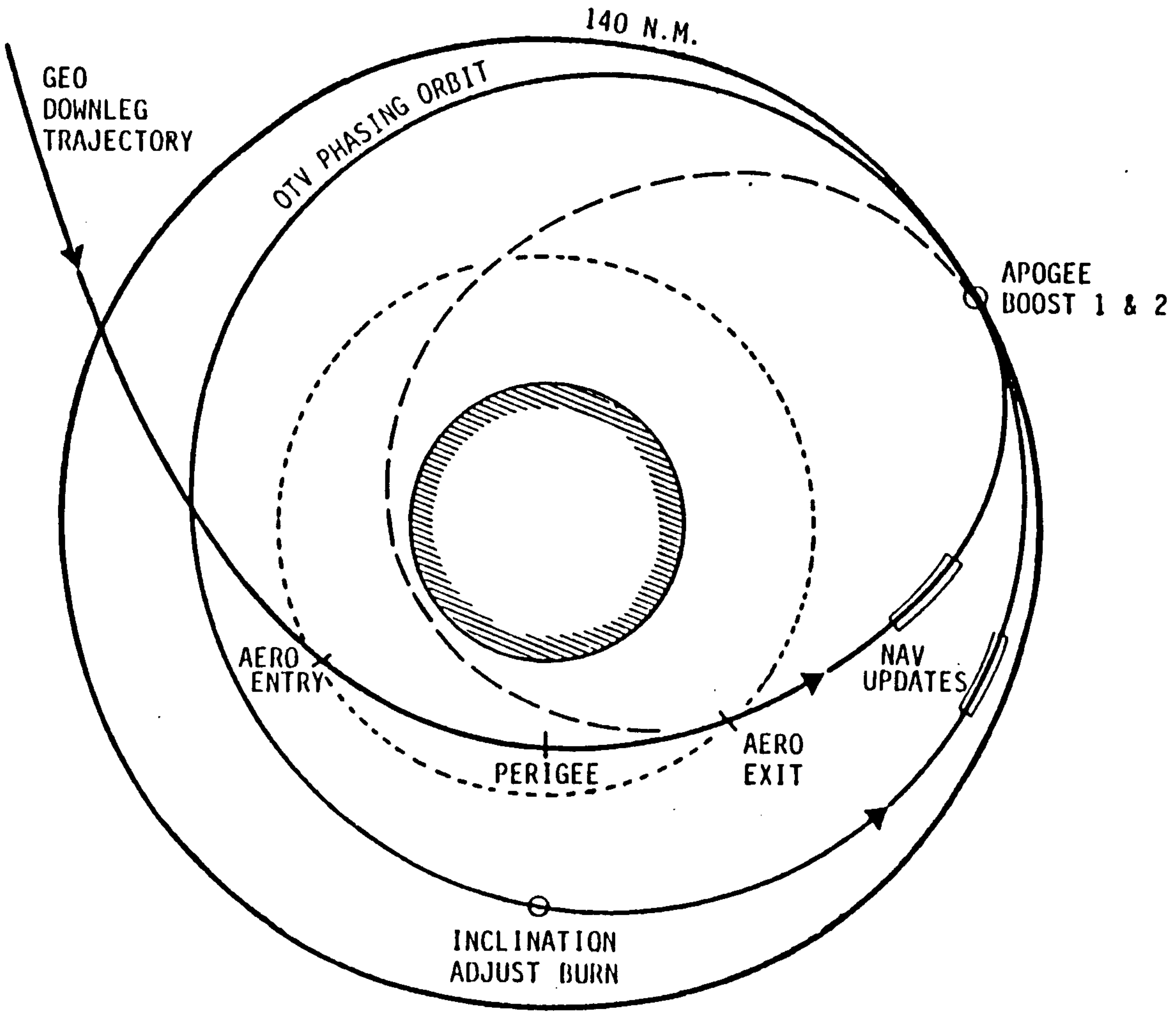

Figure 2.2.4-12 Deorbit, Aeropass, and Recovery Orbit

2.2.4.2 SPACE-BASED OTV MISSIONS

Seven missions were analyzed for space-based operations. GEO Delivery, Planetary, Low g GEO Delivery, GEO Manned and Unmanned Servicing, High Inclination, and Lunar Sortie are the driver missions, based on the mission model, to be accomplished using space-based OTV.

Cryo and Storable configurations were analyzed for each design reference mission. Most operations are the same for either configuration, so for some missions, only one timeline was generated. Also, timelines were not generated for the GEO Unmanned Servicing Mission, as the only difference from the GEO Manned Servicing mission from the OTV perspective is dwell time at GEO. The GEO Delivery and Low g GEO delivery missions are of shorter duration for Storable than Cryo since they are perigee stages only and do not dwell at GEO.

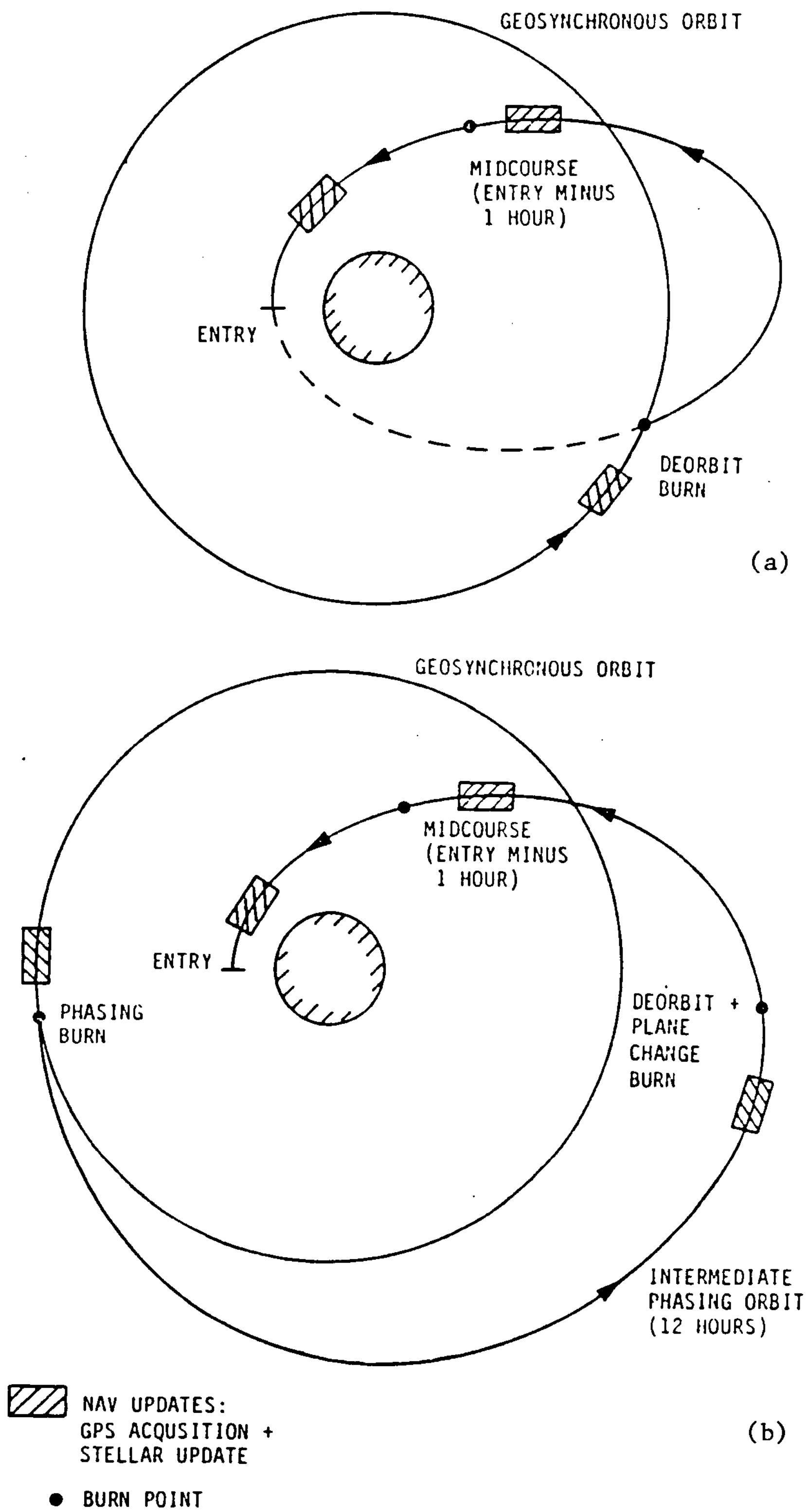

Figure 2.2.4-13 Low Earth Orbit Phasing

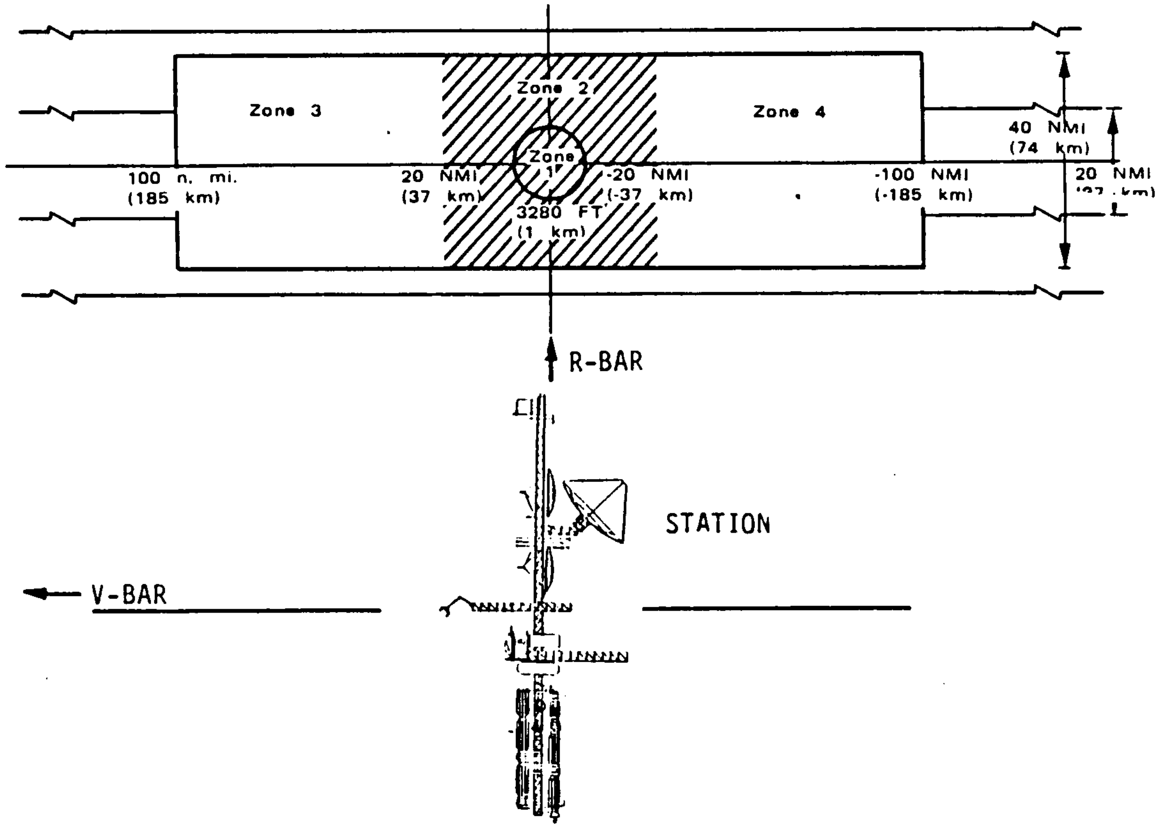

Figure 2.2.4-14 Space Station Operational Control Zones

Nine operational control zones have been defined around the Space Station as shown is Figure 2.2.4-14. Of particular interest for OTV/Space Station proximity operations are zones 1 through 4. Zone 1 is the proximity operations zone wherein unmanned vehicles are under the control of the station and care must be exercised in the operation of RCS systems to minimize hot gas plume impingement. Zone 2 is the control zone. Here unmanned vehicles are under the control of the station. Zone 3 is the zone for departure activity and zone 4 is set aside for rendezvous activity.

2.2.4.2.1 Mission Phases

The Mission phases for space-based OTV operations are:

1. OTV/Space Station Separation
2. OTV Delivery and Return
3. OTV/Space Station Rendezvous - Capture

The timelines were developed with the goal of minimizing operational complexity within a given mission and maximizing the use of standard operations between all missions. OTV/Space Station Separation and OTV/Space Station Rendezvous - Capture phases are the same for all missions because they are mission independent. Only the OTV delivery and return phase has unique mission-to-mission operations caused by differences in design reference mission requirements, primarily the mission orbit.

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2.2.4.2.1.1 OTV/Space Station Separation Phase

This phase consists of release from Space Station and those operations required to safely exit zone 2 at 20 n mi ahead of the Space Station.

The location of the OTV fuel facility will influence the OTV deployment/separation scenario. The separation described here assumes that the OTV is fueled at the Space Station prior to deployment. A modification of this scenario would be suitable for OTV fueling at a free flying tank farm.

Deployment is initiated by providing a 1-2 ft/sec retrograde velocity to the OMV/OTV/payload stack as shown in Figure 2.2.4-15. The relative separation velocity is provided by a motorized separation mechanism mounted on the OTV hangar or alternatively by the OMV cold gas system. After a coast of about 1/2 hour, the assembly will exit zone 1 below and slightly ahead of the Space Station. An additional 7 fps retrograde velocity addition by the OMV at this time further reduces perigee altitude and causes the OTV and payload to move more rapidly through zone 2, ahead of the station. The OMV separates from the OTV at this time to begin its maneuvers to return to the station.

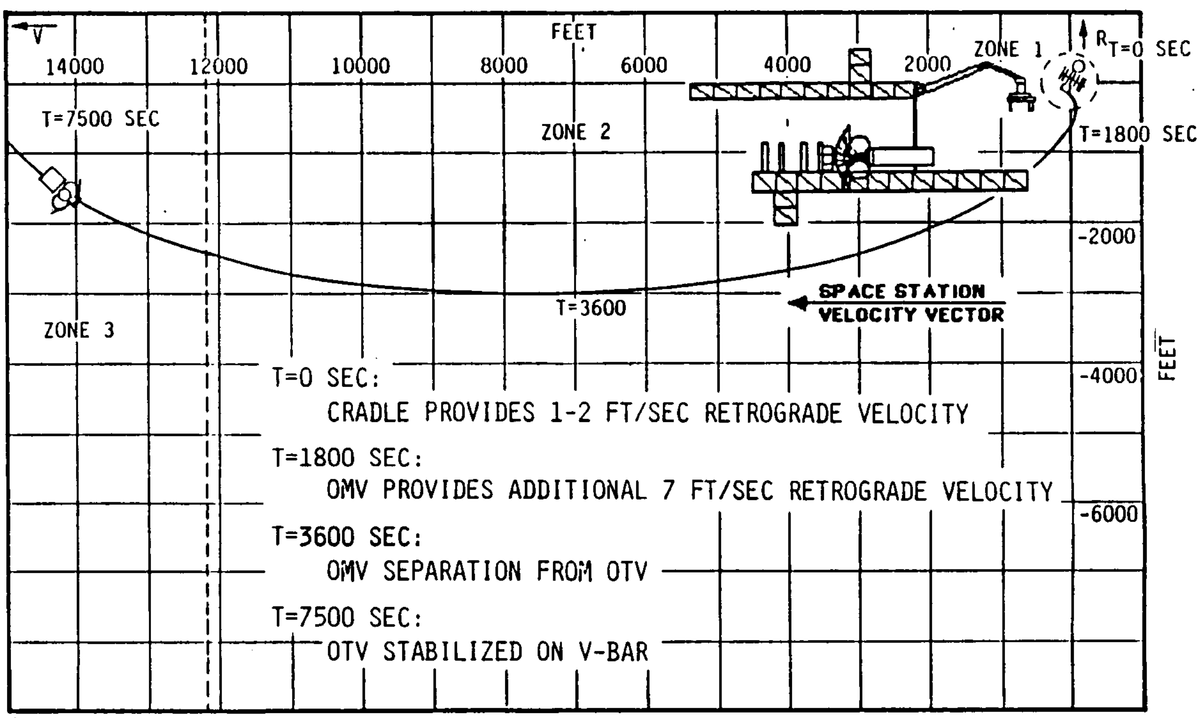


Figure 2.2.4-15 OTV Deployment From Space Station by OMV

The OTV RCS is activated as the vehicle continues to coast to apogee in zone 3. During this coast the OTV performs navigation and attitude update functions in preparation for transfer orbit burn which occurs about 2 hours after deployment.

An alternative deployment scenario would use the Space Station separation mechanism and OTV RCS to impart the retrograde velocity components thus eliminating the need for OMV operations for this mission phase. The relative separation trajectory would be the same as for the OMV assisted deployment. Although use of the OMV adds cost to the OTV mission, it has been included as part of the baseline scenario because of the added flexibility provided in case of an early OTV anomaly following deployment.

2.2.4.2.1.2 OTV Delivery and Return Phase

This phase of OTV space-based operations begins after separation from the Space Station when zone 3, 20 n mi ahead of the Space Station, has been reached. It ends upon return to low earth orbit when a stable orbit with respect to the Space Station has been achieved in zone 4, approximately 25 n mi behind the station. Operations include major OTV burns, mission orbit operations, deorbit burn(s), aeropass and reboost.

The operations during this phase are quite similar to the ground-based missions. One exception is the post aeropass reboost orbits. Post aeropass targeting is to a 4 x 245 n mi orbit with a 115 x 245 n mi reboost orbit used to establish proper phasing with the Space Station. The OTV performs more of the rendezvous operations as a space-based vehicle. At the proper time, the OTV is required to transfer from the 115 x 245 n mi phasing orbit to a 270 x 270 n mi orbit approximately 25 n mi behind the Space Station. This requires an active interface between the OTV ground control station and the Space Station support center for state vector comparison and OTV commanding. Figure 2.2.4-16 depicts the deorbit, aeropass, and reboost operations for the GEO mission. Other missions will have a different downleg trajectory prior to the aeropass from different mission orbits, but all other operations are the same.

This mission phase contains unique mission operations for each of the seven baseline reference missions. Each mission is addressed separately below.

2.2.4.2.1.2.1 Space-Based GEO Delivery

The operations required for this phase of the GEO Delivery mission are primarily the same as its ground-based counterpart and the storable OTV is only a perigee stage. Refer to Section 2.2.4.1.1.3.1 for more detailed discussions of this mission type.

The Space Station in its 28.5 deg inclined orbit, is the same as the orbiter for this mission type. One key difference is the launch window. The orbiter can launch into any RAAN plane each and every day if a payload has a RAAN requirement. The opportunities from the Space Station are considerably less, as its orbit regresses only 6.72 deg per day. One opportunity for each

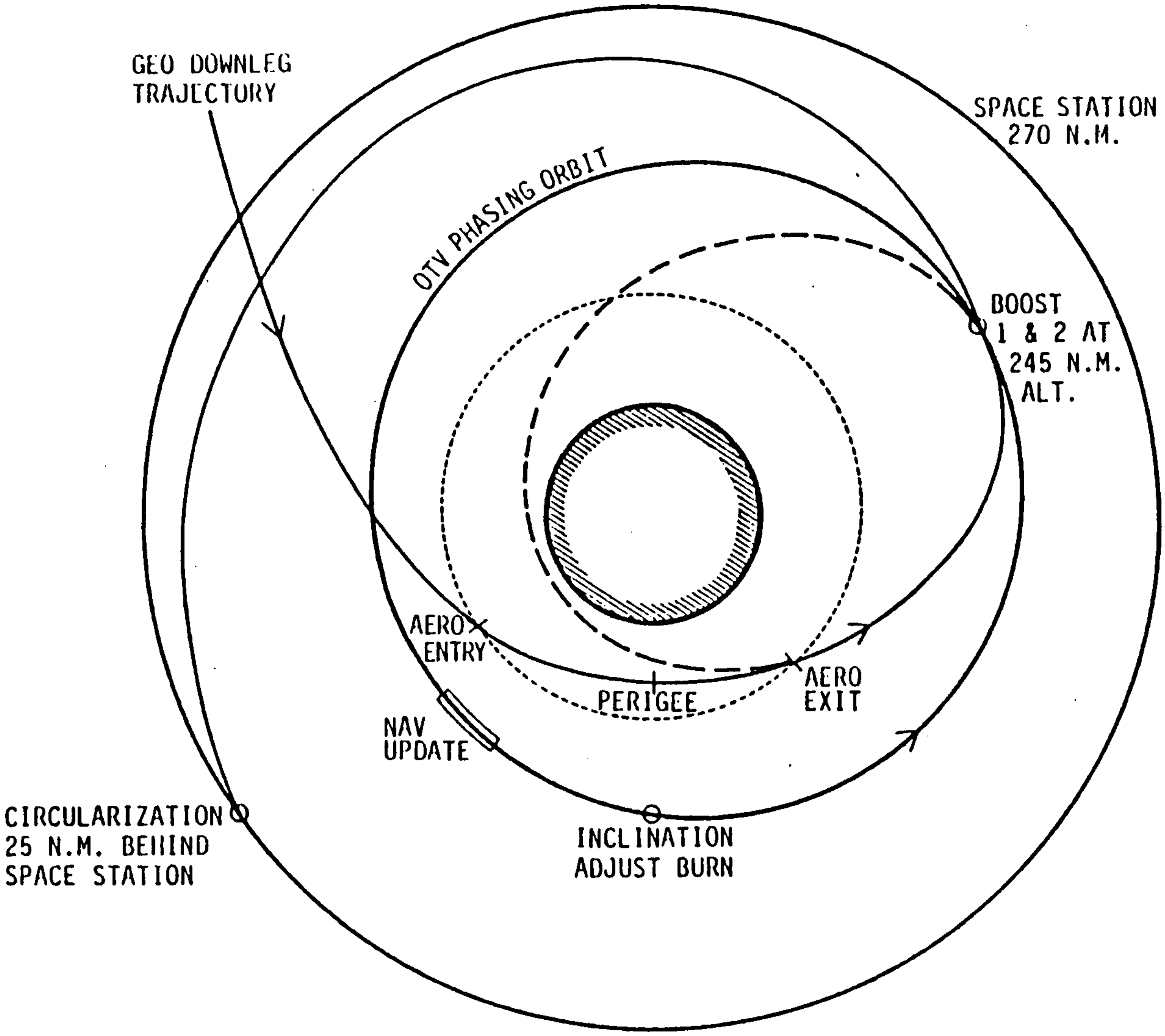


Figure 2.2.4-16 Deorbit, Aeropass and Rendezvous Orbit

RAAN plane exists every 26.8 days if both ascending and descending node burn opportunities are utilized. This does not affect OTV operations duration, but it reduces the flexibility of the Space Station and OTV in manifesting payloads and scheduling OTV refurbishment. It may also affect the fleet sizing requirements. Many GEO payloads have a longitude requirement. One method of satisfyiing this type of requirement is to let the spacecraft drift to its desired longitude, since locations within about 23 deg can be achieved each day by selection of the proper node for the perigee burn. An alternative method with fine tuning can be accomplished by an additional perigee burn to produce a phasing orbit with a period of between 90 and 180 minutes. The target in the GEO arc moves 0.25 deg in its orbit every minute. By starting the mission 90 minutes earlier, and then adding an orbit 90 to 180 minutes long, any longitude desired can be achieved. Either of these two methods minimizes the launch window problem and OTV scheduling/fleet sizing concerns.

2.2.4.2.1.2.2 Space-Based Planetary

This mission is also like its ground-based counterpart. The differences, other than the reboost and rendezvous to the Space Station orbit, discussed later, are in launch window opportunities. Since the inclination is fixed at 28.5 deg, and the station orbit regresses only 6.27 deg per day, a less optimum planetary inject, compared to ground-based, may be available. Also, the frequency of launch opportunities is reduced as it was for the GEO mission. Each planetary mission requires a unique set of OTV burns. Refer to section 2.2.4.1.3.2 for more discussion of this mission type.

2.2.4.2.1.2.3. Low g GEO Delivery

One variation on the GEO delivery mission introduces a low g constraint to the allowable acceleration during powered flight. The constraint of 0.1g is accommodated by reducing the thrust level during main engine burns by operating the cryo engine in a pumped idle or tank head idle mode. For storable OTVs the same effect is produced by operating with fewer engines on the stage.

At the lower acceleration levels much longer burns are required to gain the required orbit transfer velocity. To reduce gravity losses during the perigee burn, it is divided into seven separate burns of approximately equal duration. Figure 2.2.4-17 represents the low g GEO Delivery mission.

2.2.4.2.1.2.4 Space-Based GEO Manned/Unmanned Servicing

Other variations on the GEO mission are the manned and unmanned servicing missions. As orginally envisioned with respect to the Revision 7 mission model, the OTV would be used in these missions as a basic transfer vehicle to transport autonomous manned or unmanned servicing vehicles to a desired location in the GEO arc. All servicing and rendezvous/proximity operations would be done by the servicing vehicles. An OMV might be utilized in this role.

The Revision 8 mission model introduced the concept of a mobile GEO service station (MGSS) which is the GEO operations base for unmanned and manned servicing activities. The OTV role in the servicing mission is to provide logistics support to the MGSS and to ferry the manned capsule between LEO and GEO to the MGSS. Rendezvous and proximity operations are performed by a GEO based OMV. The same launch window constraints and solutions as in the GEO delivery mission are applicable here as well.

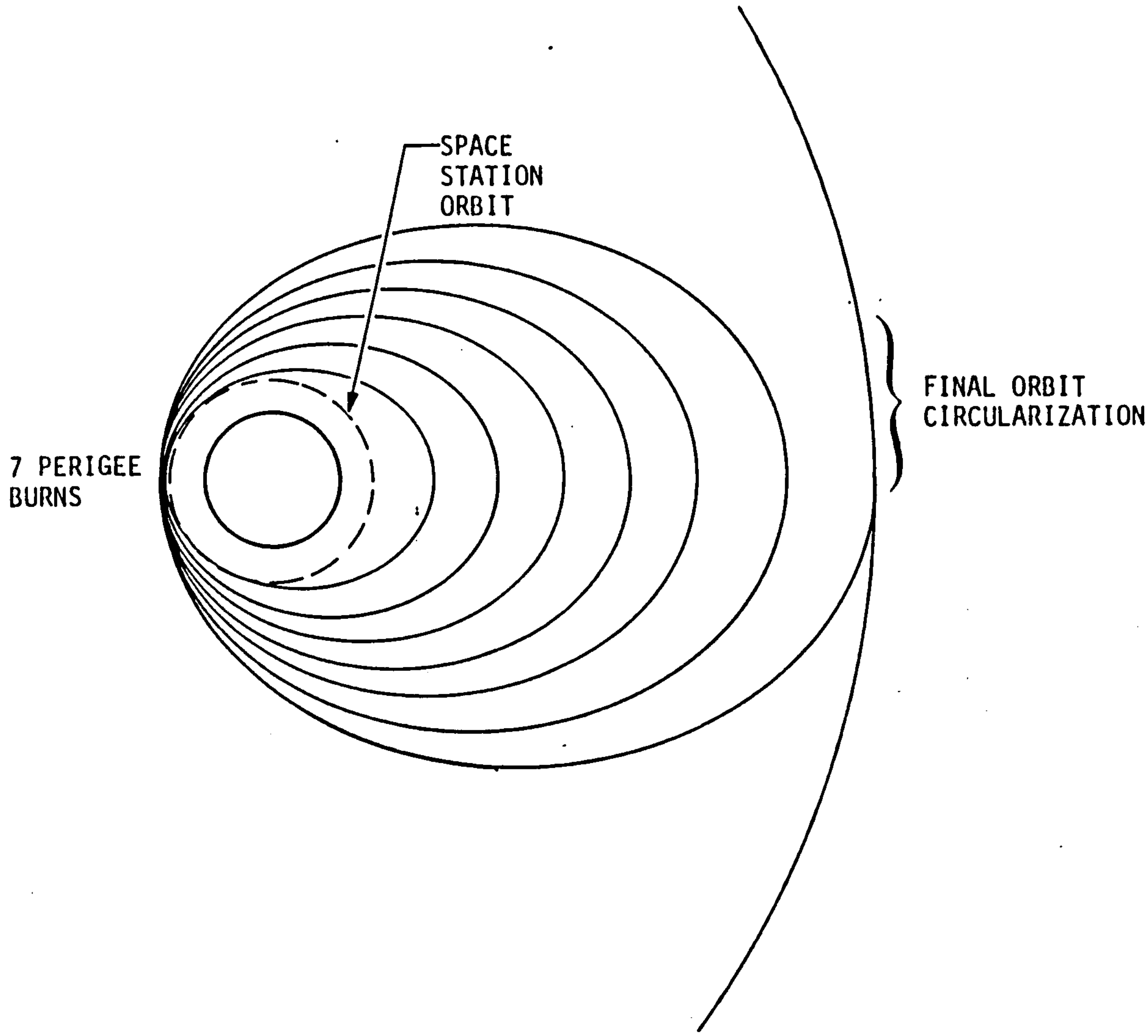


Figure 2.2.4-17 Low G GEO Delivery Mission

2.2.4.2.1.2.5 Space-Based High Inclination

High inclination orbit missions are more difficult in a space-based mode due to the fixed low inclination of the space station. Figure 2.2.4-18 shows the maneuvers required, while Table 2.2.4-2 provides the magnitude for these burn maneuvers. The strategy here is to combine the plane change and apogee/perigee burns to reach the desired first mission orbit plane, and the Space Station orbit plane. Changes between orbits, if required, are done at orbit intersections. The return leg is essentially a mirror image of the upbound trajectory with appropriate plane changes to account for Space Station orbit nodal regression. Apogee was raised to 22148 n mi to do the plane changes as this was determined to be the most delta-v efficient method and altitude.

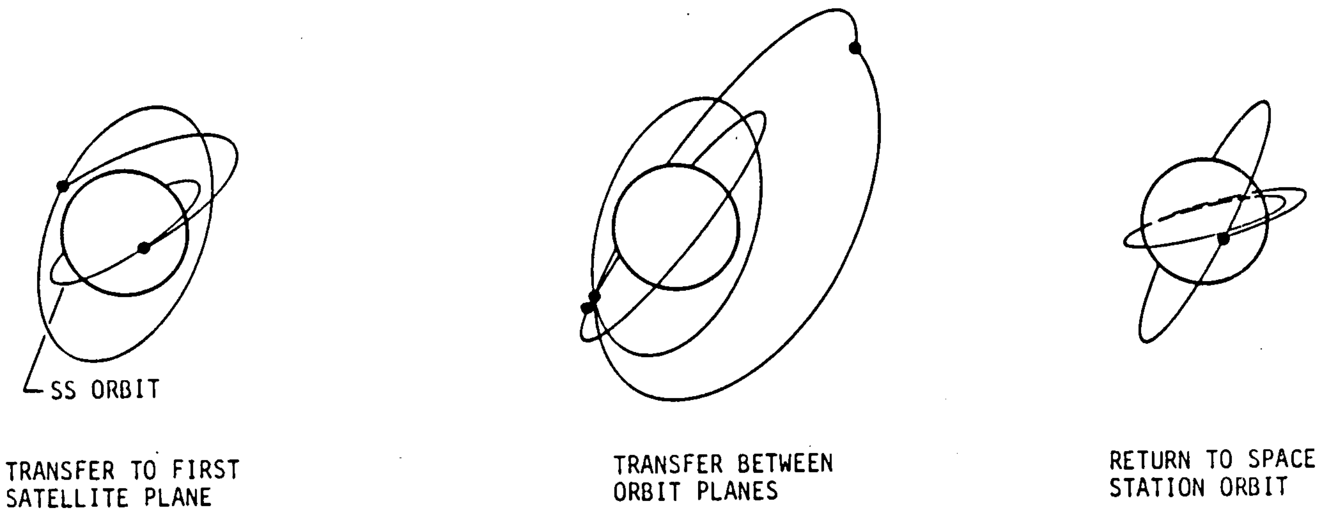


Figure 2.2.4-18 Space-Based High Inclination Mission

Once again, the launch window to a given RAAN plane from Space Station is less frequent from that of ground-based missions. For this mission, an opportunity exists only every 53.5 days (360 deg/6.72 deg/day), since the station orbit regresses 6.72 deg/day. This is only half as often as the Geo mission because this is essentially a rendezvous, and direction in mission orbit is as important as matching the plane.

One advantage of space-basing for this mission is increased available mission time. The OTV can wait in the second payload plane until the station orbit regresses to make them coplanar rather than being constrained by allowable STS mission duration.

2.2.4.2.1.2.6 Space-Based Lunar Sortie

Lunar sortie missions using the OTV are accomplished using 2 stage vehicles. Two perigee burns are employed to reduce velocity losses for trans-lunar orbit insertion. The second stage accompanies the lunar payload into lunar orbit and supplies necessary midcourse, circularization in lunar orbit, and earth return velocity. Figure 2.2.4-19 shows the trajectory of the Lunar Sortie mission.

Table 2.2.4-2 Space Based High Inclination Mission Burn Sequence

OTV BURN #	MANEUVER (NMI)	DELTA-V (FPS)
1	Mission Orbit Perigee 270 x 270 to 270 x 10898 3.256 deg Inc plane change	6696
2	Mission Orbit Apogee 270 x 10898 to 10898 x 10898 23.244 deg Inc Plane Change	6131
-	Deploy Payload #1	-
3	RAAN Plane Change 10898 x 10898 to 10898 x 22148 4.851 deg Plane Change	2032
4	RAAN Plane Change 38.655 deg Plane Change	5338
5	RAAN Plane Change 10898 x 22148 to 10898 x 10898 4.851 deg Plane Change	2032
-	Deploy Payload #2	-
6	OTV/Space Station Phasing	100
7	Deorbit to Aeropass 10898 x 10898 to 10898 x 40	6624
8	Phasing Orbit 4 x 245 to 245 x 245	427
9	Rendezvous Orbit Perigee 245 x 245 to 245 x 270	42
10	Rendezvous Orbit Apogee 245 x 270 to 270 x 270	42
		29464 Total

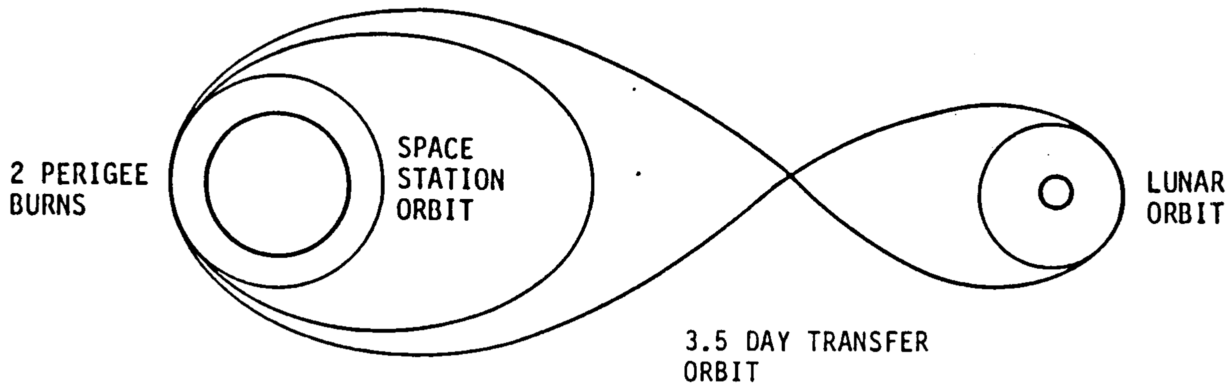
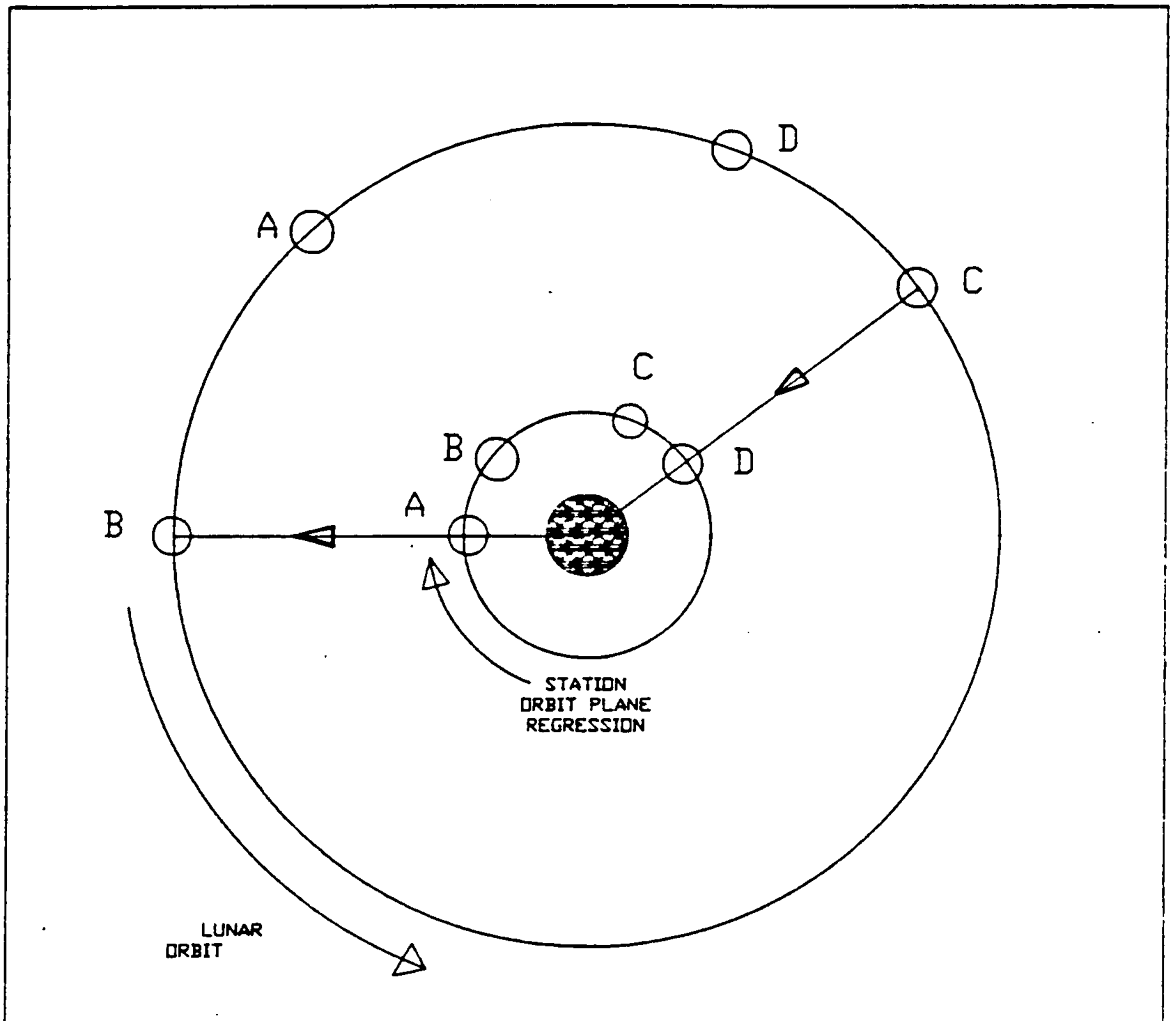


Figure 2.2.4-19 Lunar Sortie Mission

This mission has discrete times for initiating lunar transfer and also for initiating earth transfer. Figure 2.2.4-20 depicts the geometry involving the station orbit plane, transfer time to and from the moon, and the moon's orbit position. The space station circle represents its orbit plane movement. The station orbit regresses 6.72 deg per day. The lunar orbit about the earth moves 13.176 deg of true anomally per day. The OTV begins the mission with a lunar inject burn sequence (2 perigee burns) that "leads" the moon. Two stages are required for this mission. The first provides 4984 fps and raises apogee to 6180 n mi. This intermediate orbit adds 3.75 hours to the transfer time, but also decreases the velocity losses that would occur with a single burn. The first stage deorbits at its apogee and performs a standard rendezvous and returns to the space station. The second stage performs the second perigee burn of 3366 fps to provide lunar transfer. A worst case time of 3.5 days was used in the timeline development. Shorter duration transfers could also be accomplished with higher delta-V or for variations in lunar positions in orbit (apogee vs perigee). A midcourse maneuver of 180 fps is budgeted. The first and second stage targeting takes into account the transfer time of 87.75 hours and the moon's orbital rate.

Lunar orbit inject is accomplished by the OTV with a 2690 fps burn. Shortly thereafter, a lunar vehicle separates from the OTV and performs its mission. All rendezvous and proximity operations are performed by the lunar vehicle, and mating operations occur shortly before the earth return transfer orbit burn.



A. Positions at first PERIGEE BURN

B. Positions at LUNAR ORBIT INSERTION

C. Positions at EARTH RETURN TRANSFER

D. Postions at AEROPASS/STATION RENDEZVOUS

T_{MOON} = [360 -a(Tu + Td)]/(a+b) = 376 hrs

where: 'a' is space station regression rate
'b' is lunar rate
Tu is xfer time up (87.75 hrs); Td is xfer time down (84 hrs)

Figure 2.2.4-20 Lunar Sortie Mission Orbit Plane Geometry

The mission duration is selectable but has discrete values depending on the duration spent in lunar orbit. Figure 2.2.4-20 shows the equation for determining the time for 360 deg of station orbit and lunar travel. Somewhat less optimum opportunities exist at 180 deg too. The time selected in the timeline for lunar orbit is 376 hours. An opportunity for return inject exists approximately every 9 days thereafter.

The return from lunar orbit is initiated with a burn of 2690 fps and includes 2 midcourse maneuvers of 180 fps and 310 fps. These are necessary to correctly target for the aeropass. As indicated in the timeline, the operations for aeropass and station rendezvous are standard. Table 2.2.4-3 lists the burns, orbits and delta-Vs used in performance of this mission.

Table 2.2.4-3 Lunar Sortie Mission Orbits and Maneuvers

OTV BURN #	MANEUVER (N MI)	DELTA AV (FPS)
1	Stage #1 Perigee Burn 270 x 270 to 270 x 6180	4984
2	Stage #2 Perigee 270 x 6180 to Lunar XFER	5366
3	Midcourse	180
4	Lunar Inject	2690
5	Lunar orbit to Earth XFER	2690
6	Midcourse	180
7	Midcourse	310
8	Phasing orbit 4 x 245 to 245 x 245	428
9	Rendezvous Orbit Perigee 245 x 245 to 245 x 270	42
10	Rendezvous Orbit Apogee 245 x 270 to 270 x 270	42
		16910 TOTAL

2.2.4.2.2 OTV/Space Station Rendezvous - Capture

This phase of space-based OTV operations begins when the OTV has reached a stable orbit about 25 n mi behind the space station on the velocity vector. This is in space station zone 4. These operations assume the fueling facility is located on the space station. Similar operations would be used for a remote fueling/de-fueling facility.

The OMV is utilized in returning the OTV to the space station for refurbishment. After achieving a stable orbit, the OTV continues to maintain attitude control and awaits the arrival of the OMV. The OMV is the active vehicle for the rendezvous and proximity operations and attaches itself to OMV attach points located on the aerobrake near the engine doors. The OMV then maneuvers to the space station along the velocity vector as shown in Figure 2.2.4-21. As the OMV/OTV nears the station in Zone 1, the OMV begins breaking maneuvers which arrest its motion within range of the space crane. The OMV/OTV assembly is grappled and returned to the OTV hanger area.

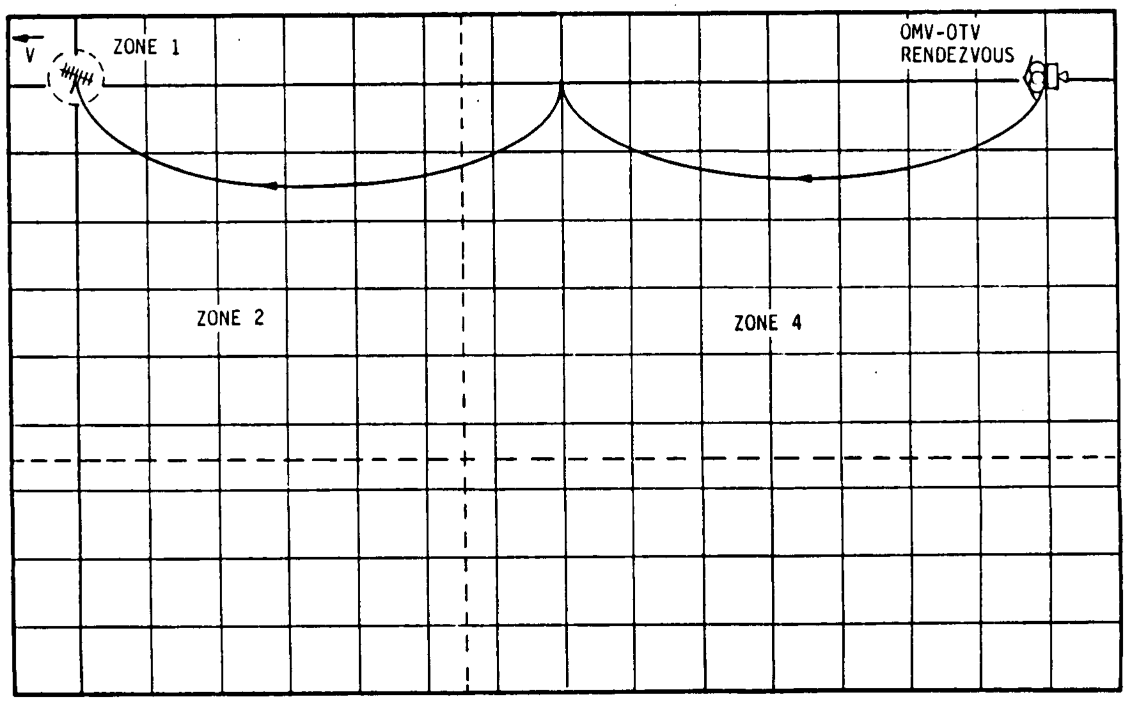


Figure 2.2.4-21 Space-Based Recovery to the Space Station by OMV

2.2.4.3 Assessments

A number of topics related to operations warrant special consideration and are discussed in the following sub-sections.

2.2.4.3.1 Orbiter Ku-Band Antenna Blockage

For ground-based OTV missions during RMS operations to grapple and mount the OTV on the PIDA, mate the payload to the OTV, and deploy the OTV and payload, the steerable Ku-band antenna view to TDRS will be partially masked by the payload and OTV as shown in Figure 2.2.4-22. The impact of this blockage on the primary mode of orbiter communications is highly dependent on the profile (attitude vs time and orbital position) for a specific mission. Interference with Ku-band transmission and reception is relatively common for missions planning RMS operations for the recovery or deployment of payloads. Alternate communications employing the Orbiter S-Band PM system with TDRS are available to supplement the Ku-band system during periods of blockage.

2.2.4.3.2 Orbiter Radiator Blockage

While the OTV is mounted on the PIDA and especially during payload mating and checkout, the Orbiter's radiators located inside the payload bay doors will be partially blocked from their usually space viewing. This can be seen in Figure 2.2.4-23. A portion of the Orbiter heat load will be directed at the payload and/or OTV. From the Orbiter perspective, this is not expected to be a major concern as the radiators have been sized to handle a much larger heat load than they will be experiencing at this time in the OTV mission. Orbiter attitudes may be selected which effectively dump this heat load. The proximity of the radiators is also not expected to present problems for the OTV. Avionics equipment is located away from the high heat environment and tank insulation will minimize radiation into the propellants.

2.2.4.3.3 STS Crew Activities

An objective throughout the development of the ground-based mission scenarios was to minimize, if not eliminate, the need for EVA for nominal operations. This was accomplished partly by developing the payload to OTV mating scenario described earlier. Recovery operations should also be possible without EVA. The storable OTV configurations are sized to fit in the payload bay without disassembly. Forward and aft longeron and keel trunnions which mate with Orbiter longeron and keel mounted latches are used to return the OTV. The OTV is maneuvered into the payload bay using the RMS. The cryogenic OTV requires removal and storage of the LH_2 tanks separate from the main structure and LO_2 tanks. The cryogenic OTV is first mounted on the PIDA following RMS grapple. Each LH_2 tank in turn is held by the RMS while the tank is separated from the support struts and then stowed in the payload bay in keel and longeron fixtures. The tank support struts are folded to allow the remaining core structure to fit in the payload bay. Finally the core structure, engine, and LO_2 tank assembly is stowed using the RMS. EVA would be used only as a backup in the event of inseparable latches or failure to release tank attachment points.

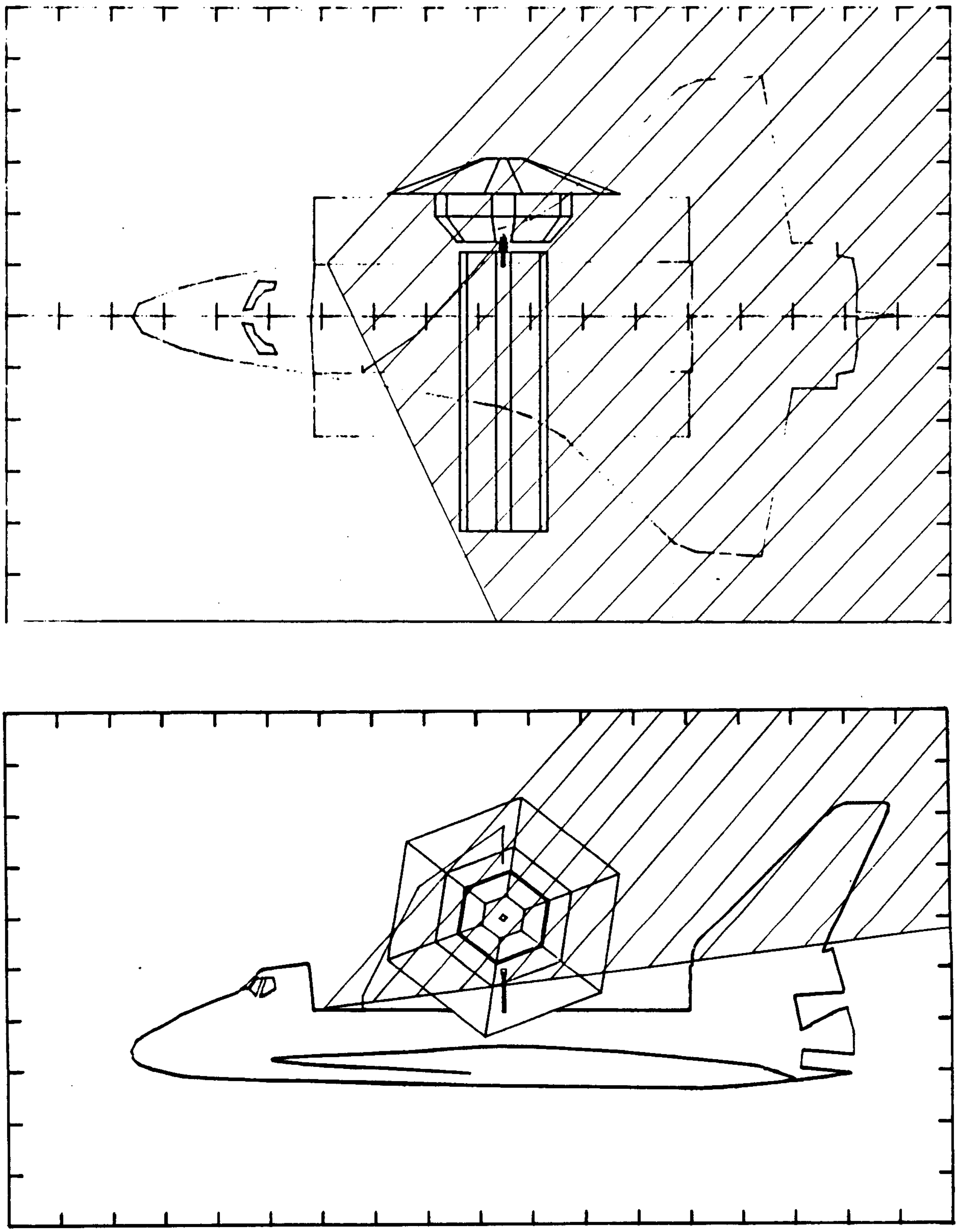


Figure 2.2.4-22 Orbiter Ku-Band Antenna Blockage

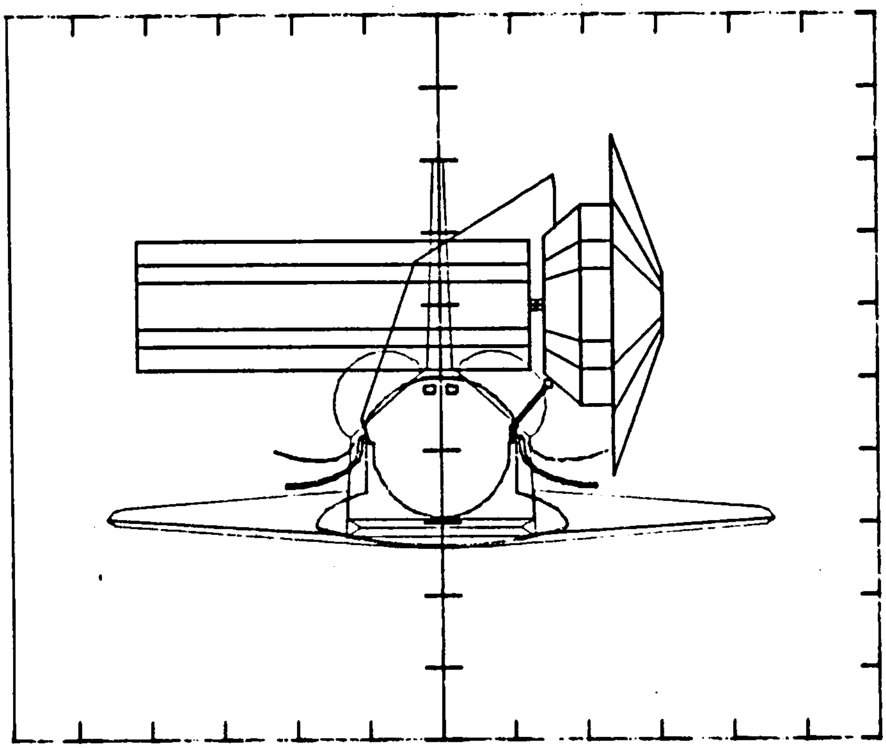


Figure 2.2.4-23 Orbiter Radiator Blockage

The OTV timeline must consider orbiter crew availability when performing joint operations. The crew is required for all rendezvous, proximity and RMS operations. Other orbiter functions, as well as crew needs, such as sleep periods and meals must be equally considered with OTV requirements when developing a ground based timeline, though some flexibility is provided. Figure 2.2.4-24 is an integrated timeline showing basic crew activities and major OTV/orbiter milestones for an ACC launched OTV. This timeline was used as a guide in developing the OTV ground-based timelines. The sleep periods "move" earlier each day to track landing opportunities.

The crew timeline shown assumes one shift orbiter operations. Additional flexibility is gained, though not required, by two shift operations. Currently, about ten percent of orbiter missions utilize two shift operations.

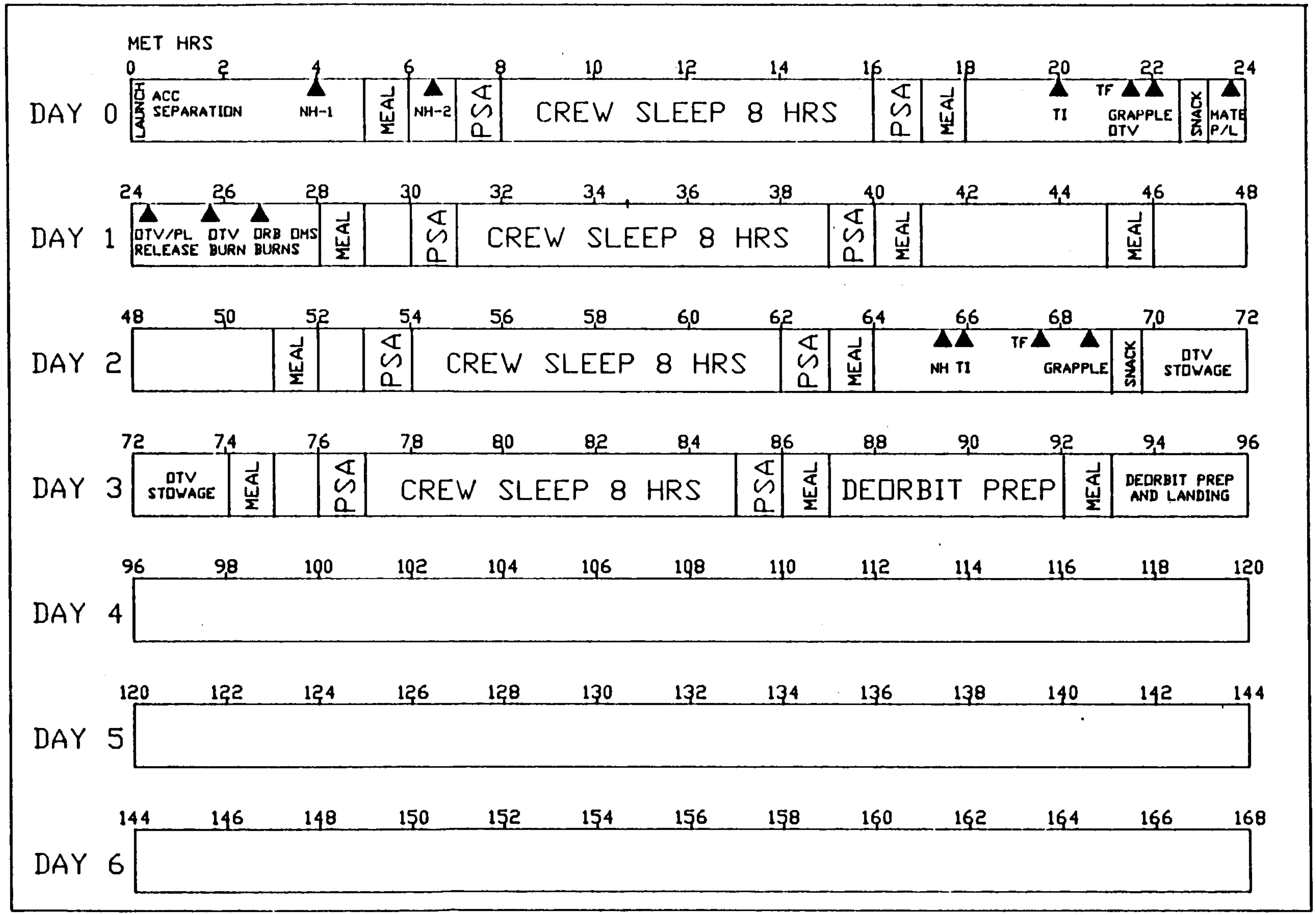


Figure 2.2.4-24 ACC Launched OTV/Orbiter Crew Timelines

GEO delivery missions that require specific RAAN placement will necessarily dictate which node the OTV will utilize for its burn. As such, the sleep cycles will be adjusted to accommodate. The crew is required to be awake between 5 and 10 hours at the scheduled liftoff. The first crew day can be as long as 20 hours, though 16 to 18 is generally considered the practical maximum. The crew day cannot be shorter than about 15 hours. This results in a scheduling shift of up to 10 hours. Since up to 12 hours is required to achieve the desired RAAN, the OTV may be required to wait after RMS release for up to 2 hours before executing its burn.

The flexibility in scheduling crew activities appears to provide ample opportunity for completing all ground-based OTV operations without scheduling conflict, thus permitting the OTV to meet all DRM requirements.

Space-based OTV missions require less crew time for flight operations than is needed for ground-based missions. Following separation from the Space Station a crew member will be involved in monitoring the OTV/OMV trajectory through zone 2. Crew participation in the OMV return to the station after separation from the OTV is also probable. Elapsed time from initial departure to OMV return is on the order of 2.5 hours. The OTV exits zone 2 at about 2.5 hours after deployment. Upon return to Space Station zone 4, the OMV is dispatched to retrieve the OTV. The retrieval which will be monitored by a crew member requires approximately 5 hours from OMV departure to OMV/OTV grapple.

2.2.4.3.4 OTV Autonomous Space Station Departure

The space-based timelines reflect a station departure which utilizes the OMV. This is based primarily on the requirements for cold gas thrusters in zone 1 and for station control authority in zones 1 and 2. An alternative departure could be done by the OTV itself. The OTV (and payload) could be deployed with a motorized cradle system. It would be required to produce about 1-2 fps velocity on the combined OTV/payload. This velocity is the same used in the current timelines. The difference starts after deployment in zone 1.

Space station zone 1 restricts the use of hot gas thrusters. Attitude stability requirements of payloads and the combined configuration dynamics require analysis to determine compatibility. Thermal requirements may be met operationally; e.g. deploying in orbital darkness.

Once space station zone 2 is reached, the OTV can activate its RCS and maintain altitude. An RCS burn of 7 fps (same as in the timeline) increases the velocity and decreases the time required to reach zone 3 for OTV Boost-1. The requirement in zone 2 is for control authority. This may be something as simple as a disabling signal that could be sent from the station in an emergency situation. The timeline and operations are the same for each method after OMV separation in zone 2.

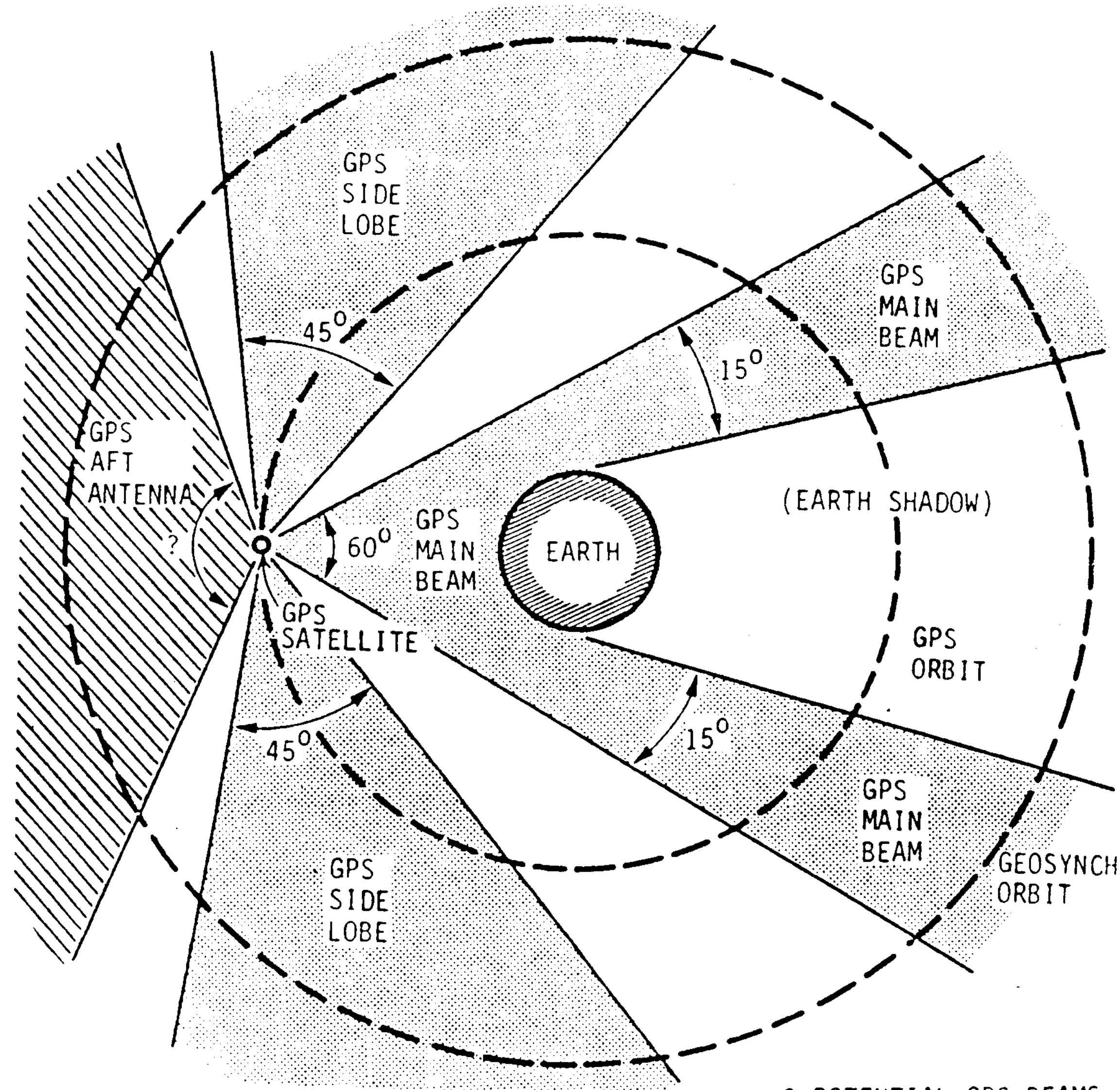
This alternative method is operationally less complex and does not create secondary requirements for OMV refurbishment and OMV control although it provides less flexibility in the event of a post-deployment OTV anomaly. It is important to track the refinement of space station operational requirements as they mature.

2.2.4.3.5 STANDARD OPERATIONS

Some operations occur throughout the mission independent of mission objectives. These include attitude and state vector updates, communications with the OTV ground control station, and passive thermal control via attitude.

Attitude updates require attitude maneuvers for star tracker observations. The nominal time allowed for this operation should assume the acquisition of 2 stars 90 deg apart with a total slew of 120 degrees from start to finish. At 1 deg per second, this is 2 minutes per update. State vector updates will be done autonomously using GPS. At lower orbits, two standard hemispheric coverage omni antennas will likely be used. No attitude maneuvers are required for these and no impact to operations is expected. At higher altitudes, a fixed 20 deg horn provides sufficient gain and coverage for unambiguous triangulation. Figure 2.2.4-25 shows the coverage problem at higher (greater than 10,000 nmi) altitudes. Figure 2.2.4-26 shows the number of GPS satellite visible for a typical GEO downleg trajectory. Four to six GPS satellites are required to determine OTV positions and they must be within the coverage as shown in Figure 2.2.4-25. Some attitude maneuvers will be necessary for navigation updates at higher altitudes. The number and time required for this operation is variable, and 20 minutes has been allocated in the timelines. An additional minute was allocated for transition from an attitude update to the state vector update, so the total allocated is 23 minutes. While this will vary with altitude and GPS availability, 23 minutes was used throughout the timeline for conservatism and simplicity. Attitude and state vector updates are scheduled before each major burn.

Communications coverage for OTV is much like GPS coverage. At low altitudes, TDRSS provides near continuous availability. At higher altitudes, above 6000 nmi, the coverage begins to decrease. Near GEO the coverage for most missions is greatly reduced. Figure 2.2.4-27 and figures 2.2.4-28a through 2.2.4.28-d show this reduction in coverage. Some enhancement is available by the GSTDN and Deep Space Network, which will be required for lunar missions, and by Remote Tracking Stations for DoD missions as shown in Figures 2.2.4-29a through 2.2.4-29d. Telemetry coverage of major events at high altitudes is less than desirable. Improvements to the TDRS system such as additional satellites located to provide increased GEO coverage and/or wider antenna steering angle limits are recommended. Even with such improvements, OTV operations in high altitude orbits require some degree of autonomous operational capability and the ability to store telemetry for later downlink.



- 3 POTENTIAL GPS BEAMS
  - GPS MAIN BEAM
    15° WIDE AFTER EARTH OBSCURATION
  - GPS SIDE LOBES
    45° WIDE
  - GPS AFT ANTENNA
    NOT ON CURRENT DESIGNS
    STATUS INDETERMINATE
- MOST PROMISING APPROACH IS TO USE SIDE LOBES BECAUSE OF WIDER COVERAGE

Figure 2.2.4-25 GPS Satellite Coverage

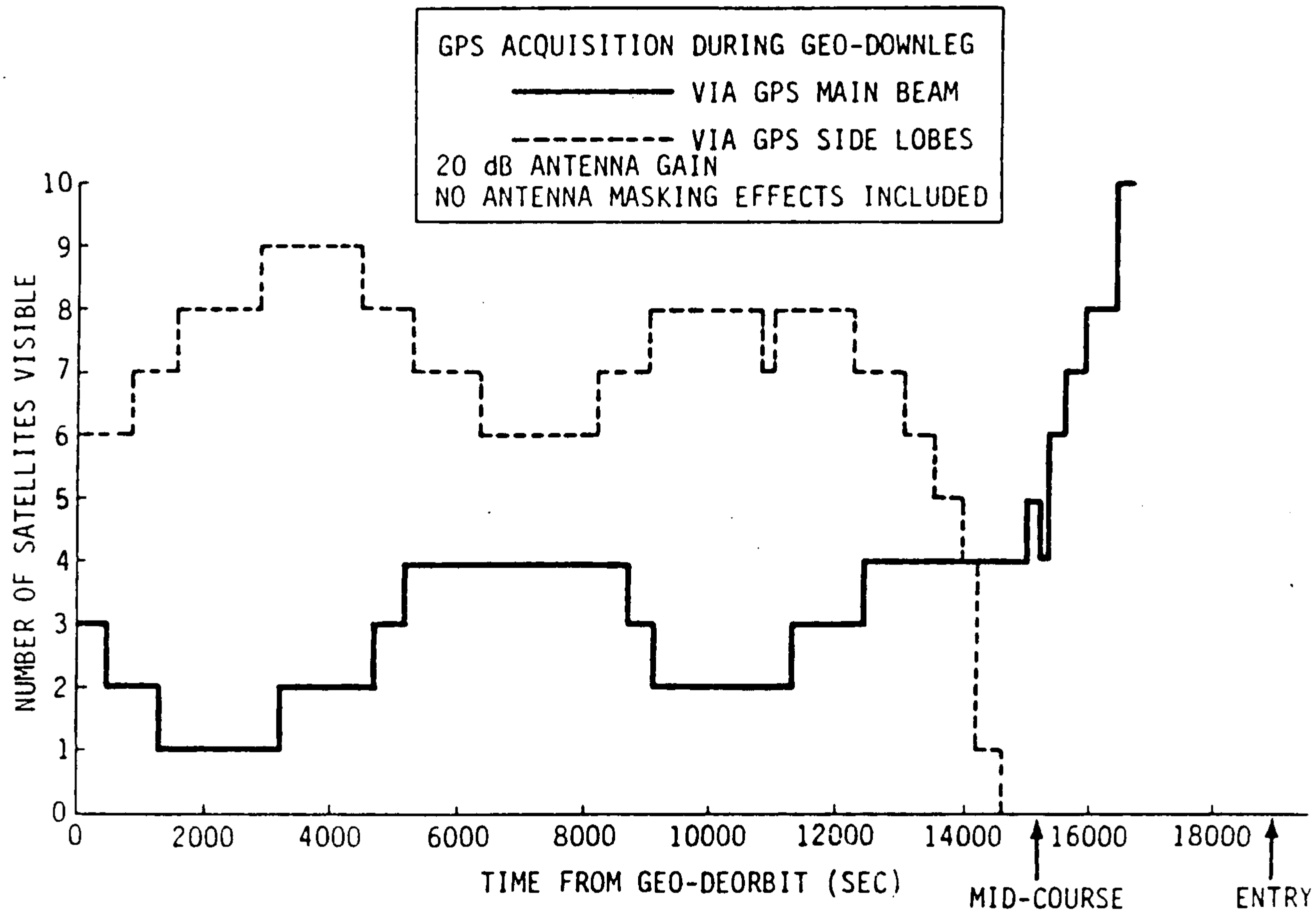


Figure 2.2.4-26 GEO Downleg GPS Availability

It is expected that some payloads will need thermal environment maintenance to be provided by the OTV. Thermal roll attitude maneuvers are planned whenever in a coast period. Special attitudes can be accommodated as identified. Interruptions in the desired attitude should be anticipated for communications, and attitude and state vector updates. Also, rendezvous and proximity operations will undoubtedly have attitude requirements and will require a "stable" visual reference for grapple and/or docking operations.

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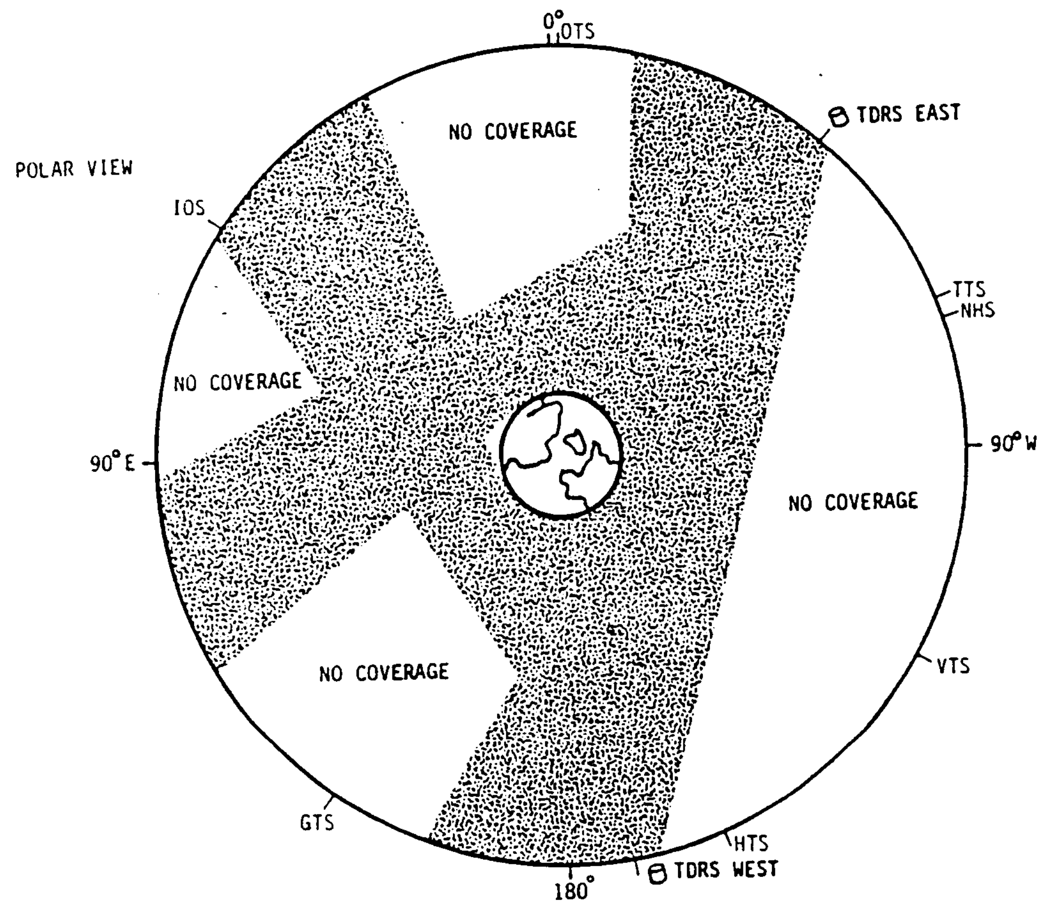

Figure 2.2.4-27 TDRS Coverage at GEO

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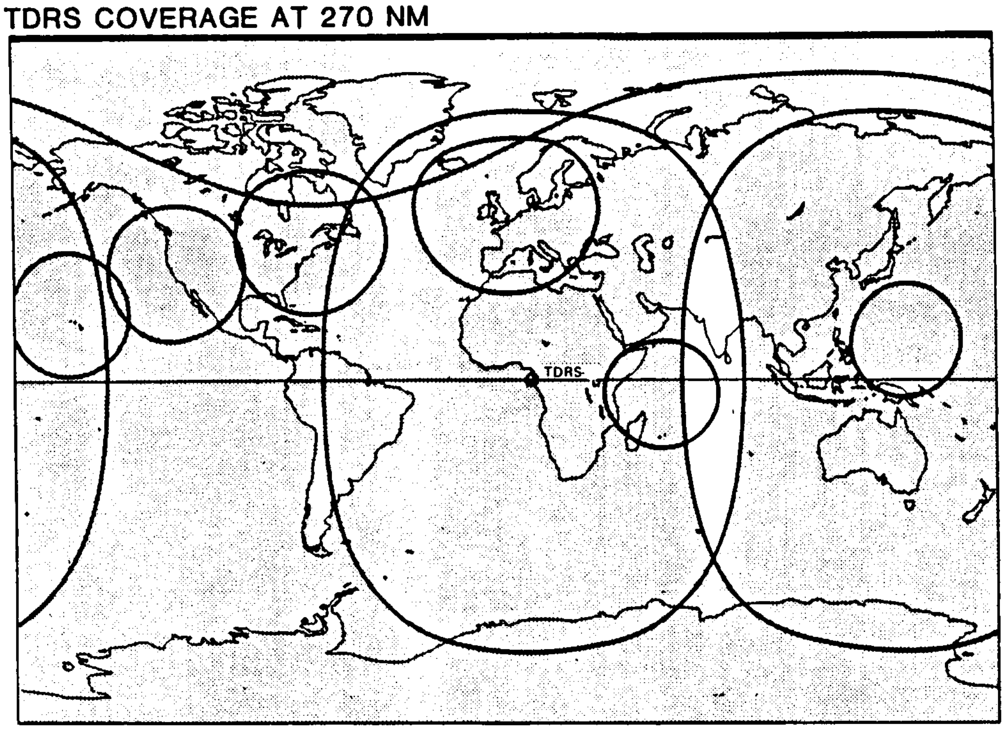
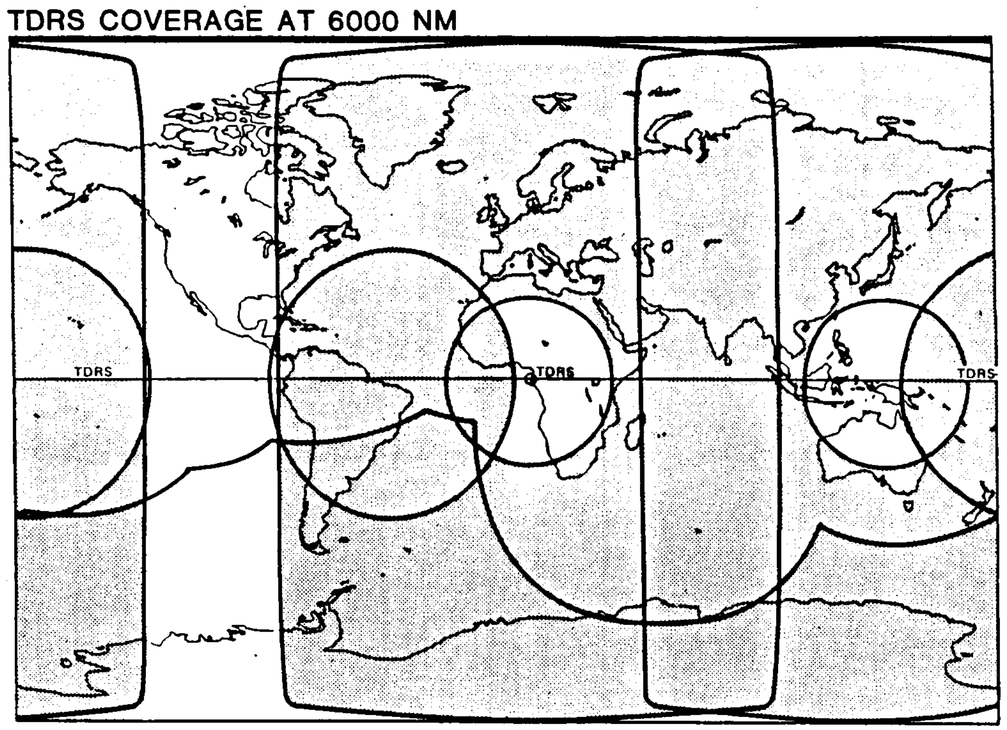


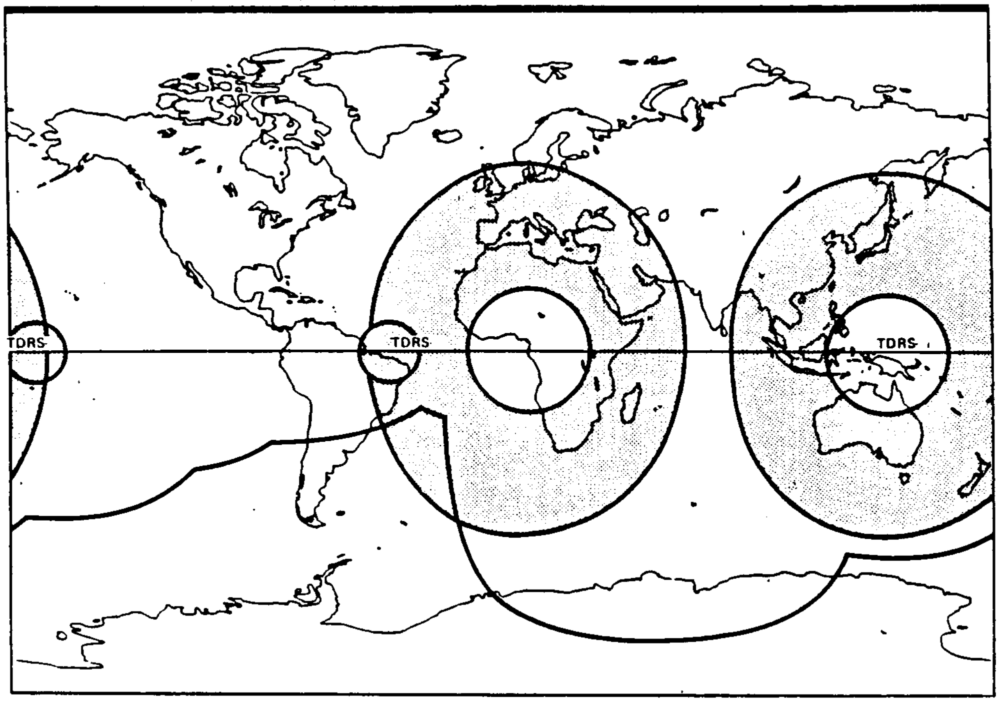
(a)



(b)

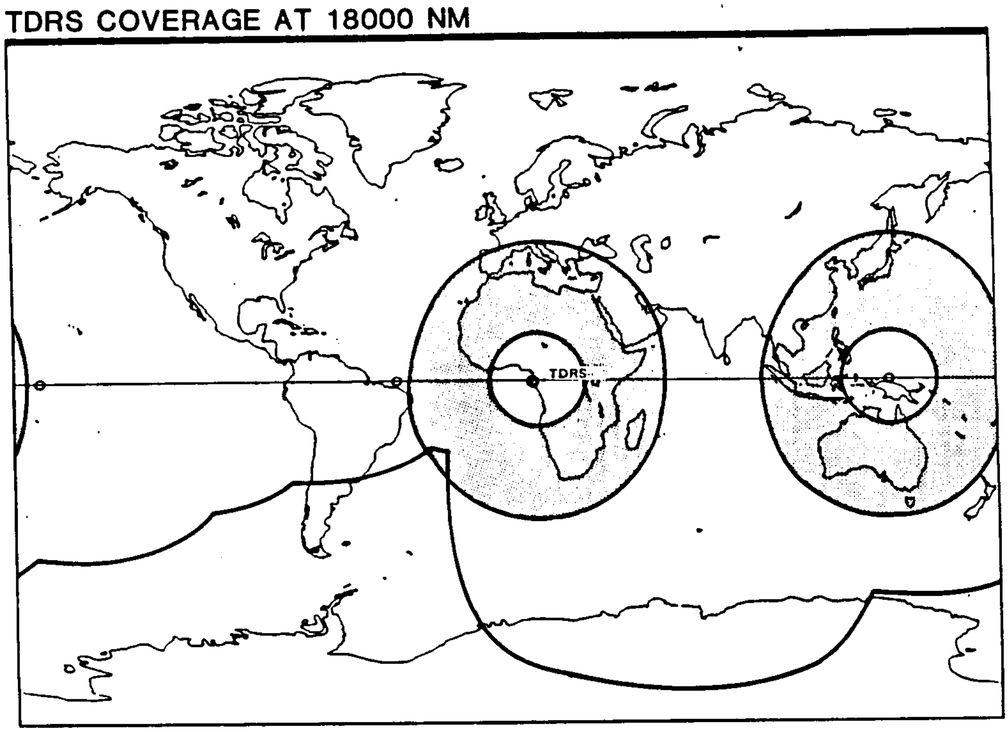
Figure 2.2.4-28 TDRS Coverage vs Altitude

TDRS COVERAGE AT 12000 NM



(c)

TDRS COVERAGE AT 18000 NM



(d)

Figure 2.2.4-28 TDRS Coverage vs Altitude

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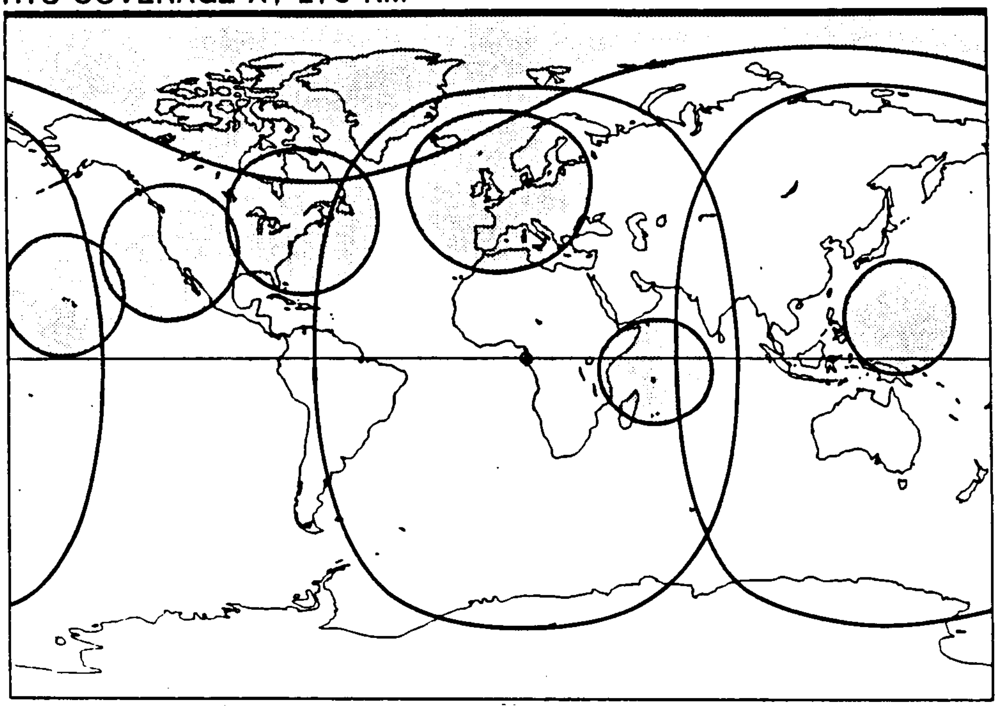
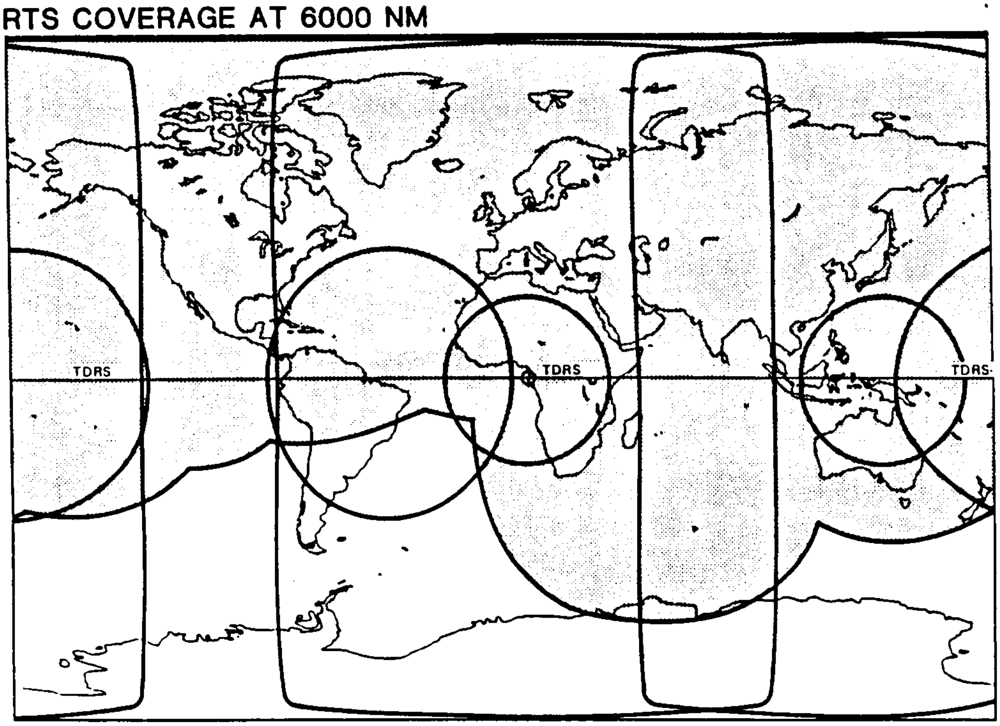
RTS COVERAGE AT 270 NM



(a)

RTS COVERAGE AT 6000 NM



(b)

Figure 2.2.4-29 RTS Coverage vs Altitude

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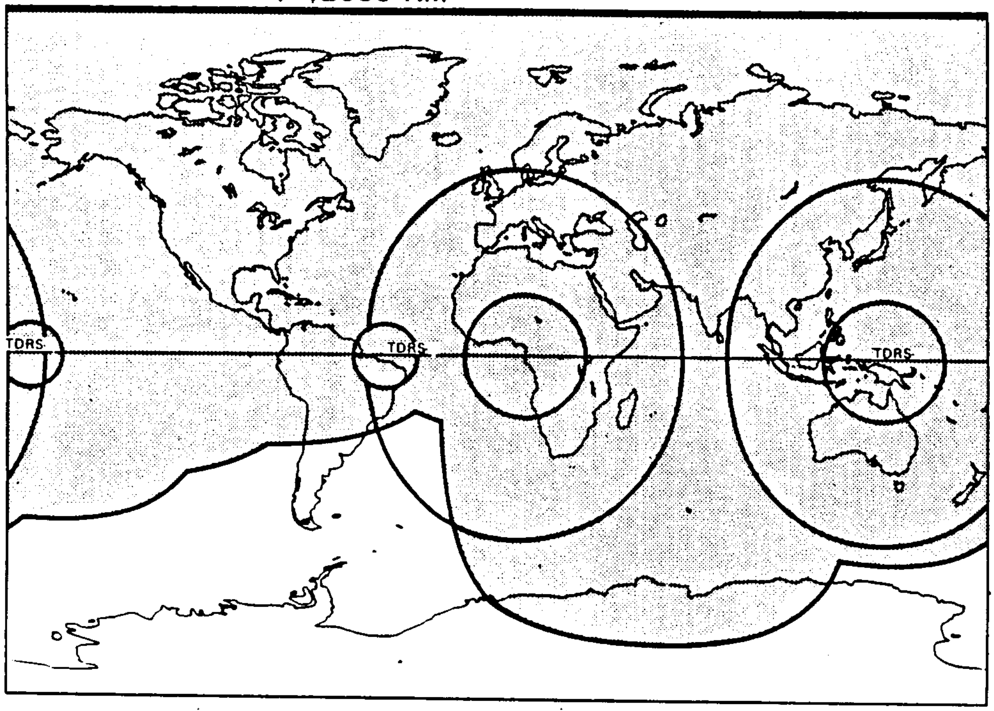
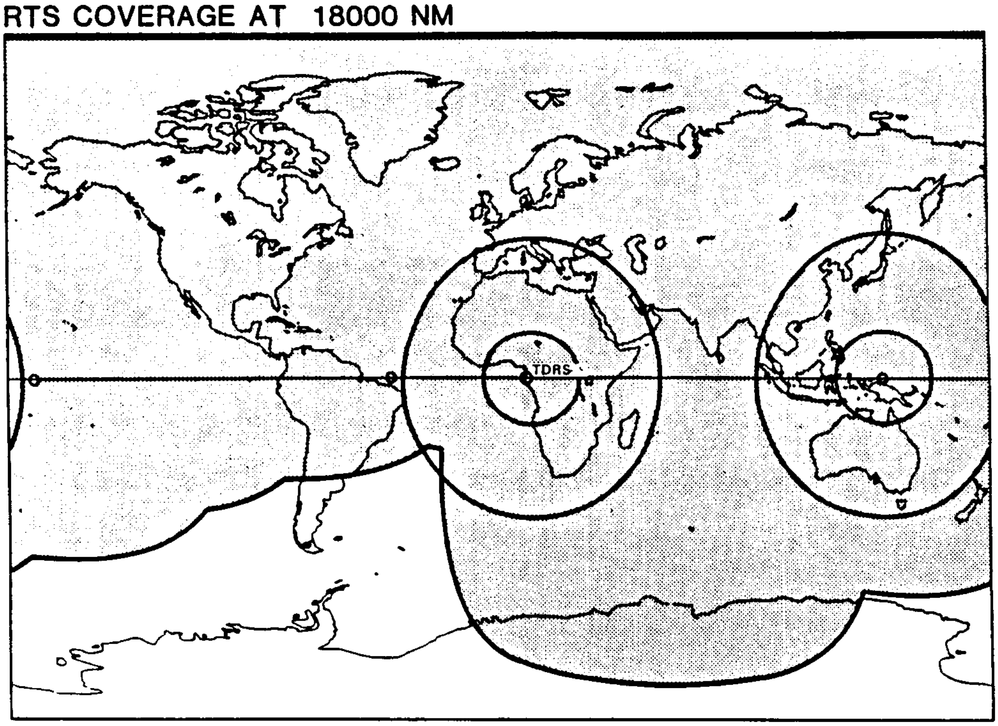
RTS COVERAGE AT 12000 NM



(c)

RTS COVERAGE AT 18000 NM



(d)

Figure 2.2.4-29 RTS Coverage vs Altitude

2.2.4.3.6 CONTINGENCIES AND ABORT WORKAROUNDS

Certain factors should be considered when sizing subsystems for the OTV.

1. The orbiter and space station/OMV can cause delays in both deployment and rendezvous/retrieval operations. It does not take a large delay to cause activities to slip to the next crew day. A backup day deployment and backup day retrieval capability should be maintained.

2. Situations can occur that would result in the orbiter performing an Early Flight Termination to the launch site or the OMV not available for operations. An OTV "quiet" mode should be examined to determine the impact of maintaining OTV minimum functions for a period of 2 weeks to 1 month. No functions other than minimum computers and periodic attitude maintenance for possible ground station communication and OTV "awakening" would be necessary.

3. A TDRS may be down or unavailable when at GEO where coverage is minimal. This situation reinforces the concept of a semi-autonomous OTV which can execute planned major events without additional ground commanding or targeting.

2.2.4.3.7 Flight Operations Design Criteria

Among the objectives for the development of mission scenarios and timelines was the development of criteria to be used in the design of OTV systems.

2.2.4.3.7.1 Physical Interfaces

a) The ground-based OTV shall be capable of being retrieved and stowed in the orbiter payload bay without protruding into the EVA envelope (forward 48 inches).

b) The ground-based OTV shall be capable of being stowed using the RMS. EVA shall be used as a backup for disassembly and stowage operations - EVA criteria are as specified in references 1 through 3.

c) The OTV shall have grapple fixtures of a type compatible with the Orbiter RMS and PIDA, OMV and space crane. These fixtures shall be sufficient in number to allow handling of the OTV by two of these devices simultaneously and should be located as close as possible to the CG of the OTV or subassembly.

d) The space-based OTV shall be designed to be delivered to the Space Station in pieces in the Orbiter payload bay. It shall comply with all relevant STS payload requirements as specified in references 1 and 2.

2.2.4.3.7.2 Functional Interfaces

a) During STS ascent, if an abort occurs prior to a nominal MECO the OTV may be jettisoned from the ACC to enhance the orbiter's ability to make a safe landing. For ground-based OTVs the destruct system shall be capable of destroying the OTV after intentional or inadvertent separation from the ACC.

b) A ground-based OTV shall be capable of performing RCS attitude and separation maneuvers as soon as permitted by STS safety criteria. These maneuvers will place the OTV in a position to perform a main engine burn approximately 1/2 hour later.

c) For ground-based OTVs, the primary mode of mating the OTV and payload shall be by RMS operations. Sufficient visual cues and mechanism visibility shall be provided to permit operations using only payload bay and RMS cameras and payload bay lights.

d) The OTV shall be capable of providing a state vector as determined from GPS or ground track data to the orbiter, OMV, or ground control center prior to a rendezvous and retrieval operation.

e) The OTV shall be capable of performing an automated self-test and checkout prior to launch, prior to release from the orbiter or OMV at initiation of solo operations and on return to the launch site (ground or Space Station). Results of the self-test shall be provided to the OTV control center in the telemetry stream. No crew involvement shall be required other than a command from the aft-flight deck or Space Station control console to initiate the self-test function.

f) The OTV guidance, navigation, and attitude control system shall be compatible with attitude rates and accelerations induced by the orbiter RMS, MMU, OMV, and Space Station manipulator during deployment and retrieval operations. The OTV shall be capable of recovering from residual rates resulting from separation mechanisms. The OTV RCS system shall remain inactive for a period of time after separation to allow the orbiter or OMV to achieve a safe separation distance.

g) The OTV shall be capable of autonomously determining its state vector and attitude without support from data processing located on the ground. It shall be capable of using these data to determine burn targeting parameters for target conditions specified on a mission by mission basis. The OTV shall have the capability to receive updated target inputs by uplink from the ground control center.

h) The OTV shall be capable of providing any earth relative or inertial attitude to a payload at the time of payload separation. It shall be capable of performing a collision/contamination avoidance maneuver after payload separation and prior to deorbit to LEO.

i) OTV subsystem activity times including only that portion of the mission requiring a self powered active OTV, are provided in Table 2.2.4-4.

C-2

TABLE 2.2.4-4
OTV Subsystem Active Time (Hours)

GROUND-BASED				MISSION	SPACE-BASED			
STORABLE*		CRYO			STORABLE		CRYO	
STG 1	STG 2	STAGE 1	STAGE 2		STG 1	STG 2	STG 1	STG 2
19.7	---	68.2	---	GEO DELIVERY	20.0	---	43.1	---
---	---	---	---	LOW G GEO DEL	37.4	---	62.2	---
105.2	---	129.6	---	PLANETARY	104.9	---	105.0	---
96.0	---	123.6	---	HIGH INCLINATION	222.7	---	222.7	---
---	---	140.1	---	GEO UNMANNED SERV	19.3	263.0	263.0	---
---	---	---	---	GEO MANNED SERV	19.3	531.0	531.0	---
---	---	---	---	LUNAR	14.5	554.9	14.5	544.9

*IN-BAY CONFIGURATION, FOR ACC ADD:

GEO DEL 35.3

PLANETARY 22.1

HIGH INC 22.1

2.2.4.3.7.3 Structures

a) In order to accommodate grapple by the orbiter RMS with nearly a full load of propellants, the grapple fixture and RCS jets for a ground-based OTV shall be arranged so as to preclude plume impingement on the orbiter and yet provide a very stable attitude during proximity operations.

2.2.4.3.7.4 Mechanical Elements

a) Components or subassemblies jettisoned by the OTV in transfer orbits or final orbits are required to be placed in specific orbits outside the GEO corridor or in orbits which will cause reentry into the earth's atmosphere within three days. Elements jettisoned in GEO transfer orbit require 140 ft/sec delta-velocity at apogee in the opposite direction to the velocity vector. Elements jettisoned in GEO orbit require a total of 406 ft/sec delta-velocity in the direction of the velocity vector (of which 205 ft/sec must be added after a coast of approximately 12 hours).

2.2.4.3.7.5 Safety

a) The OTV shall be capable of being put in a safe condition following initial boost to rendezvous orbit and following reboost to rendezvous orbit after the aeropass. For ground-based OTVs, the safe condition shall be as defined in NHB 1700.7A as pertaining to rendezvous with the orbiter. For space-based OTVs, a similar safe condition is assumed for OTV return to the Space Station after rendezvous with the OMV.

2.2.4.3.7.6 Electromagnetic Compatibility

a) The ground-based OTV shall be compatible with orbiter electromagnetic environments as defined in ICD2-19001 so as to allow normal orbiter communications (S-band and Ku-band) and the use of the Ku-band system in the rendezvous radar mode.

2.2.4.3.7.7 Thermal

a) The ground-based OTV shall be capable of withstanding solar irradiation in the proximity of the orbiter during rendezvous and payload mating operations. This shall include consideration of solar ray focusing from the payload bay doors.

b) The space-based OTV shall be compatible with a constant attitude while docked with a GEO platform (i.e., thermal roll or specific orientations may not be permissible).

2.2.5 <u>Operations and Support Requirements</u>

Operations support includes those functions performed in the OTV control center, in conjunction with onorbit resources and other operations centers, which aid in the accomplishment of the OTV mission. Many of these functions are common to ground and space-based missions although some will of necessity be modified to suit the respective operating bases. Control center activities include telemetry monitoring, data preprocessing, system performance evaluation, and command generation, and uplink..

2.2.5.1 Ground-Based Operations Concept

Because of the design approach adopted in the area of avionics which includes the use of intelligent systems and extensive fault tolerance, most vehicle control functions can be accomplished autonomously by the OTV. During launch preparation and final countdown, the OTV payload operations control center (POCC) monitors OTV final checkout self test and telemetry data and communicates launch readiness status to the STS launch control center (LCC). All OTV functions during the ascent phase are pre-programmed in the flight software. The POCC will continue to monitor telemetry and report status of onboard systems during this operations phase.

When the OTV reaches the 140 nmi STS rendezvous orbit, the POCC receives the state vector from the OTV and provides it to the STS mission control center (MCC) for final rendezvous targeting. As the STS performs the final approach for grapple the OTV POCC monitors the safety inhibits. The orbiter will have the capability to send commands to the OTV through the payload interrogator (PI) to inhibit RCS, pyro and main engine functions should telemetry indicate improper status. The POCC will continue to monitor the vehicle telemetry and provides a back-up capability to issue commands through the STDN (TDRS). The POCC continues to monitor activities and provide back-up commanding capability throughout proximity and payload mating operations including payload OTV interface checkout and deployment by the RMS.

After STS safe separation distance is achieved, the OTV begins the guidance system determined sequence of maneuvers and burns to deliver the payload to the mission orbit. The POCC monitors these maneuvers and burns. The only action required by the flight control team would be in the event of an OTV anomaly requiring analysis and corrective action. After deployment of the payload, the OTV coasts near the mission orbit until the proper orbital geometry for return to LEO.

Shortly before the deorbit burn, the POCC obtains updated atmospheric data and runs a computer simulation to determine updated aeropass target parameters. The POCC then uplinks these parameters and the current orbiter state vector to the OTV. The uplinked data will be used to target the deorbit burn to assure a successful aeropass and proper orbit phasing with the orbiter following the aerobraking and recircularization maneuvers. The POCC monitors the deorbit burn and transfer orbit coast to low earth orbit. After insertion into the 140 nmi STS rendezvous orbit, the POCC extracts a state vector from OTV telemetry and transmits the data to the STS MCC for rendezvous targeting. As before, the OTV POCC monitors the safety inhibits and related system parameters during the STS final rendezvous maneuvering and grapple. As the OTV is disassembled (cryogenic configuration) and stowed in the bay, the POCC monitors the activities and can provide back-up commanding capability if necessary for disassembly and stowing operations. After the deactivated OTV is stowed in the payload bay, the POCC activities are completed.

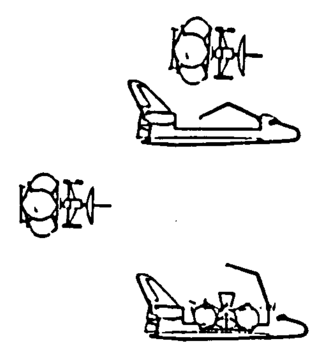
Figure 2.2.5-1 shows the transition of flight control responsibility as the mission progresses. The involvement of multiple control centers and onorbit resources results in multiple operational interfaces with the OTV POCC. These interfaces represented as communications and data interfaces, are depicted in Figures 2.2.5-2 through 2.2.5-4 for the prelaunch, ascent, and onorbit mission phases. The POCC is linked directly with the STS LCC and MCC, with Goddard Space Flight Center (GSFC) which schedules and controls STDN mission support with the payload operations control center (POCC), and for DoD missions with the STC/CSOC. The POCC also has access indirectly to the other centers supporting the mission including the TDRS ground station, the NASA Jet Propulsion Laboratory (JPL) which controls the Deep Space Network (DSN), and NASA and DoD tracking stations.

2.2.5.2 Space-Based Operations Concept

The operations concept for the space-based OTV uses an approach similar to the ground-based OTV. During refurbishment and preparation for the next mission, the OTV POCC monitors the activities and prepares the flight computer data load for uplink to the Space Station. Following final checkout and deployment from the station, the POCC monitors telemetry and provides a backup capability to safe the OTV should an anomaly occur in station zone 1 or 2. Shortly after arrival in zone 3, the OTV autonomously performs a sequence of operations to update its state vector and attitude using the GPS and star tracker. The onboard guidance system uses the updated information to target the main engine burns for the transfer and final mission orbits. The POCC continues to monitor telemetry and provide standby anomaly analysis for these OTV mission phases.

As in the case of the ground-based mission, the OTV requires updated targeting information for its deorbit burn. Atmospheric data and the current Space Station state vector are provided to the OTV by the OTV POCC which then monitors the deorbit burn and coast to low earth orbit. After insertion into the 270 nmi Space Station orbit in zone 4, the POCC relays the OTV state vector to the OMV control center in preparation for rendezvous. The OTV POCC continues to monitor and provides commanding capability during OMV rendezvous and return to the station where servicing activities begin anew.

	LOCATION			
PHASE	STS LCC	STS MCC	OTV POCC	P/L POCC
LAUCH PREP	P	M	M	M
ASCENT	-	P	M	M
STS PROXIMITY OPS	-	P/D	S/D	M/S
OTV MISSION	-	S/D	P/D	M
STS RECOVERY	-	P/D	S/D	-
LANDING	-	P	M	-



P - PRIMARY RESPONSIBILITY
S - SUPPORT ACTIVITY
D - DATA TRANSMITTAL
M - MONITOR ACTIVITY

Figure 2.2.5-1 Flight Control Responsibility - Ground-Based Missions

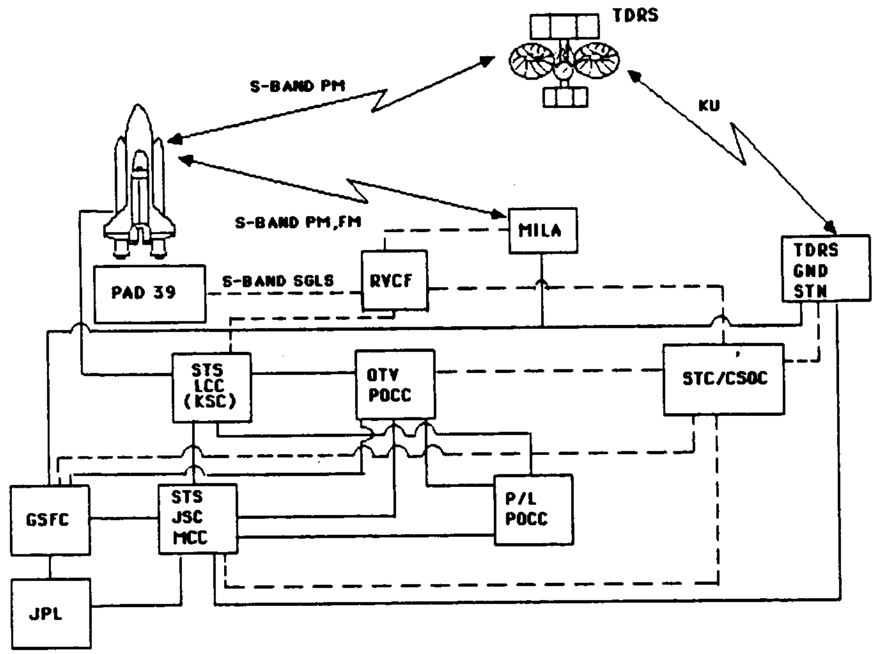


Figure 2.2.5-2 Prelaunch Communications/Data Flow

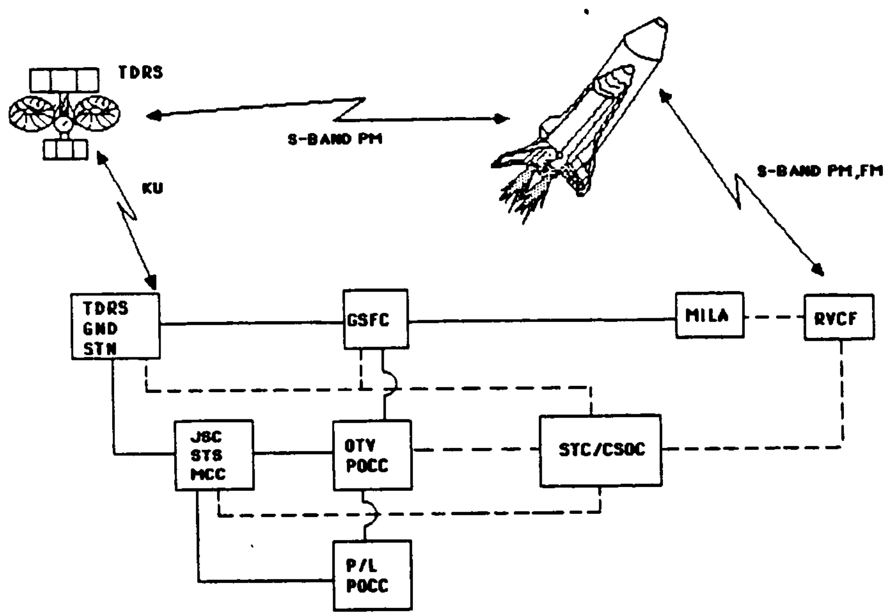


Figure 2.2.5-3 Ascent Communications/Data Flow

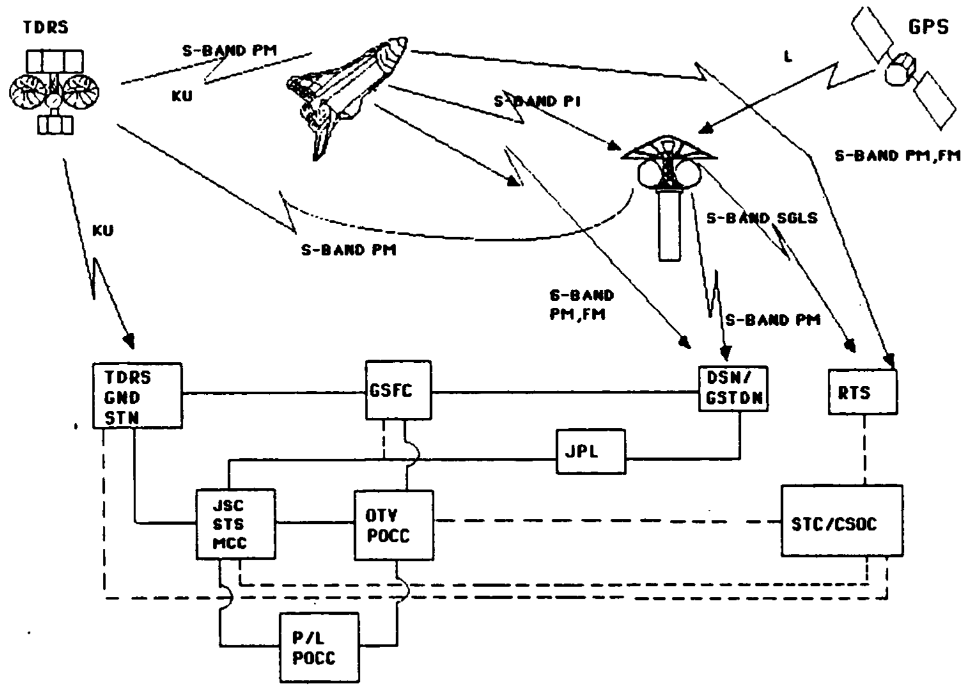


Figure 2.2.5-4 Onorbit Communications/Data Flow

The transitions in flight control responsibilities for the space-based scenario are shown in Figure 2.2.5-5. The control center interfaces and communications paths are shown in Figure 2.2.5-6 and 7. Control centers involved in OTV operations are the same as for ground-based missions with the exception that the STS MCC is replaced by the Space Station Support Center (SSSC) and the OMV control center.

2.2.5.3 OTV Control Center Requirements

The requirements on an OTV payload operations control center are in most respects similar to requirements on control centers for today's expendable orbit transfer stages. These requirements consist of communications, commanding, telemetry, trajectory generation, training, simulation support testing and postflight analysis.

2.2.5.3.1 Communications Interface Requirements

The OTV POCC shall provide voice, teletype, facsimile and data communications with the POCCs, GSFC, and STS MCC or SSSC and OMVs. These communications interfaces shall be capable of secure operations for DoD missions. The POCC shall be capable of supporting multiple (up to four) payload operations on a single OTV mission.

PHASE	LOCATION OTV POCC	OMV POCC	SSSC	SS	P/L POCC
LAUNCH PREP	S/D		S	P	M/S
STATION DEPARTURE					
ZONE 1	M	S	M	P	M
ZONE 2	M	P	M	M	M
ZONE 3	M	P	M		M
OTV MISSION	P/D		S/D		M
OTV RECOVERY					
ZONE 4	S/D	P/D	M/D	M	-
ZONE 2	M	P	M	M	-
ZONE 1	M	S	M	P	-

P - PRIMARY RESONSIBILITY
S - SUPPORT ACTIVITY
D - DATA TRANSMITTAL
M - MONITOR ACTIVITY

Figure 2.2.5-5 Flight Control Responsibility - Space-Based Missions

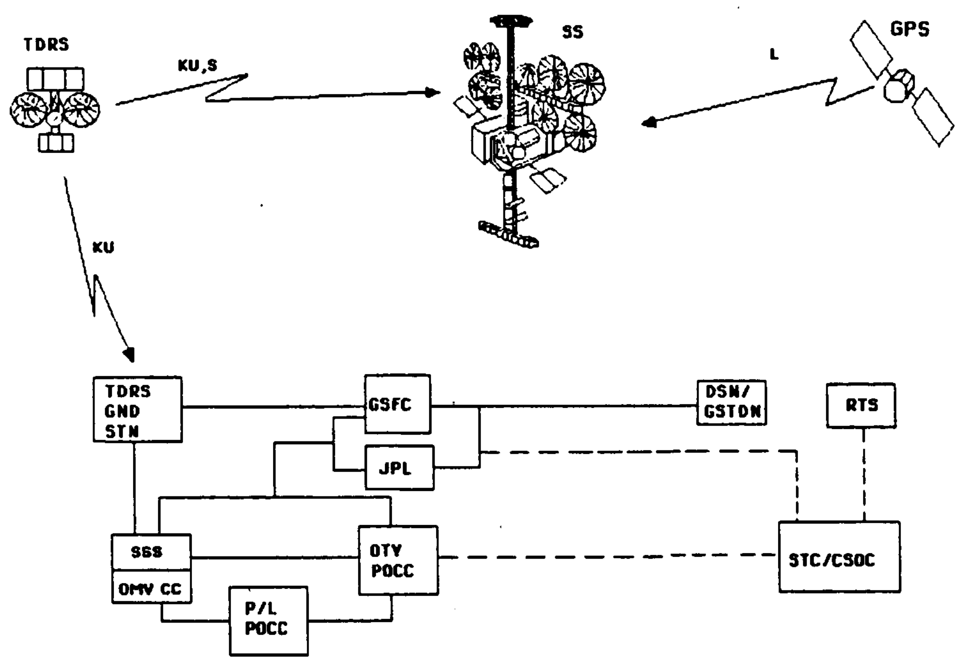


Figure 2.2.5-6 At Space Station - Communications/Data Flow

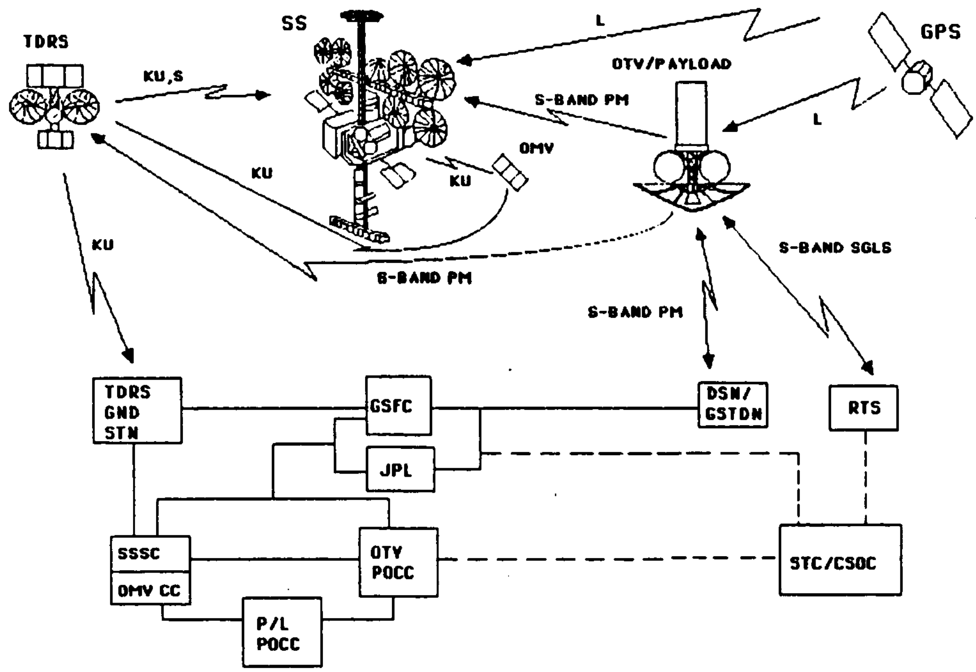


Figure 2.2.5-7 Deployed Communications/Data Flow

2.2.5.3.2 Commanding Requirements

The OTV POCC shall be capable of generating and formatting commands in the NASCOM format for uplink to the OTV through the STDN system. Commands may be routed through the STS or Space Station command interfaces or directly to the OTV via TDRS, GSTDN or DSN systems. The POCC shall also be capable of formatting commands in the SGLS format for transmittal through the AFSCF RTSs for DoD missions.

2.2.5.3.3 Telemetry Requirements

The OTV POCC shall be capable of receiving, deformatting, deinterleaving, processing, and recording telemetry data received through the STS and Space Station telemetry links and directly from the STDN system. The POCC shall also be capable of performing the same operations for telemetry received through the AFSCF RTSs for DoD missions.

2.2.5.3.4 Trajectory Processing Requirements

The OTV POCC shall be capable of receiving ephemeris and state vector information from the STDN and AFSCF as well as from the OTV as determined from the GPS system. The POCC shall be capable of propagating the trajectory based on the data received and providing the data to other operations centers. The propagation capability shall include the software necessary to utilize updated atmospheric information and to generate revised aeropass trajectory commands for uplinking to the OTV.

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2.2.5.3.5 Personnel Training

The OTV POCC shall establish an ongoing training program for flight control personnel to develop and maintain proficiency in operating the systems and software necessary for the conduct of OTV missions and for joint operations with other control centers. The POCC shall participate in training and simulation planning activities held in conjunction with these centers.

2.2.5.3.6 Simulations and Rehearsals

The OTV POCC shall provide an OTV simulation capability to support joint operations simulations with other operations centers.

2.2.5.3.7 Testing Requirements

The OTV POCC shall have the capability to verify compatibility of its software and systems with the interfaces at other operations centers prior to simulation or flight activities.

2.2.5.3.8 Postflight Analysis Requirements

The OTV POCC shall provide mission data to analysis groups after the completion of the mission. The data shall include recorded payload telemetry, OTV and payload command history including crew initiated commands, payload and OTV ephemeris data, recorded OTV telemetry and operational voice recordings.

2.2.5.4 Control Team Structure

The control team that operates the OTV POCC will consist of an OTV Flight Director and a number of flight controllers representing several technical disciplines. The OTV Flight Director will be the primary point of contact between the POCC and the other operations centers. Four members of the flight control team will report directly to the OTV Flight Director. Each will have responsibility for a distinct aspect of mission support activities.

The vehicle systems controller will analyze OTV power, thermal, propulsion, safety, GN&C and TT&C systems and provide health assessment and recommended corrective actions to the OTV Flight Director. He will be supported by several subsystem specialists.

The ground systems controller will be responsible for all POCC resources in support of the mission. He will manage communications interfaces, computer operations, and display console configuration as well as coordinate with the GSFC network controller for OTV mission support activities. He will also have support personnel available to operate and troubleshoot support systems during the mission activities.

The mission planning controller will be responsible for monitoring and maintaining current mission timeline and trajectory information and for performing real-time replanning in the event of flight anomalies. He will be supported by mission timeline and orbit analysis personnel.

The payload communicator (PAYCOM) will be responsible for monitoring all air-to-ground communications and for communicating with the flight or Space Station crew on OTV and payload related activities.

As previously discussed, the OTV design calls for extensive use of adaptive flight control systems and extensive fault tolerance in the avionics and related systems. The extent to which this is ultimately incorporated in the OTV and into the POCC software systems will influence the number of additional support personnel reporting to the vehicle systems, ground systems and mission planning flight controllers. A reasonable number of support personnel is probably in the range of 12 to 15 people as operations mature and confidence develops in the ability of the expert systems to monitor operations and reliably identify and rectify problems. Figures 2.2.5-8 and 2.2.5-9 show the functional organization of the POCC and the major interfaces with other operations centers for ground and space-based missions, respectively.

2.2.5.5 Manned Mission Considerations

The manned GEO and lunar missions impose subsystem reliability and redundancy requirements on the OTV over and above what is necessary for unmanned delivery missions. The history of the manned spaceflight program indicates that there will very likely be a large flight control team assembled for manned OTV missions because of the more complex man-rated systems and the criticality of failures with regard to the safe return of the flight crew. The approach taken with respect to the OTV has been to reduce the size of the flight control team and rely on OTV avionics and related systems fault tolerance to reduce operating costs and maintain acceptable reliability. For manned missions the additional flight control functions will be directed at monitoring, troubleshooting, and advising on activities related to the manned capsule and other man-related mission aspects. The OTV POCC will interface with the manned mission control center in much the same fashion as it would with a payload operations control center for an unmanned mission. The only difference might be the addition of a few flight control support personnel to specifically monitor and advise on the systems which interface directly with the manned capsule.

2.2.6 OTV Fleet Implications

The OTV Mission Model, reference 4 was analyzed from an operations perspective with several objectives in mind. The missions were initially classified by type, and each classification was represented by a design reference mission for timeline and profile development. In parallel with the profile development, a basic strategy for flying each mission with a specific OTV configuration (i.e., perigee stage, single stage or 2-stage) was arrived at in conjunction with the design activities. Manifests for OTV flights were developed on a yearly basis so that processing times from section 2.1 and from Space Station accommodations, and flight times could be combined to determine total yearly operations times. The fleet size needed to satisfy the mission model was derived and an operations concept for the fleet was developed.

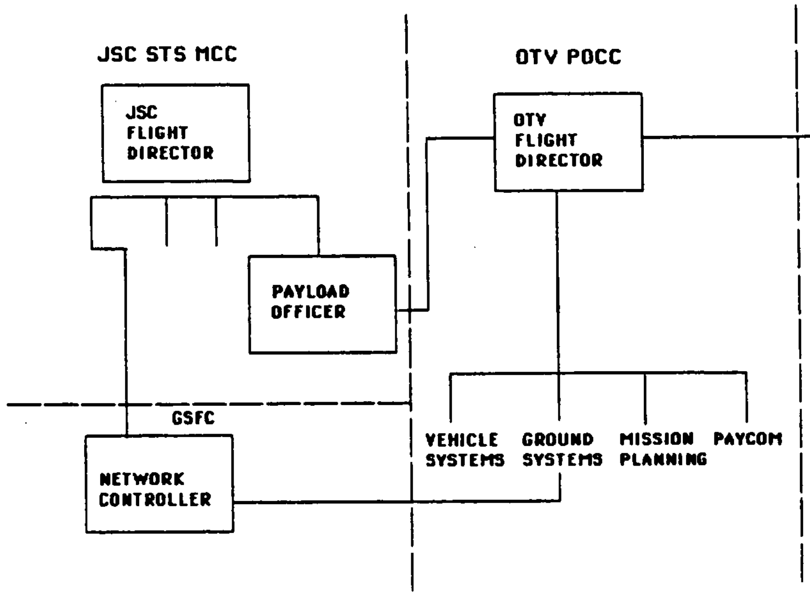

Figure 2.2.5-8 Mission Control Center Interfaces - Ground-Based

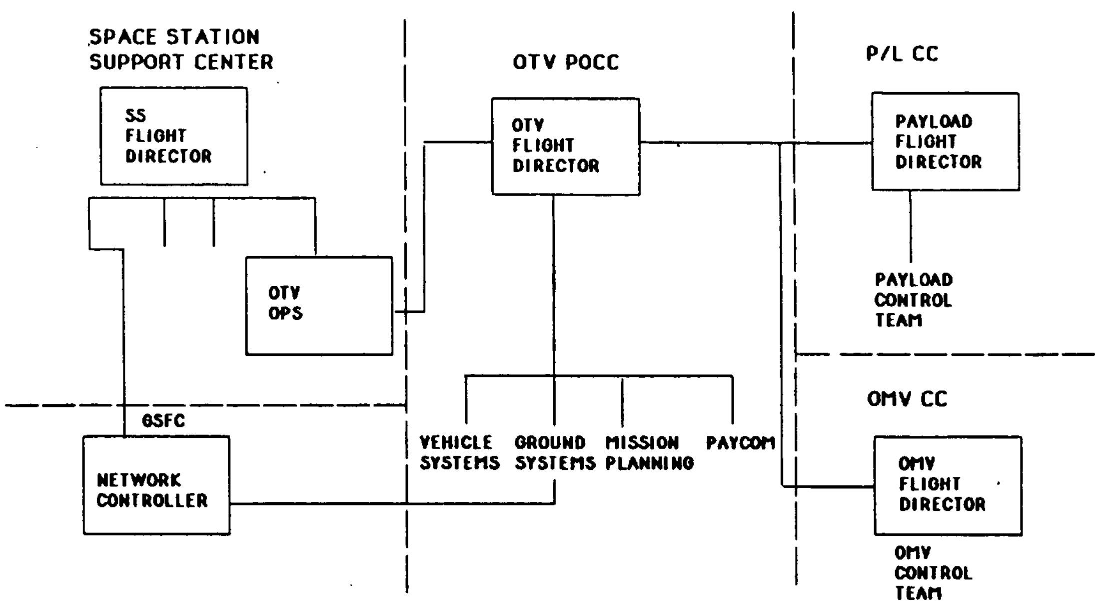

Figure 2.2.5-9 Mission Control Center Interfaces - Space-Based

2.2.6.1 Mission Classifications

The missions of the Revision 7 Mission Model were categorized into the following groups for operations and fleet size analyses:

1) Geosynchronous equatorial orbit delivery (GEO delivery)
2) GEO delivery with a low g acceleration constraint (low g GEO delivery)
3) Unmanned, satellite servicing (unmanned service)
4) Manned, satellite servicing (manned, servicing)
5) Manned, GEO station logistics support (manned, logistics)
6) Planetary
7) Lunar, delivery of a small payload (Lunar delivery, small)
8) Lunar, delivery of a large payload (Lunar delivery, large)
9) Lunar, manned sortie (Lunar sortie)
10) High inclination 12-hour period earth orbit (high inclination)

Designated design reference missions and corresponding Rev 7 and 8 mission payload numbers are shown in the accompanying Table 2.2.6-1. Launch processing times for each stage as derived from relevant analyses were 660 hours for ground-based vehicles and 48.7 hours for space-based vehicles. Flight operations times were derived from Appendix B.

2.2.6.2 Cryogenic OTV Mission Strategy

Mission strategies for both storable and cryogenic propellant configurations were developed based on the Revision 7 Mission Model. The strategies were revisited with regard to the Revision 8 model only for the cryogenic configurations. The approach, primarily based on individual stage performance, is to utilize a single 45K propellant capacity vehicle for all ground-based missions. All space-based missions utilize a single 55K propellant capacity vehicle except the Lunar delivery (large) and Lunar sortie missions which require two 81K propellant capacity stages.

2.2.6.3 Operations Times

The low and nominal model yearly manifests were categorized and stage use derived from the operational strategies. The number of times that the individual stages are used on a yearly basis is shown in Table 2.2.6-2. Launch processing and flight times were then combined to derive total operations times for each stage as shown in Table 2.2.6-3.

2.2.6.4 Fleet Operations Concept

With the total operations times determined, the minimum number of OTVs necessary to accomplish the mission model can be derived. The analysis was based on the total cmount of time during a year that is available for operations. Assumming around the clock activities at the launch site or Space Station and continuous flight operations, 8760 hours are available in a year. Multiples of this number become thresholds above which additional launch processing and/or additional OTVs must be added to accomplish the required level of flight support activities.

TABLE 2.2.6-1
OPERATIONS/FLEET MISSION CATEGORIES

MISSION CATEGORY	DESIGN REFERENCE MISSION	REVISION 7 PAYLOAD NUMBER	REVISION 8 PAYLOAD NUMBER
GEO Delivery	No	18040	18040
Low G GEO Del	Yes	13003	13700
Unmanned Service	Yes	18910	13002
Manned, Servicing	Yes	15006	15700
Manned, Logistics	No	15003	N/A
Planetary	Yes	17065	17065
Lunar Del. (Small)	No	17202	17202
Lunar Del. (Large)	No	17204	17204
Lunar Sortie	Yes	17203	17203
High Inclination	Yes	*	N/A

* Derived from DoD mission parameters

Table 2.2.6-2

CRYOGENIC STAGES
STAGE USE BY YEAR

VEHICLE CONFIGURATION	(NOMINAL MODEL, REV 8) GB 45K SINGLE STAGE	SB 55K SINGLE STAGE	SB 81K SINGLE/ FIRST STAGE	SB 81K SECOND STAGE	(LOW MODEL, REV 8) GB 45K SINGLE STAGE	SB 55K SINGLE STAGE	SB 81K SINGLE/ FIRST STAGE	SB 81K SECOND STAGE
YEARS								
1994	9	0	0	0	7	0	0	0
1995	9	0	0	0	7	0	0	0
1996	12	0	0	0	7	0	0	0
1997	0	12	0	0	7	0	0	0
1998	0	14	0	0	7	0	0	0
1999	0	15	0	0	0	7	0	0
2000	0	14	0	0	0	8	0	0
2001	0	15	0	0	0	9	0	0
2002	0	16	0	0	0	7	0	0
2003	0	16	0	0	0	9	0	0
2004	0	15	0	0	0	9	0	0
2005	0	14	0	0	0	8	0	0
2006	0	0	18	1	0	10	0	0
2007	0	0	17	1	0	9	0	0
2008	0	0	19	3	0	11	0	0
2009	0	0	21	3	0	12	0	0
2010	0	0	21	4	0	11	0	0

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Table 2.2.6-3
CRYOGENIC STAGES
STAGE OPS TIME BY YEAR

VEHICLE CONFIGURATION	(NOMINAL MODEL, REV 8) GB 45K SINGLE STAGE	SB 55K SINGLE STAGE	SB 81K SINGLE/ FIRST STAGE	SB 81K SECOND STAGE	(LOW MODEL, REV 8) GB 45K SINGLE STAGE	SB 55K SINGLE STAGE	SB 81K SINGLE/ FIRST STAGE	SB 81K SECOND STAGE
YEARS								
1994	7452	0	0	0	5796	0	0	0
1995	7452	0	0	0	5796	0	0	0
1996	[illegible]	0	0	0	5796	0	0	0
1997	0	1225.4	0	0	5796	0	0	0
1998	0	1366.2	0	0	5796	0	0	0
1999	0	1500.0	0	0	0	703.1	0	0
2000	0	1304.3	0	0	0	732.0	0	0
2001	0	1691.9	0	0	0	1044.5	0	0
2002	0	1942.6	0	0	0	641.2	0	0
2003	0	2669.4	0	0	0	886.3	0	0
2004	0	2200.0	0	0	0	843.5	0	0
2005	0	2128.1	0	0	0	732.8	0	0
2006	0	0	2590.5	603.6	0	977.9	0	0
2007	0	0	2374.9	603.6	0	1139.3	0	0
2008	0	0	2605	1378.8	0	1438.6	0	0
2009	0	0	2665.9	1594.8	0	1887.9	0	0
2010	0	0	2656.3	2414.4	0	1457.7	0	0

In scanning Table 2.2.6-3 for both nominal and low models only in 1996 for the nominal model does the total operations time exceed the first 8760 hour threshold. This would indicate a need for a second OTV to meet the flight rate in this final year of ground-based operations. The nominal model has 12 flights scheduled where as the maximum ground-based flight rate for a single OTV is 10 per year (with 480 hours of slack time for unscheduled maintenance or other contingencies). A single set of processing facilities is adequate to support up to 13 ground-based flight per year with 180 hours of slack time. With two flight vehicles, launch processing for one OTV would overlap with processing and flight of the second vehicle.

An alternative to a multiple vehicle fleet during the ground-based operations phase is to readjust the flight manifest by scheduling a small number of missions earlier or later to stay within the operations time limitation for a single vehicle . By moving one flight from 1996 to late 1995 and another to early 1997, the need for a second ground-based vehicle could be eliminated.

For space-based operations a single OTV suffices up to the time when the second vehicle is required for the large lunar missions (2006 in nominal model).

Scheduling of flight dates for individual payloads can be accomplished in much the same fashion as the STS is manifested today. OTV flight dates will be established based on mission durations and processing time requirements. Payload launch date requirements can then be matched to the available flight dates which are on approximately 35 day centers.

2.2.7 OTV, STS, and Space Station Orbit Considerations

The STS, OTV and OMV are capable of operating in a range of orbital attitudes. The specific impulse, mass fraction and system constraints for each vehicle were considered in the selection of STS park orbit altitude and the orbital altitude used for departure from and arrival at the Space Station.

2.2.7.1 Ground-Based Missions

The STS can deliver payloads to low earth orbits ranging in altitude from 130 nmi to over 300 nmi and inclinations from 28.5 deg to 57 deg from the Eastern Launch Site (ELS). The STS lift capability as reproduced in Figure 2.2.7-1 from reference 5 shows that higher STS orbits result in decreased lift capability. Conversely, for a fixed STS payload gross weight, performance to GEO increases somewhat for higher park orbit altitudes. This relationship is shown in Figure 2.2.7-2. Other factors which constrain the selection of an optimum STS orbit include increased aerodynamic drag at lower altitude and resultant increased Orbiter propellant consumption for the STS mission. The orbiter is 10 nmi below and behind the OTV at the initiation of rendezvous maneuvers. The object is to determine the STS and OTV park orbits that result in the maximum payload capability to GEO.

Figure 2.2.7-3 shows the net effect, that payload capability to GEO is maximized by adopting the lowest OTV park orbit consistent with STS rendezvous and drag considerations. NASA has not defined a minimum altitude for nominal 7 day STS missions. However, the lowest altitude shown on the current manifest is 130 nmi. Informal conversations with JSC MPAD personnel substantiate that this is near the lower end of STS park orbit altitude for 7 day missions.

2.2.7.2 Space-Based Missions

OTV departure and return orbit determination for space-based missions is somewhat more complex and involves different performance trades and constraints than for ground-based missions. Several scenarios are possible for leaving and approaching the Space Station.

The baseline OTV scenario involves the use of the OMV which is capable of deploying and retrieving spacecraft at orbital altitudes several hundred miles above the Space Station orbit. A portion of the velocity requirement for space-based missions could be shifted from the OTV to the OMV thereby enhancing OTV payload capability or reducing OTV propellant required. Some additional cost for OMV operations would be incurred for use of the OMV in this manner rather than simply moving the OTV to a safe distance for main engine operation and retrieval from a similar safe standoff location. For OMV assisted departure and return there is a net savings of propellant as indicated by Figure 2.2.7-4 if the OTV departs from and returns to the Space Station orbit altitude.

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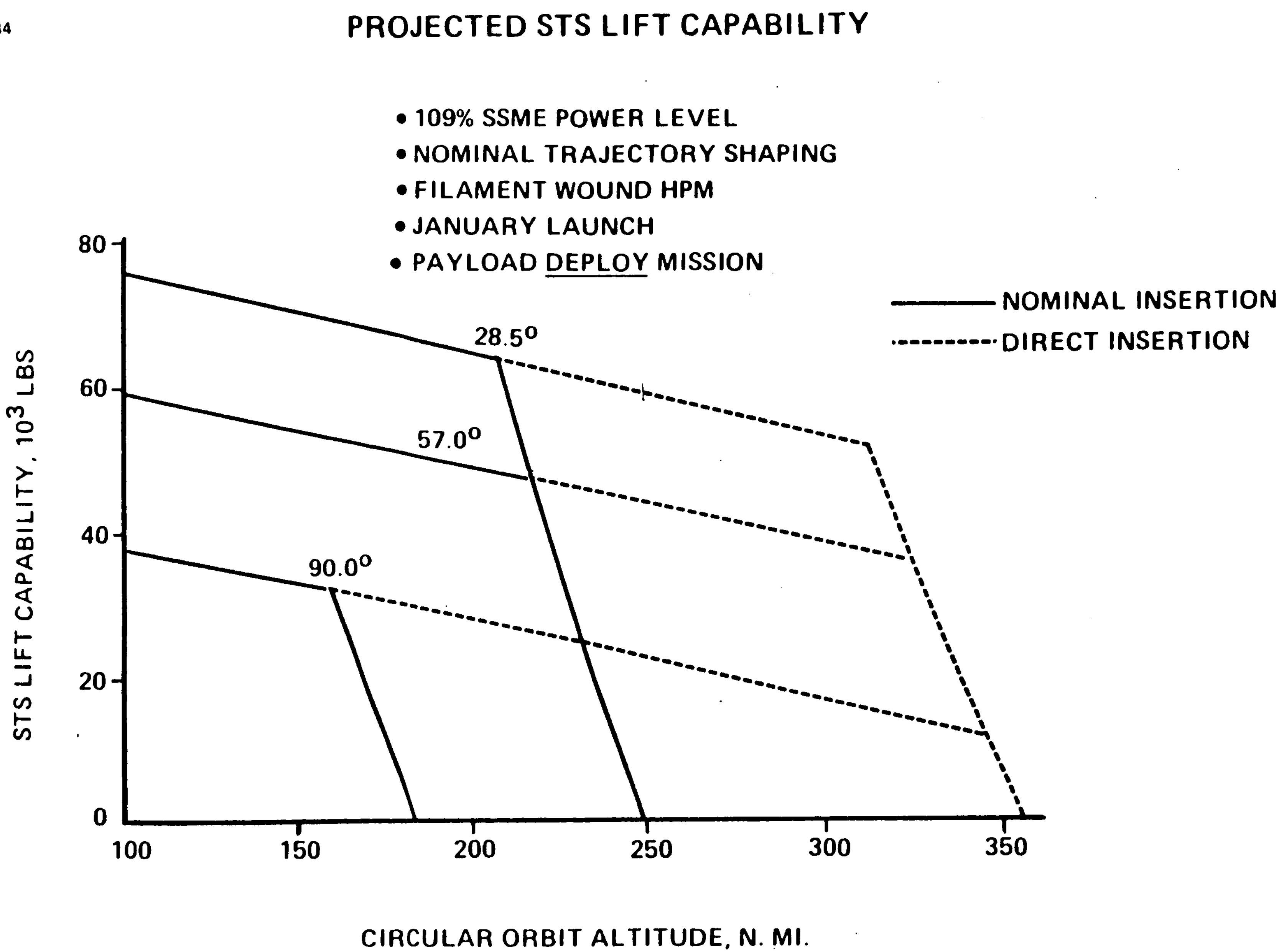

Figure 2.2.7-1 Projected STS Lift Capability

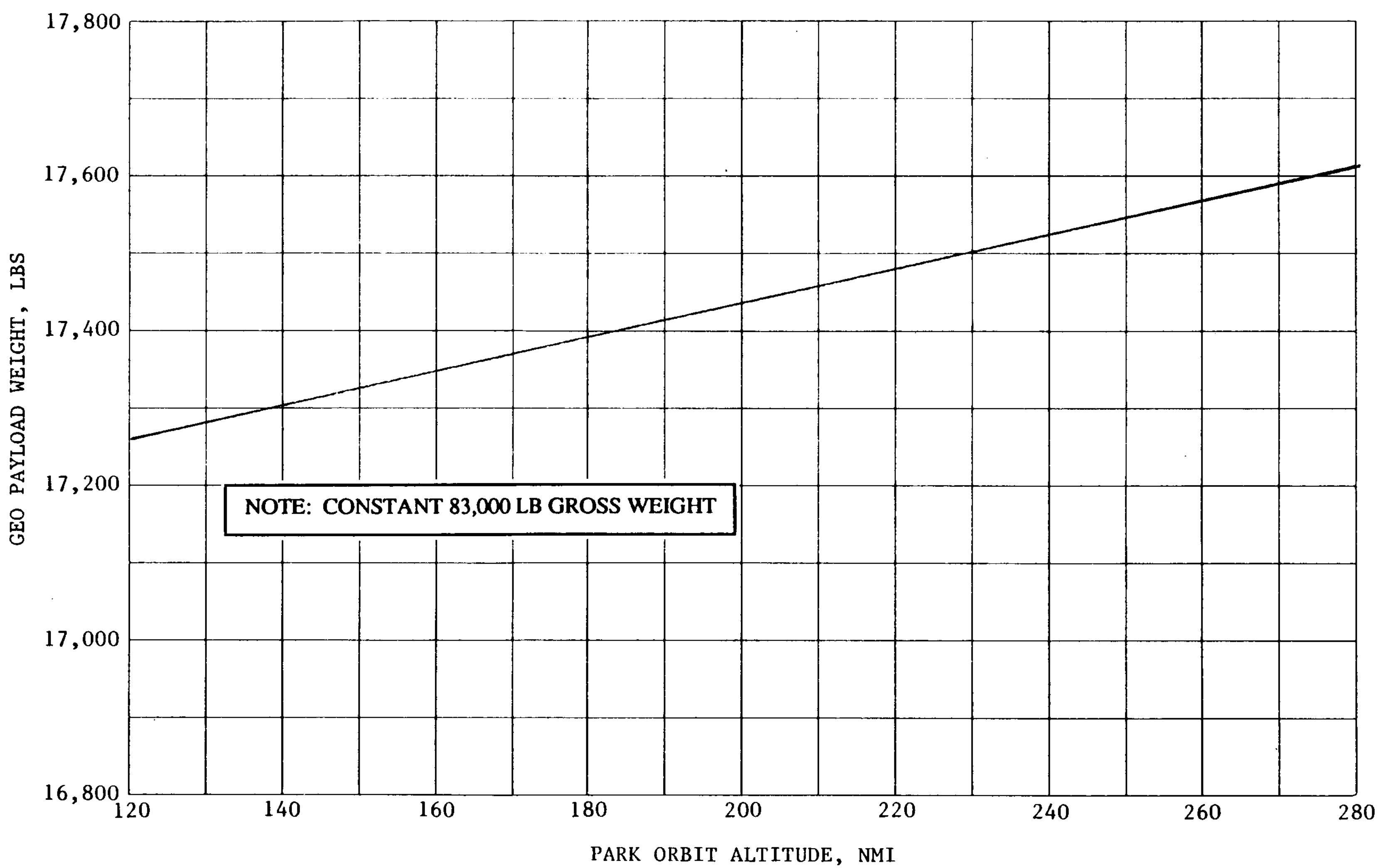

FIGURE 2.2.7-2 OTV PAYLOAD VS PARK ORBIT ALTITUDE

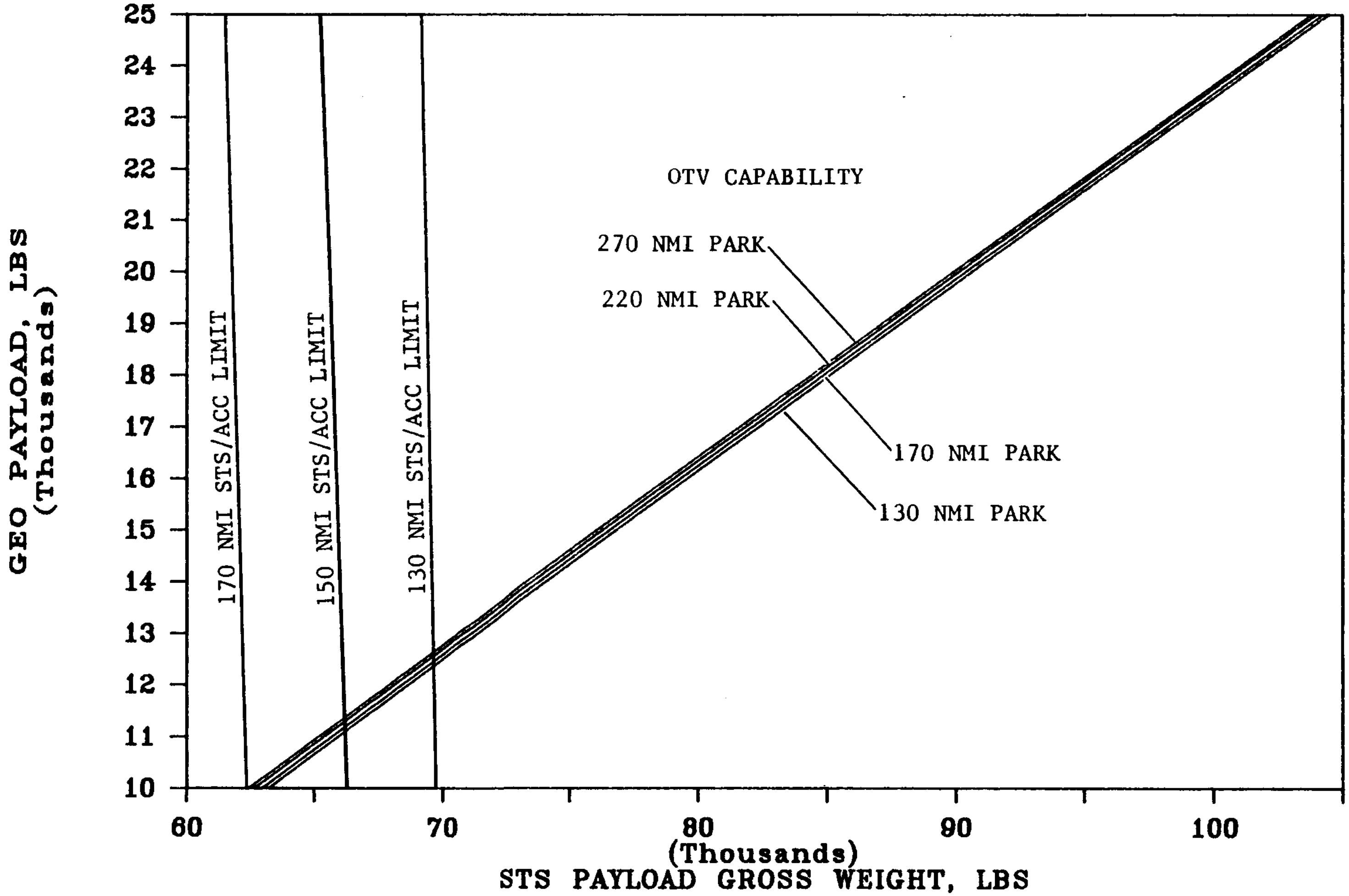

FIGURE 2.2.7-3 PARK ORBIT EFFECT ON NET PAYLOAD TO GEO

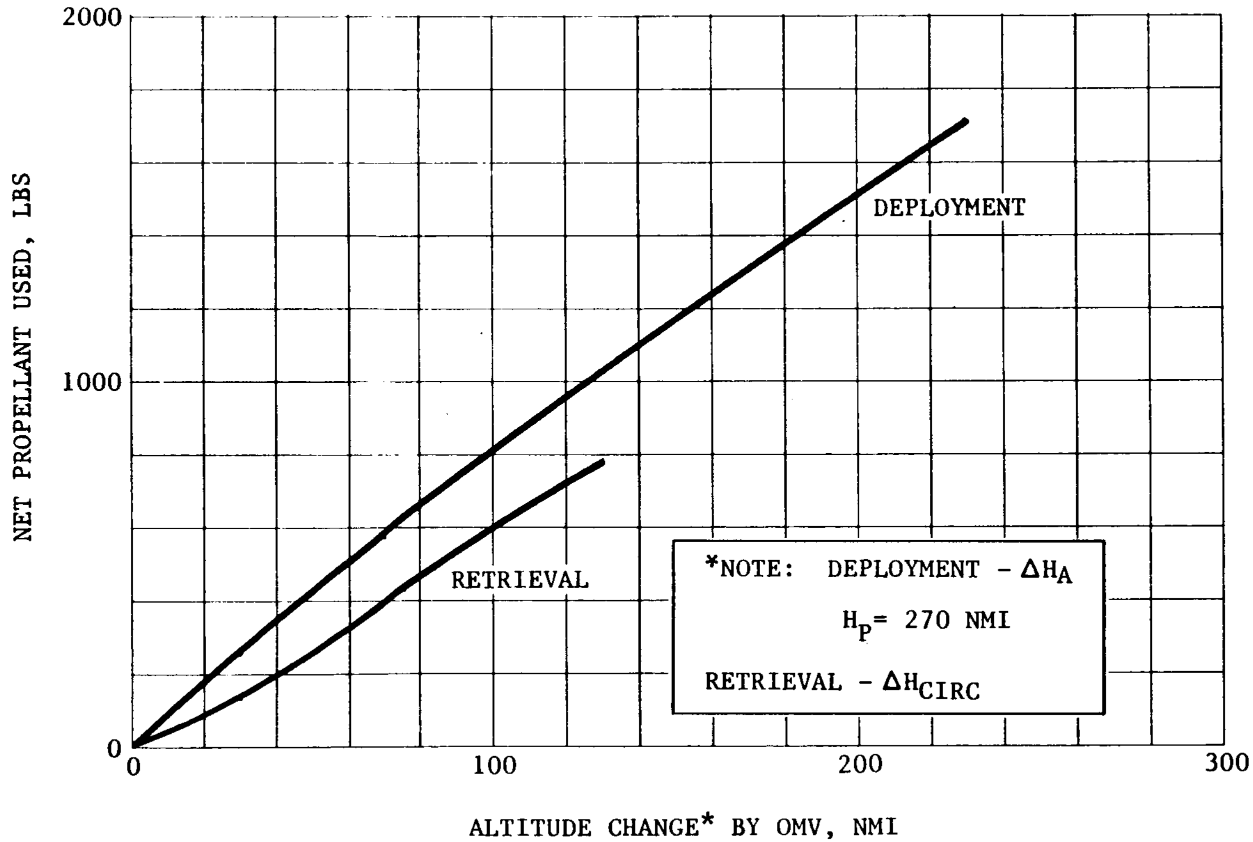

FIGURE 2.2.7-4, OMV, OTV NET PROPELLANT USAGE FOR DEPLOY/RETRIEVE

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2.2.8 Tether Launch

Another possible method of OTV deployment is via a tether deployment mechanism attached to the Space Station. It would be advantageous from an OTV energy standpoint to deploy the OTV many miles above the station. If this is accomplished by tether, momentum is transferred from the station to the OTV without the expenditure of OTV propellant. The OTV momentum gain comes at the expense of the station which must use reboost propellant or some other means to gain altitude prior to or after the deployment operation. One such alternate method is to use the tether mechanism to deboost the orbiter following visits to the Space Station for payload delivery or logistics support.

The OTV deployment technique is depicted in Figure 2.2.8-1. It begins with the attachment of the OTV and payload stack to a payload interface deployment module (PIDM) at the top of the Space Station keel structure. The tether is then reeled out to a length of as much as 81 nmi. This phase of the deployment would require from four to six hours. When the tether reaches full deployment length, the PIDM releases the OTV and payload which are instantaneously placed in a 342 x 801 nmi orbit. After the tether release, the OTV performs state vector and attitude updates in preparation for the transfer orbit burn at the next perigee passage.

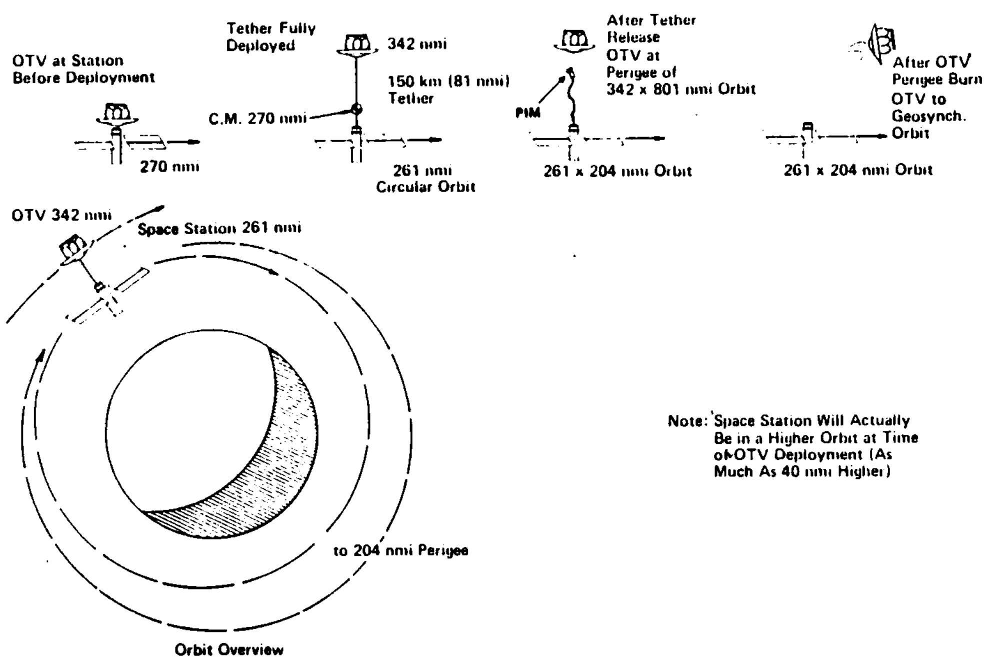

Figure 2.2.8-1 Deployment by Tether

At the same time that the OTV and payload are released, the Space Station orbit is lowered to 204 x 261 nmi based on a nominal 270 nmi orbit before initiation of tethered deployment. The most likely situation would have the station as much as 40 nmi higher than this as a result of having previously deorbited the STS using the tether system.

The increased altitude of the OTV reduces the velocity requirements on the OTV to reach GEO. The sum of the velocity savings for the perigee and apogee burns is shown in Figure 2.2.8-2 for tether lengths up to 80 nmi. The savings are translated into OTV propellant based on a 20K lb payload weight in Figure 2.2.8-3. Substantial propellant savings (as much as 4770 lbs) are available using this method of OTV and payload deployment.

A number of operational issues require further investigation before a recommendation to use tethered deployment can be made. The recoil dynamics of the tether following release should be investigated to determine if any hazardous situations could arise. A considerable amount of energy will be generated during the deployment as the result of the gravity gradient induced tether force. Satisfactory methods of dissipating the energy must be investigated for impacts to the station. The zero-g environment at the station will be disturbed during the 4-6 hour deployment period; reaching about 10^{-3}g at full tether length of 80 nmi. The acceptability of changes in station orbit of the magnitude described on a regular basis has not been assessed from a station, orbiting platform integrated operations perspective. Finally, the operational implications of mating the OTV to the tether at the top of the station keel have not been explored.

2.2.9 OTV Control Impact on Flight Operations

The mission model for the OTV dictates a design which is capable of performing a wide variety of missions, some of which will be manned. Current flight control practice frequently involves a high degree of interaction between the orbital transfer stage and ground support control centers. A flight control function analysis was performed and individual control functions allocated to OTV onboard systems or to ground-based or onorbit command capabilities. The mission scenarios of Section 2.2.4 and associated timelines were analyzed for flight control functional requirements. As shown in Table 2.2.9-1, a majority of the control functions were identified as OTV baseline capabilities or onorbit (STS or Space Station) and by safety considerations. There remain a subset of flight control functions which have historically been performed by the ground control center. It is probable that technology in the areas of computer computational speed and memory capability and in artificial intelligence would allow these functions to be moved from the ground control center to the OTV itself. These functions are primarily related to avionics system management and anomaly diagnosis and resolution. It would then be within reason to fly the majority of OTV missions (with exceptions being manned missions) with a ground support crew somewhat less than the 12 to 15 indicated in the operations concept (Section 2.2.5.4).

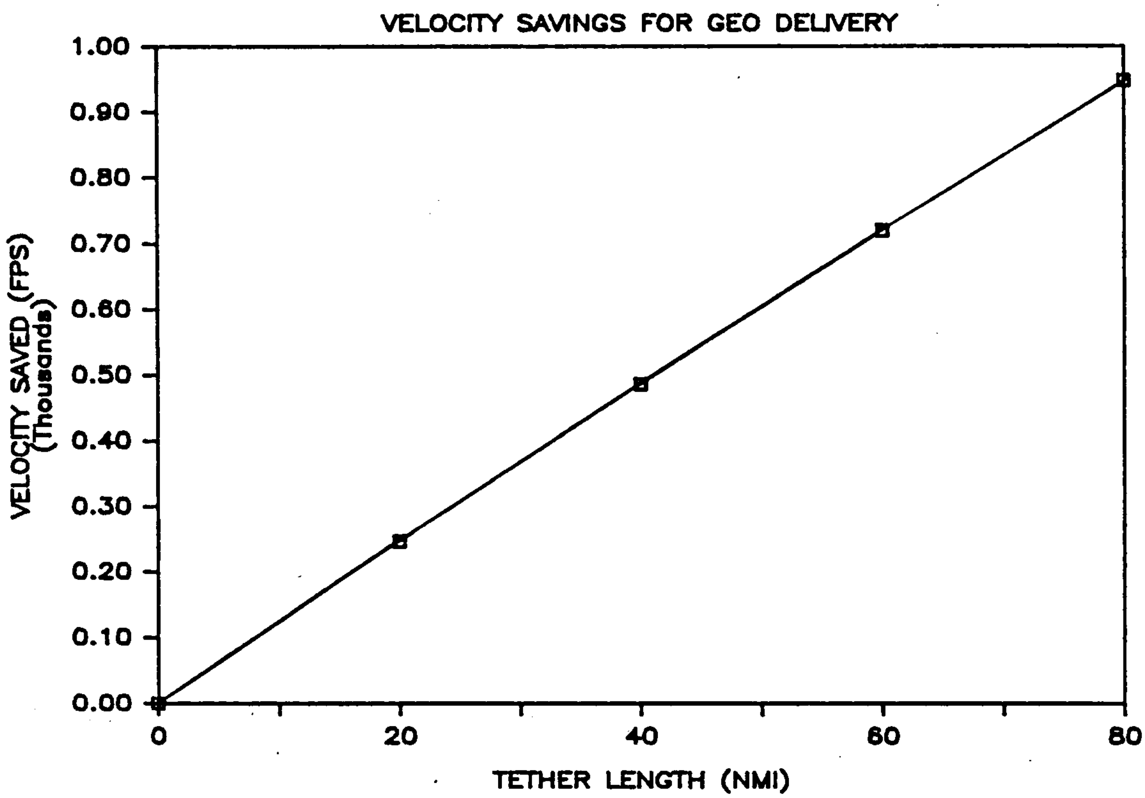

Figure 2.2.8-2 Tethered Deployment Velocity Saved

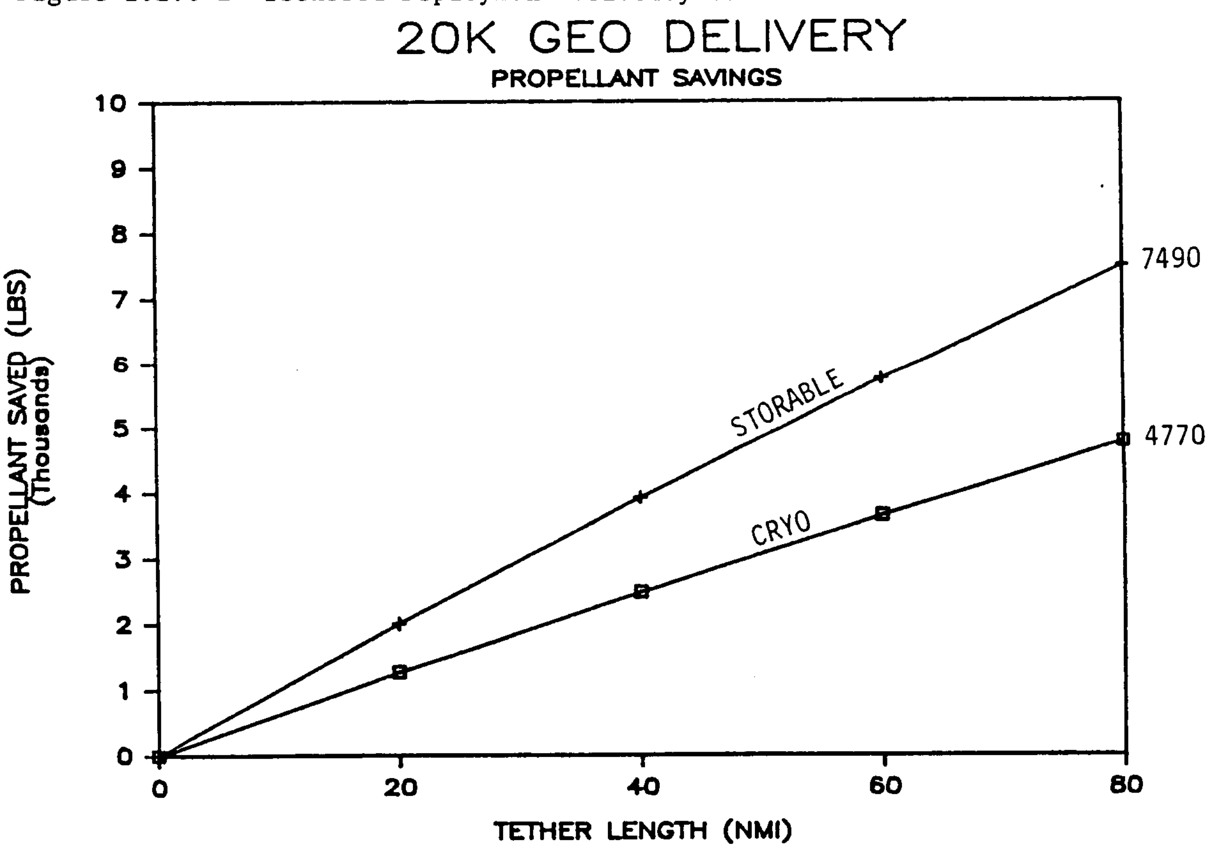

Figure 2.2.8-3 Tethered Deployment Propellant Saved

TABLE 2.2.9-1
FLIGHT CONTROL FUNCTION ALLOCATION

FUNCTION	BASELINE CAPABILITY	ENHANCED OTV CAPABILITY	GROUND CAPABILITY	ONORBIT CAPABILITY (STS OR SS)
I. OTV System Management/Status				
A. Aerobrake	✓			
1. Deploy/Jettison (Ground-based)				
2. Latch/Unlatch (Space-based)	✓(Disposal)			✓
B. Payload Retention Latch Activation (Engage/Release)	✓(Release)	o (Engage)	o (Engage)	✓(Engage)
C. Propellant Feed System Valves (Open/Closed)	✓(Safe/Dump)			✓(safe,fill/defuel)
D. Propellant Tank Disconnect & Strut Retract				✓
E. Brake Door Activation (Open/Closed)	✓			
F. Engine Nozzle Activation (Extend/Retract)	✓			
G. Avionics Configuration Operational/Standby/Off)		o	o	✓
H. Communication and Tracking System Management	✓			
I. Operating System and Flt S/W Configuration and Validation	✓	o	o	o
J. Health and Status Monitor and Vehicle Checkout	✓			
II. OTV Safety Inhibit				
A. RCS Activate/Inhibit	✓			✓override
B. Main Engine Enable/Inhibit	✓			✓override
C. Pyro Inhibit, Arm, Fire	✓			✓override
III. Main Engine Operation				
A. Engine Conditioning (Chilldown)	✓			
B. Ignition	✓			
C. Cut-off	✓			

✓ Required Capability
o Optional Capability

TABLE 2.2.9-1 (CONT.)

FUNCTION	BASELINE CAPABILITY	ENHANCED OTV CAPABILITY	GROUND CAPABILITY	ONORBIT CAPABILITY (STS OR SS)
IV Guidance and Navigation Initialization				
A. State Vector Update	✓			
B. Attitude Update (Star Scan)	✓			
C. Aeropass Target Update			✓	
V RCS Maneuvers				
A. Attitude Maneuvers (Star Scan, Burn, Entry Project Attitudes, etc.)	✓			
B. Midcourse Maneuvers (Velocity Vector Correction)	✓			
C. Propellant Dump Burn	✓			
D. Thermal Roll	✓			
VI Contingency				
A. Fault Isolation		o Technology	✓	
B. Corrective Action		o	✓	
C. Back-up Event Sequence and Targeting		o	✓	

✓ Required Capability
o Optional Capability

2.2.10 Summary and Conclusions

The following conclusions were derived from the analysis of flight operations:

1) The OTV design concepts developed in this study can be accommodated into STS and Space Station flight operations with a minimum impact to either system. This includes onorbit payload mating and retrieval operations.

2) Flight operations scenarios have been developed which accomplish the requirements of the design reference missions that are representative of the driver missions in the mission model.

3) It is highly desirable, though not mandatory, that the GPS and TDRS systems be upgraded to provide coverage at geosynchronous altitude to support extensive GEO operations of the OTV and other high earth systems.

4) The OTV is a large, high energy vehicle for transferring between LEO and HEO and making plane changes. Precision maneuvering for rendezvous and in-situ servicing should be accomplished by other available capabilities represented by the STS, OMV and potential GEO service station.

5) Tethered deployment of the OTV offers the potential of significant savings in propellant for OTV operations. However, a Space Station systems level evaluation is required before inclusion in the baseline OTV operations scenario can be recommended.

6) The OTV flight operations support concept follows current upper stage flight control practice while providing for expected advances in computational and operational capabilities of airborne systems. The wide range of missions and OTV flexibility will require numerous interfaces with other NASA and payload operations centers.

7) The utilization of an aft cargo carrier OTV allows considerable flexibility in manifesting STS payloads in both ground-based and space-based operations. The ACC can also be used to manifest secondary payloads and support propellant scavenging operations.

8) A single operational OTV, with adequate spares and logistics support, is capable of performing the Revision 8 Mission Model with minor rescheduling of flights in the 1996 time frame. Up to ten flights per year can be accommodated in a ground-based mode and the rapid turnaround possible for space-based operations allows more than a two-fold increase in flight rates without an increase in the number of flight vehicles.

9) The reduced number of OTV missions in the Revision 8 Mission Model not only permits accomplishment of all missions with a single flight ready OTV (with minor remanifesting), it also eliminates the need to provide the capability to support simultaneous OTV mission operations. This outcome greatly reduces required capabilities at the OTV operations control center.

10) The physical size of the OTV deployed aerobrake will impact the OMV maneuvering capability in proximity operations with the Space Station. Detailed analyses of the OMV maneuvering capability while attached to the OTV is needed for development of the final approach to the station.

2.2.11 References

a) Space Shuttle System Payload Accommodations, JSC 07700 Vol. XIV, thru change 47 dated 27 July 1984

b) ICD-2-19001 Shuttle Orbiter/Cargo Standard Interfaces, JSC 07700 Vol. XIV Attachment 1 thru change 47 dated 27 July 1984

c) Space Transportation System EVA Description and Design Criteria Rev A, JSC 10615, May 1983

d) OTV Mission Models, Revision 8, NASA-MSFC, March 31, 1985

e) "Projected STS Lift Capability for Advanced Programs Planning Purposes," D.R. Saxton, August 1984

f) Proceedings of the Rendezvous and Proximity Operations Workshop, NASA JSC, February 19-22, 1985

g) Space Station Operations, Vol. III, Proximity Operations, NASA JSC 19371, February 1985

h) Space Station Operations Plan, NASA JSC-19946, August 1984

i) Lunar Mission Ground Rules and Scenarios, NASA/JSC, 10 August 1984

j) Selected Tether Applications in Space, Phase II Study Interim Review, MMC, November 1984

k) Space Station Reference Configuration Description, NASA JSC-19989, August 1984

l) Selected Tether Applications in Space, Phase II Final Report, MMC, February 1985

APPENDIX A

OTV LAUNCH PROCESSING SCENARIOS

Appendix A contains the launch processing scenarios from which operations analyses and processing timelines for the various OTV configurations and basing modes were derived. Ground-based vehicles launched either in the ACC or payload bay are shown as well as ground and Space Station launch processing for space-based vehicles.

Figure A-1 depicts the scenario for processing a ground based DACC OTV through KSC facilities. This flow applies to either a storable propellant OTV or a cryogenic propellant OTV since both are integrated with the DACC in the Vehicle Assembly Building (VAB). Propellant loading occurs at the pad in conjunction with STS hypergolic/cryogenic operations. This flow will be new to the launch site since it adds another STS Payload Integration Facility requirement to KSC - the VAB. The others are the Orbiter Processing Facility (OPF) for horizontal integration and the RSS/PCR for vertical integration. For mission turnaround, the OTV will be removed from the orbiter in the OPF. From the OPF, the OTV will be transported to the designated OTV facility for turnaround refurbishment.

Ground based, storable, payload bay (PLB) OTV ground processing is shown in Figure A-2. This vehicle, launched in the Orbiter Payload Bay (PLB), follows the normal cargo flow used for STS vertical cargo integration, i.e., Vertical Processing Facility (VPF) to Canister to RSS/Payload Change-out Room (PCR) to orbiter PLB. The OTV will be built up and tested off-line in a dedicated facility. Propellant loading will also be accomplished off-line in either the dedicated facility or in one of the existing hazardous processing facilities (HPFs). Once these activities are accomplished, the OTV will be transferred to the VPF for cargo integration activities. Following a mission, OTV removal from the orbiter will be performed in the Orbiter Processing Facility (OPF). From the OPF, the returned cargo will be transported to the designated OTV facility for turnaround activities.

The ground operations scenario shown in Figure A-3 provides a proposed ground processing flow for a space based OTV. This flow is based on the "vertical processing" mode. The OTV is finally assembled at a dedicated off-line facility at KSC where it undergoes receiving inpsection and a pre-launch checkout. A minimum of servicing is performed since this will be accomplished at Space Station. No propellant loading/servicing is performed on the ground. This mode was assumed for this analysis because it intersects the STS flow later in the count. Subsequent analysis showed that horizontal processing with less handling also has merit, and further analysis is recommended before making a final decision. The following ground rules were used in the development of the analysis:

1. Space based OTV's are as described in technical memorandum Volume II, Book 2 of this report.

2. The OTV is transported complete to Space Station in the orbiter PLB except for the aerobrake which is broken down and there are no propellants. Final activation and checkout is performed at Space Station.

3. All MPS/RCS loading/servicing will be accomplished at the Space Station.

4. All Space Station logistical support required for OTV assembly/build-up, test and servicing is already at Space Station.

5. The scenario and analysis encompassed OTV turnaround ground processing from initial receipt through return and disposition for refurbishment.

6. A total integrated system test of the OTV is required on the ground after final build-up and prior to installations in the orbiter/PLB. This analysis makes provisions for this testing at KSC, however, we recommend this be accomplished at the factory.

The space based OTV launch operations turnaround scenario shown in Figure A-4 depicts a best estimate of major activity anticipated at the space station. The scenario is based on the following ground rules.

1) There will be an unpressurized OTV hangar.

2). Only one OTV will be in in flow at a time.

3) The propellant and pressurization loading system is considered to be Space Station provided and not OTV unique. The propellant storage/loading system may either be located at the Space Station or may be a Remote Propellant Tank Farm (RPTF).

4) All standard checkout and maintenance (ORU replacement) will be accomplished remotely from the OTV Control Room within the Space Station.

APPENDIX A

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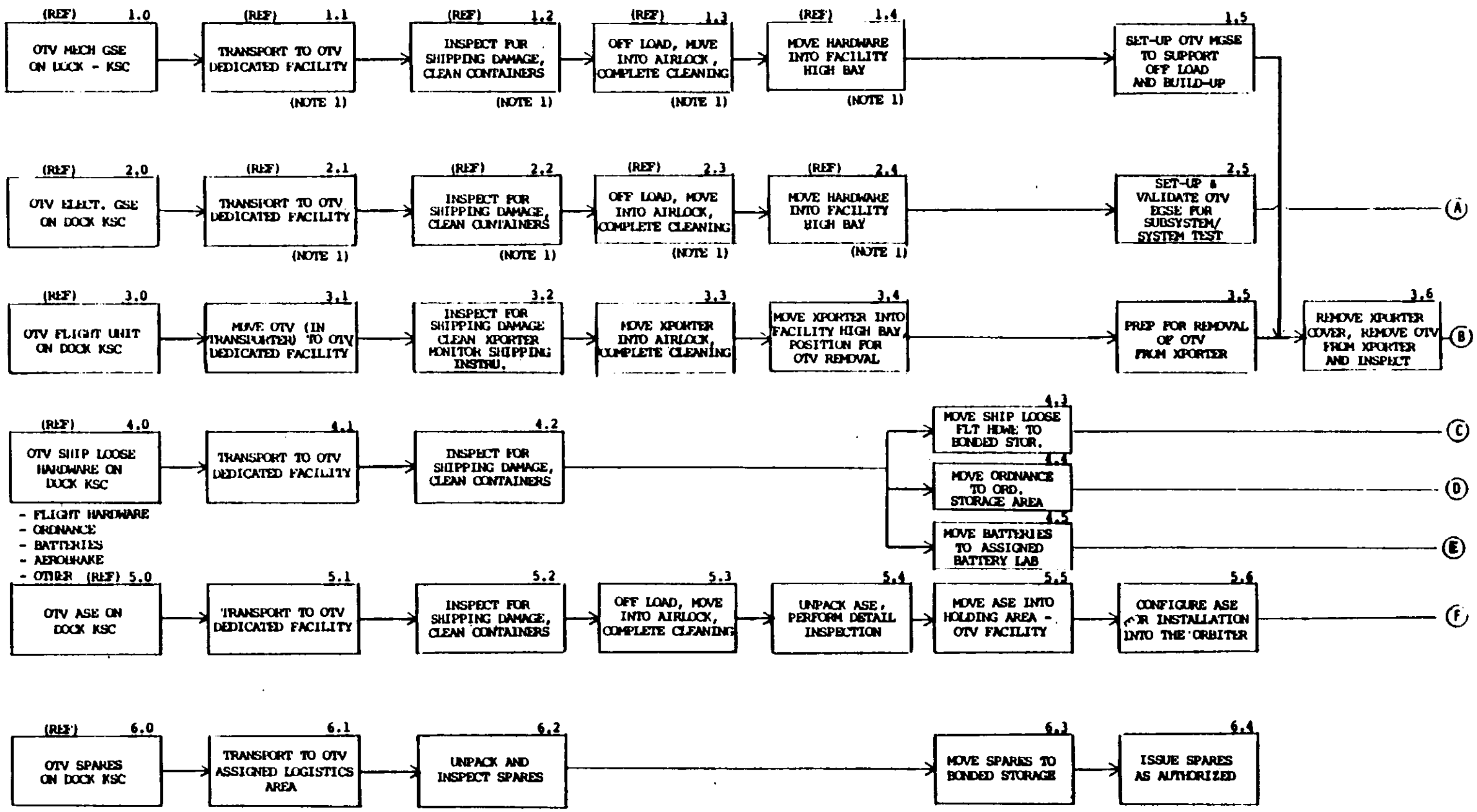

NOTE 1 REF ONLY - GROUND SUPPORT EQUIPMENT WILL BE PERMANENTLY LOCATED AT KSC AFTER INITIAL RECEIPT.

NOTE 2 ACC AS USED HEREIN REFERS TO "DEDICATED AFT CARGO CARRIER" PER ICD 80900000025.

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Figure A-1 Ground-Based DACC OTV Ground Processing

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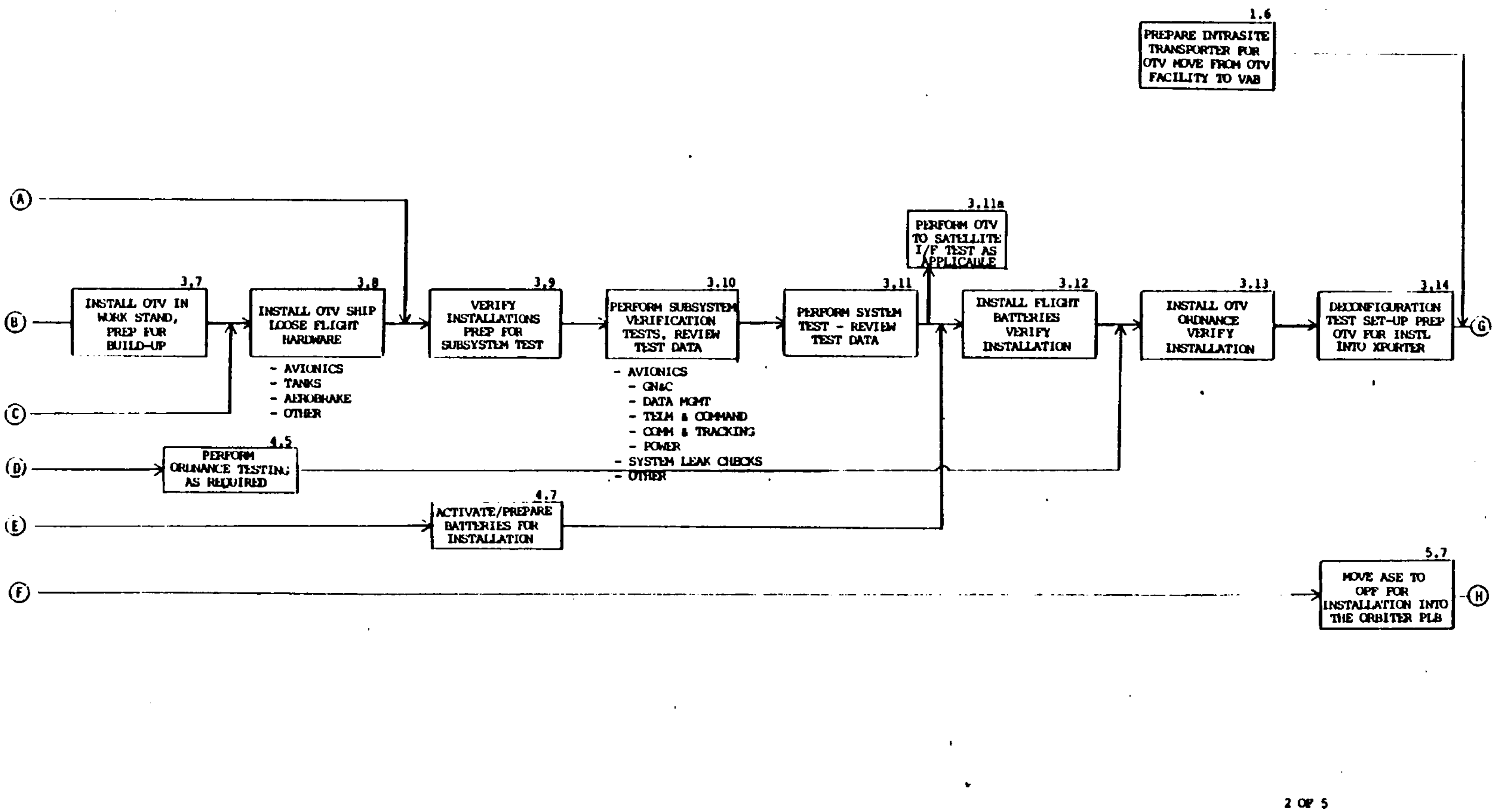

Figure A-1 Ground-Based DACC OTV Ground Processing (continued)

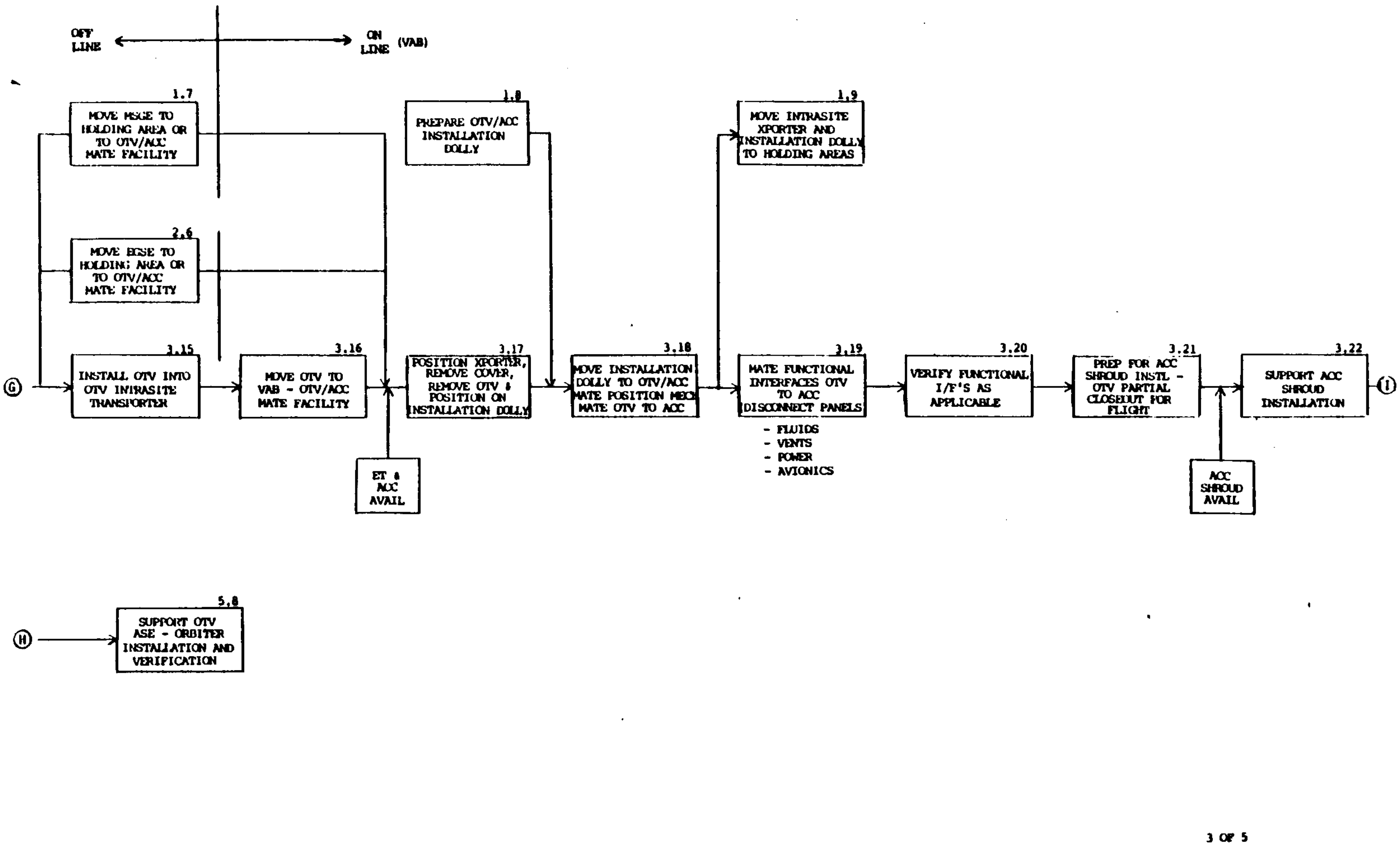

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Figure A-1 Ground-Based DACC OTV Ground Processing (continued)

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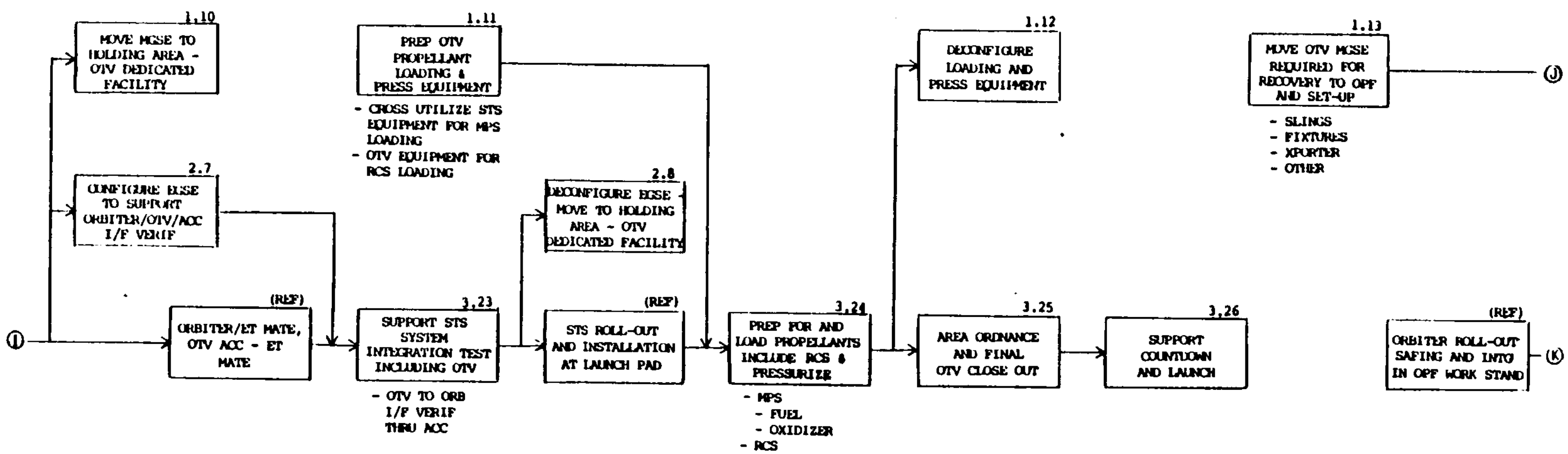

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Figure A-1 Ground-Based DACC OTV Ground Processing (continued)

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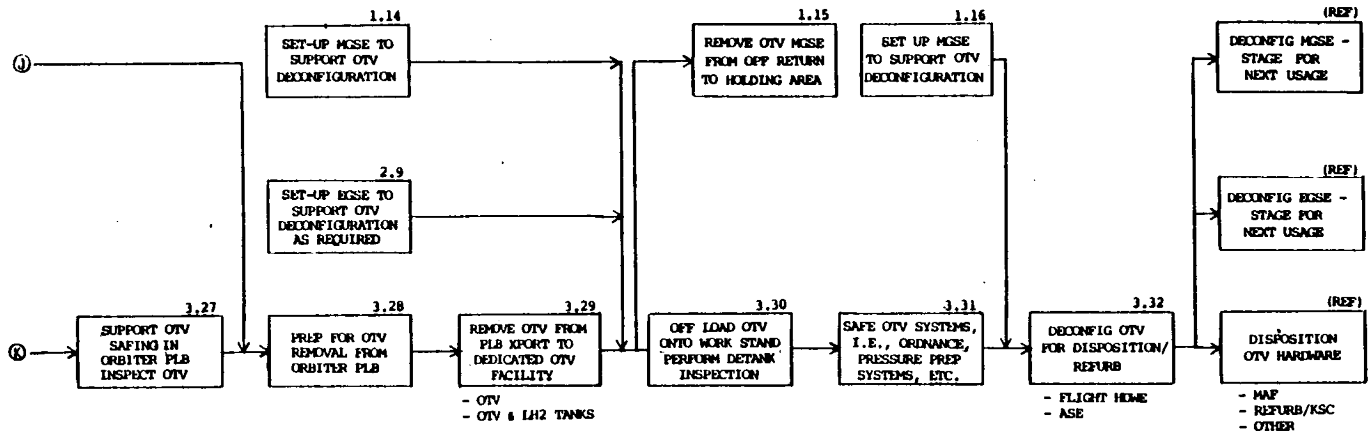

Figure A-1 Ground-Based DACC OTV Ground Processing (continued)

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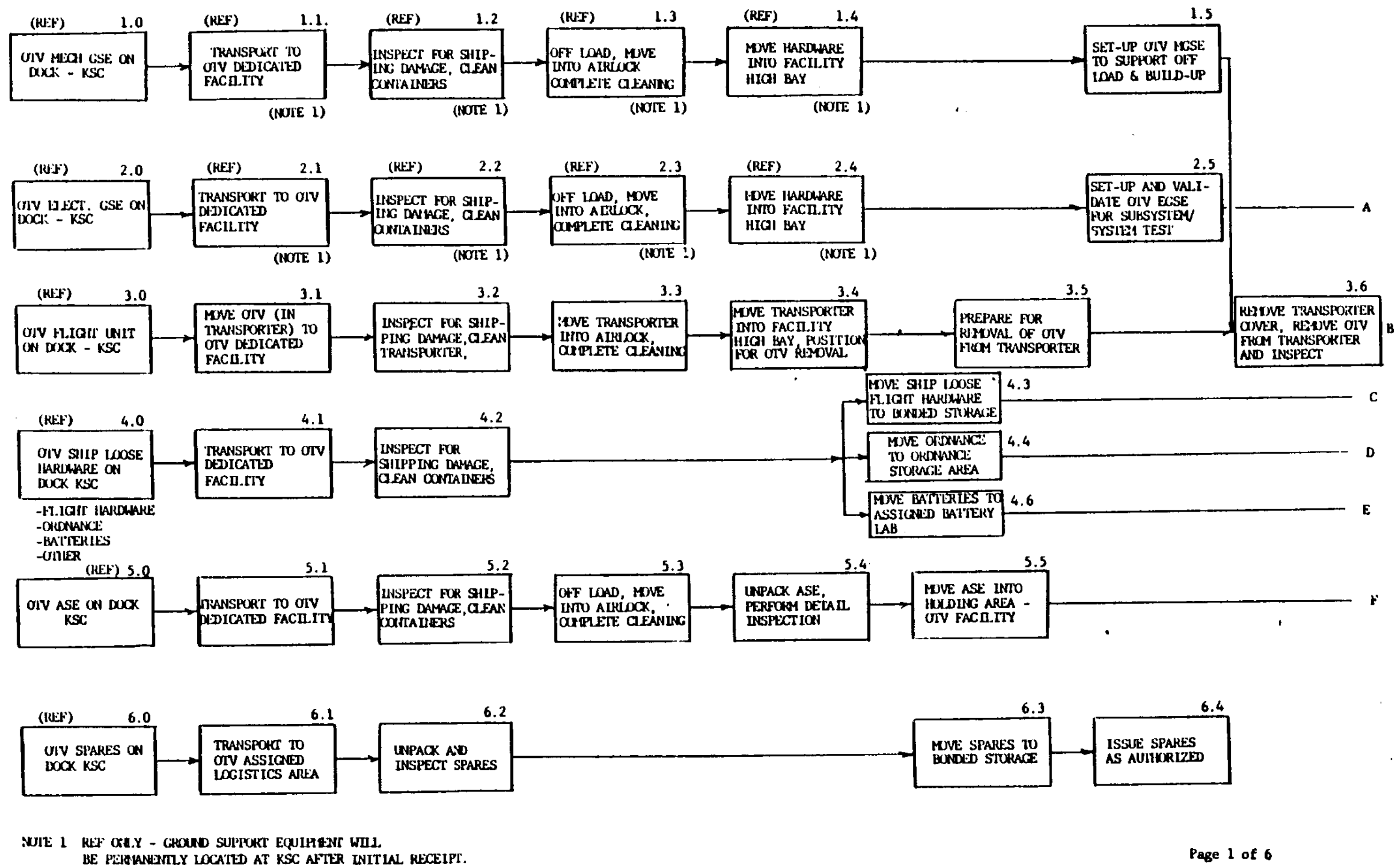

Figure A-2 Ground-Based PLB OTV Ground Processing

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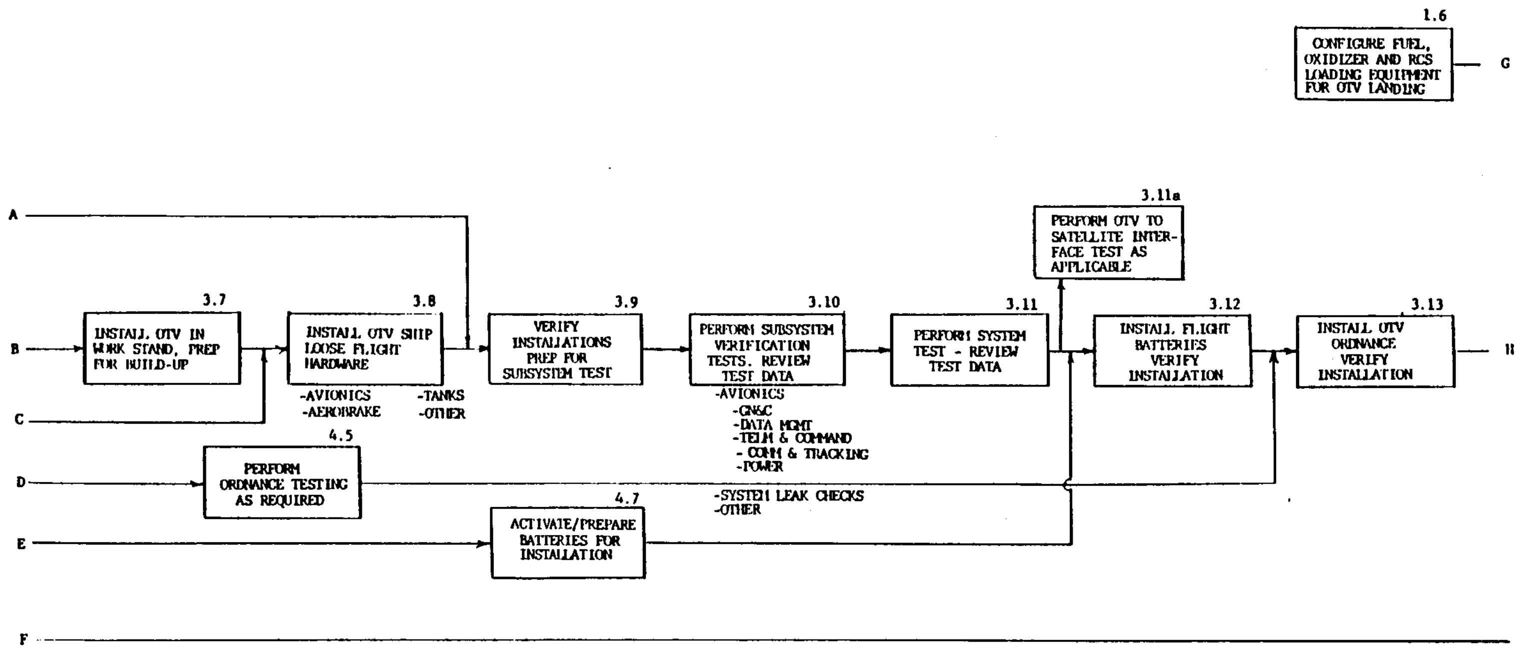

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Figure A-2 Ground-Based PLB OTV Ground Processing (continued)

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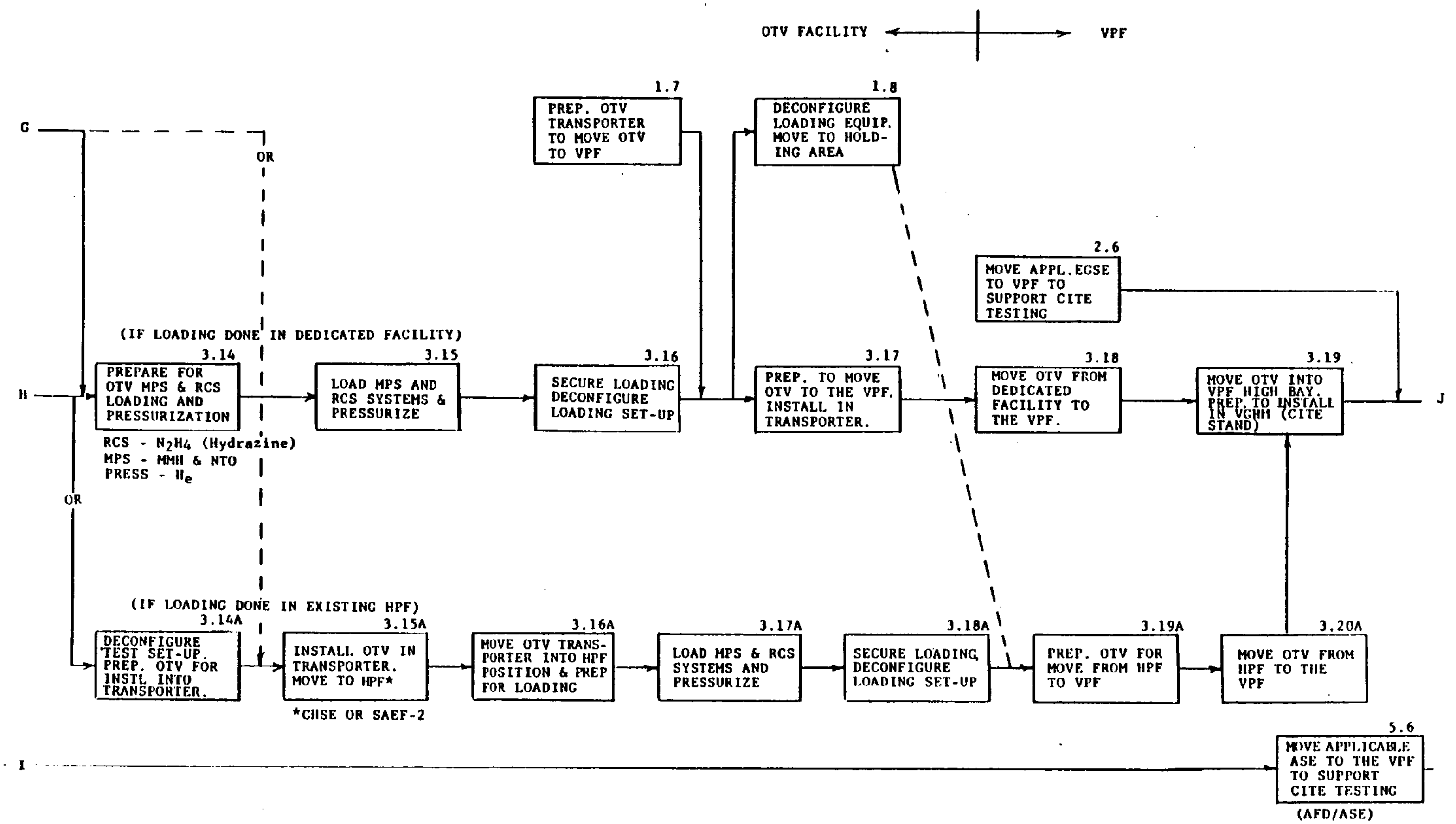

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Figure A-2 Ground-Based PLB OTV Ground Processing (continued)

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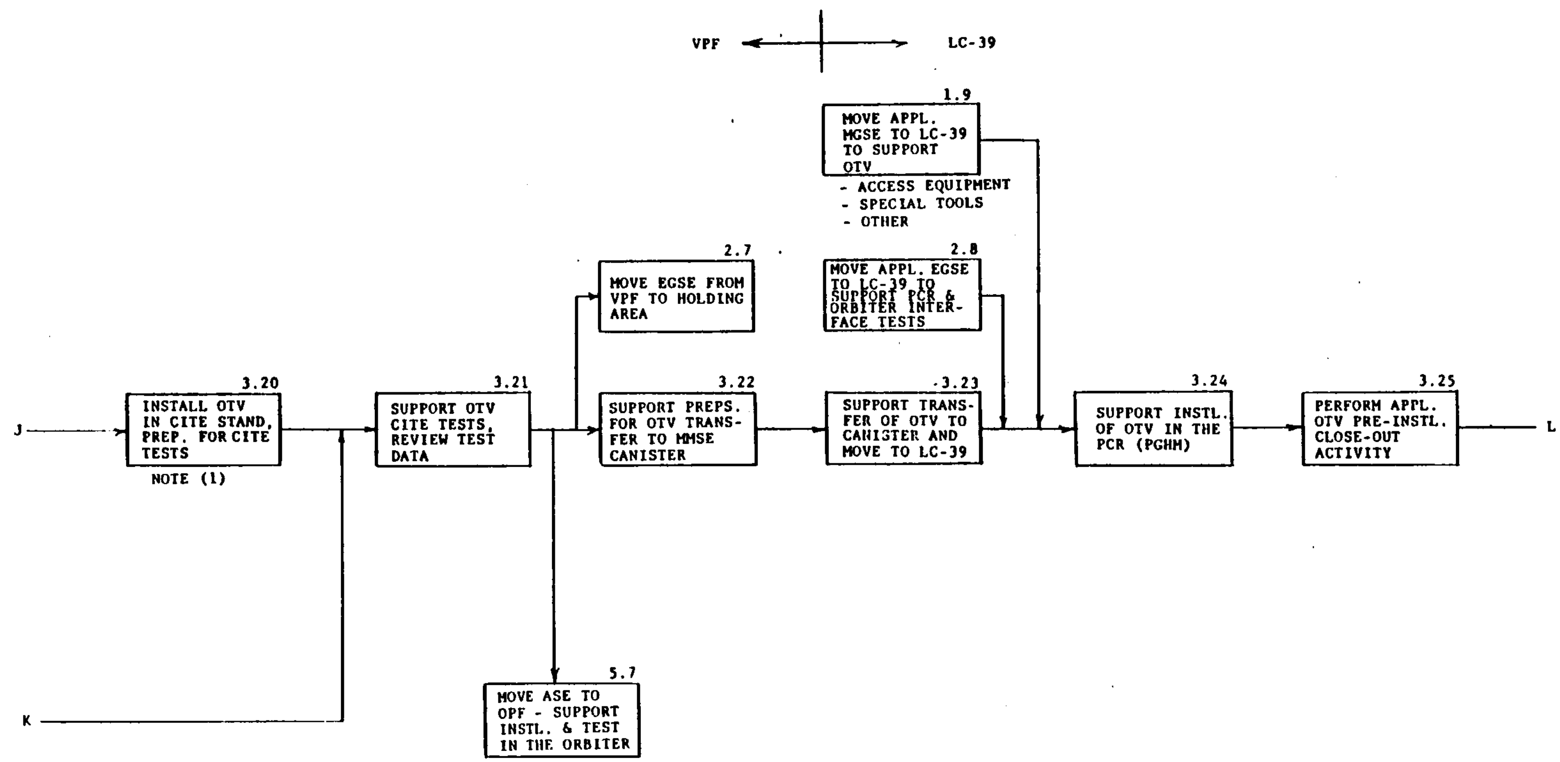

NOTE (1) OTV NOW IS PART OF CARGO

Figure A-2 Ground-Based PLB OTV Ground Processing (continued)

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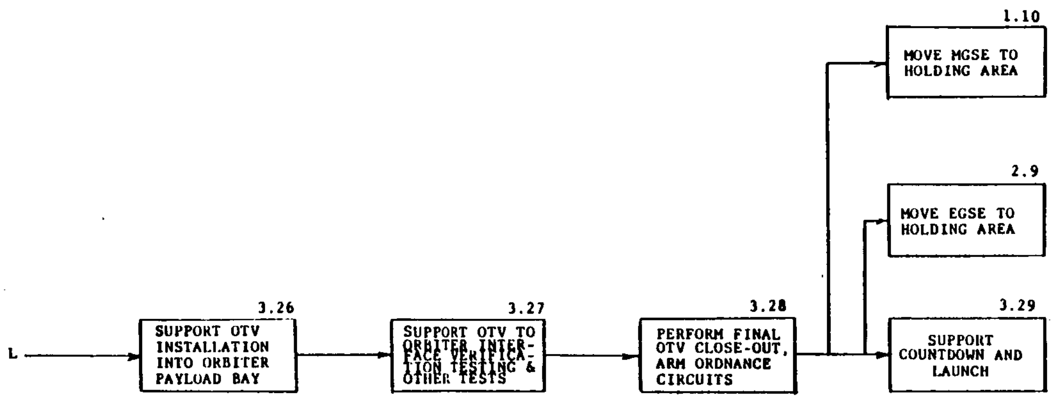

Figure A-2 Ground-Based PLB OTV Ground Processing (continued)

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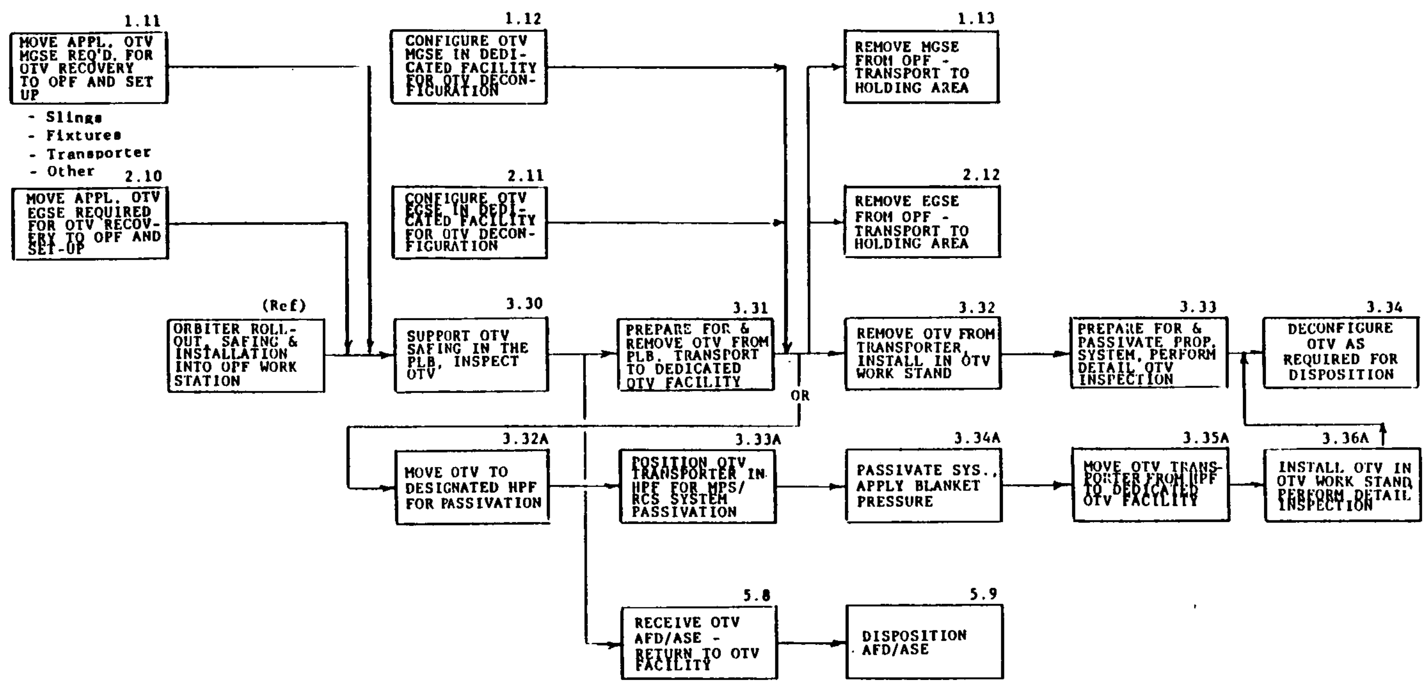

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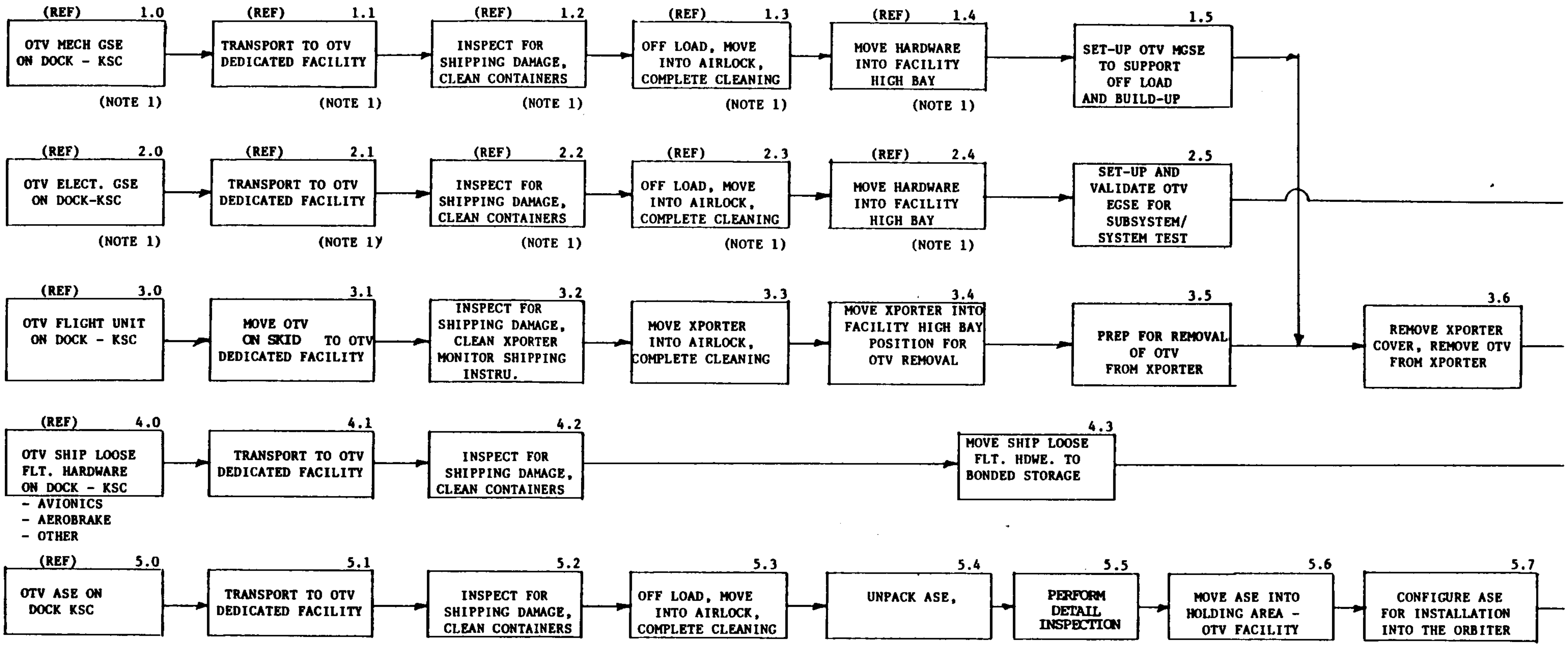
Figure A-2 Ground-Based PLB OTV Ground Processing (continued)



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NOTE 1. REF ONLY - GROUND SUPPORT EQUIPMENT WILL BE PERMANENTLY LOCATED AT KSC AFTER INITIAL RECEIPT AND IT MAY BE COMMON WITH GROUND BASED OTV.
2. AEROBRAKE MUST BE DISASSEMBLED TO FIT IN PLB.
3. ALL SPACE STATION LOGISTICS SUPPORT FOR OTV ALREADY AT SPACE STATION (FOR BUILD UP, TEST AND SERVICE).
4. TESTING AT KSC FOR S/B OTV TBD.
5. FOR PURPOSE OF THIS ANALYSIS, THE OTV IS SHIPPED FROM FACTORY TO SPACE STATION IN TWO PACKAGES; 1) OTV LESS AEROBRAKE AND 2) AEROBRAKE.
6. THE OTV IS TRANSPORTED TO KSC HORIZONTALLY ON A SHIPPING SKID (WITH SOFT PROTECTION) THAT ACCOMMODATES ROTATION TO THE VERTICAL POSITION ON REMOVAL.

Figure A-3 Space-Based OTV Ground Processing - Vertical

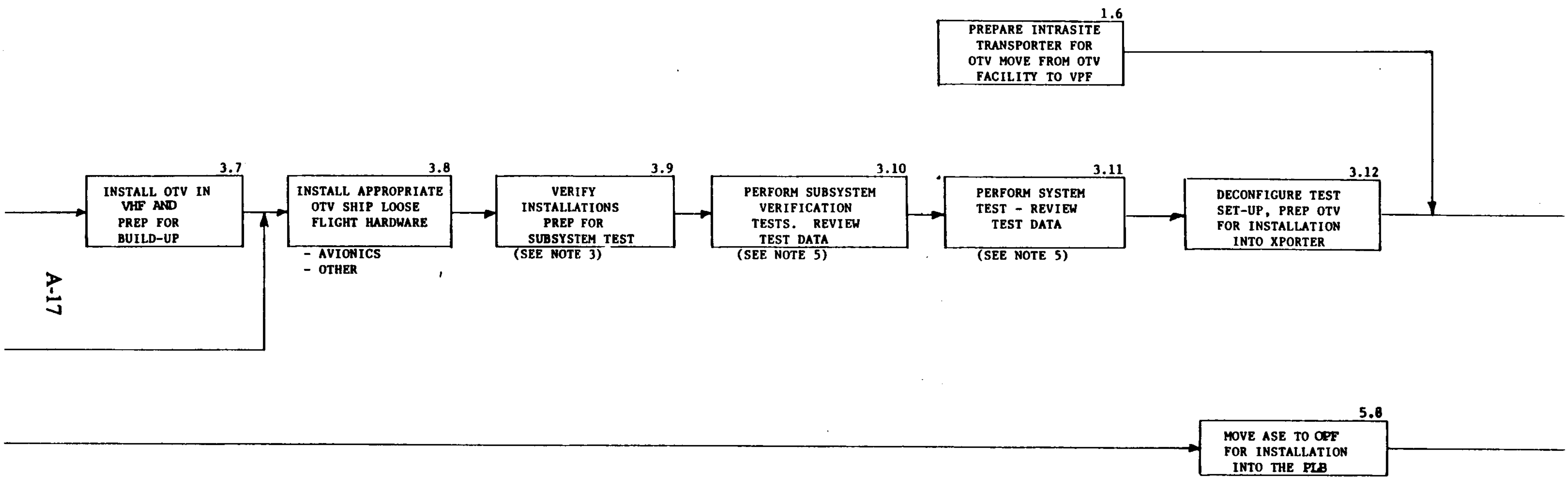

Figure A-3 Space-Based OTV Ground Processing - Vertical (Vertical)

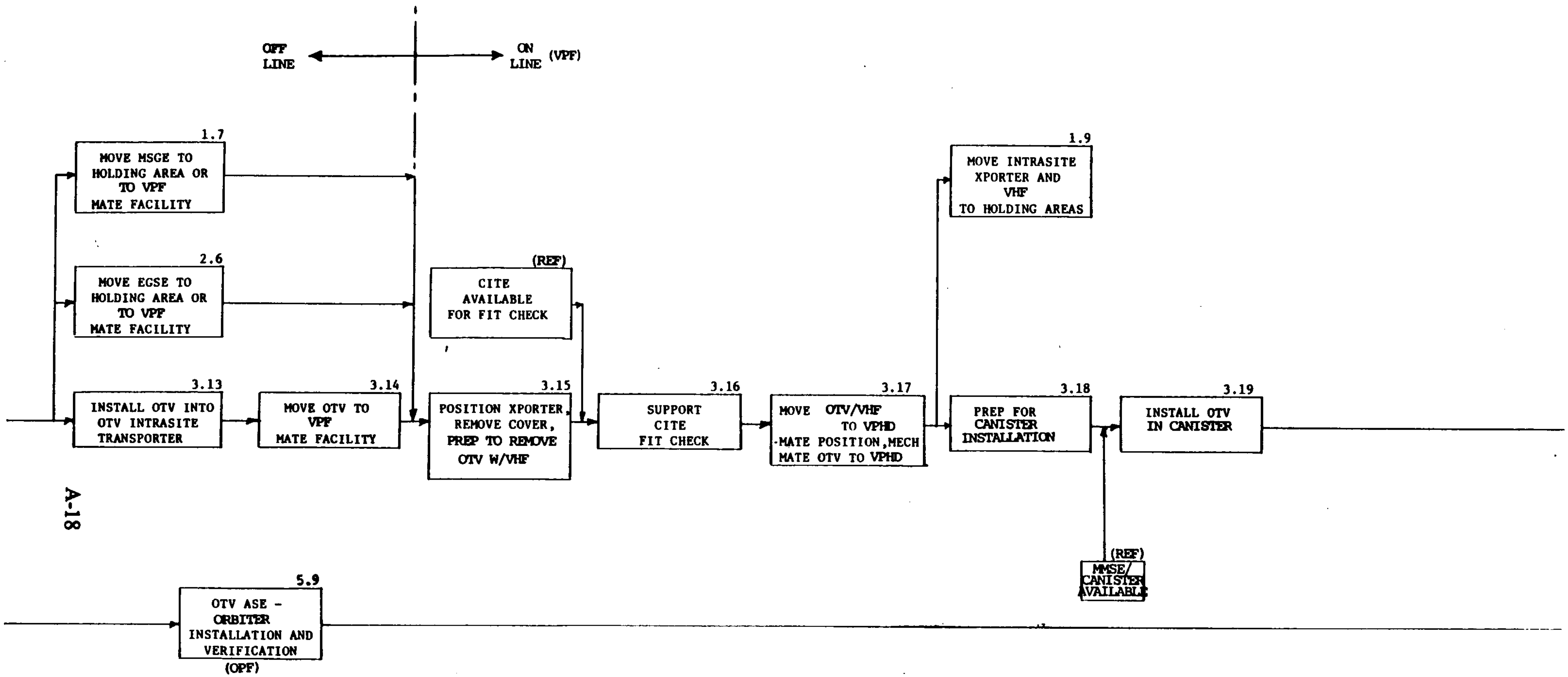

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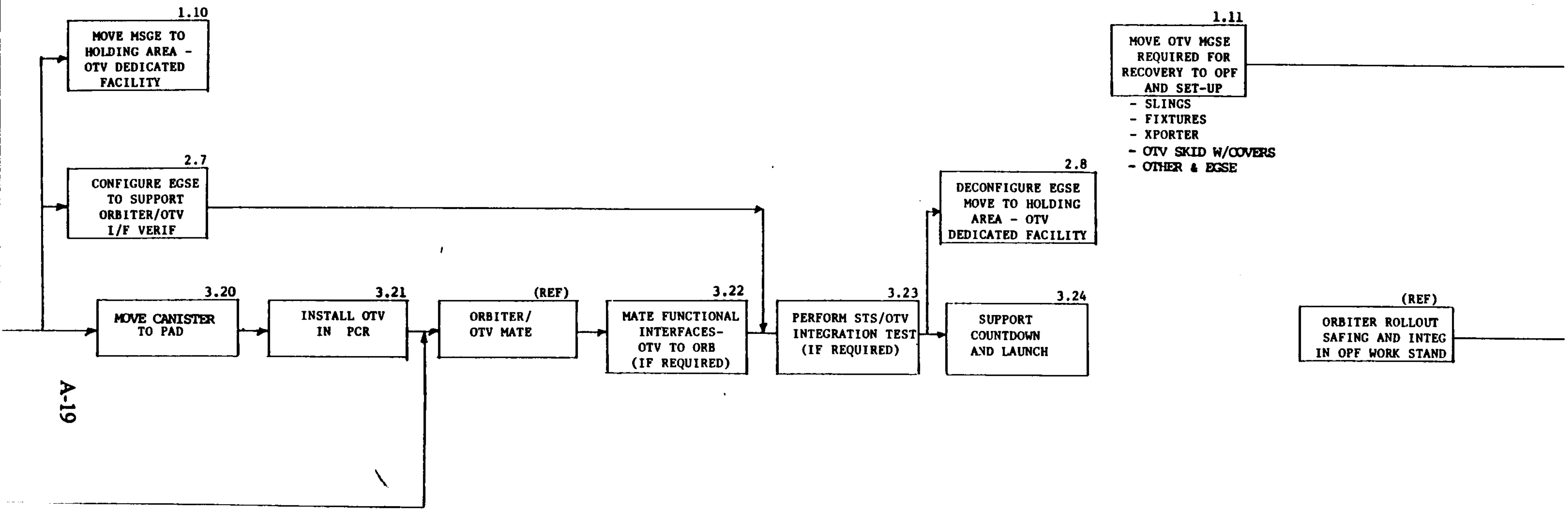
Figure A-3 Space-Based OTV Ground Processing - Vertical (Vertical)



4 OF 5

Figure A-3 Space-Based OTV Ground Processing - Vertical (Vertical)

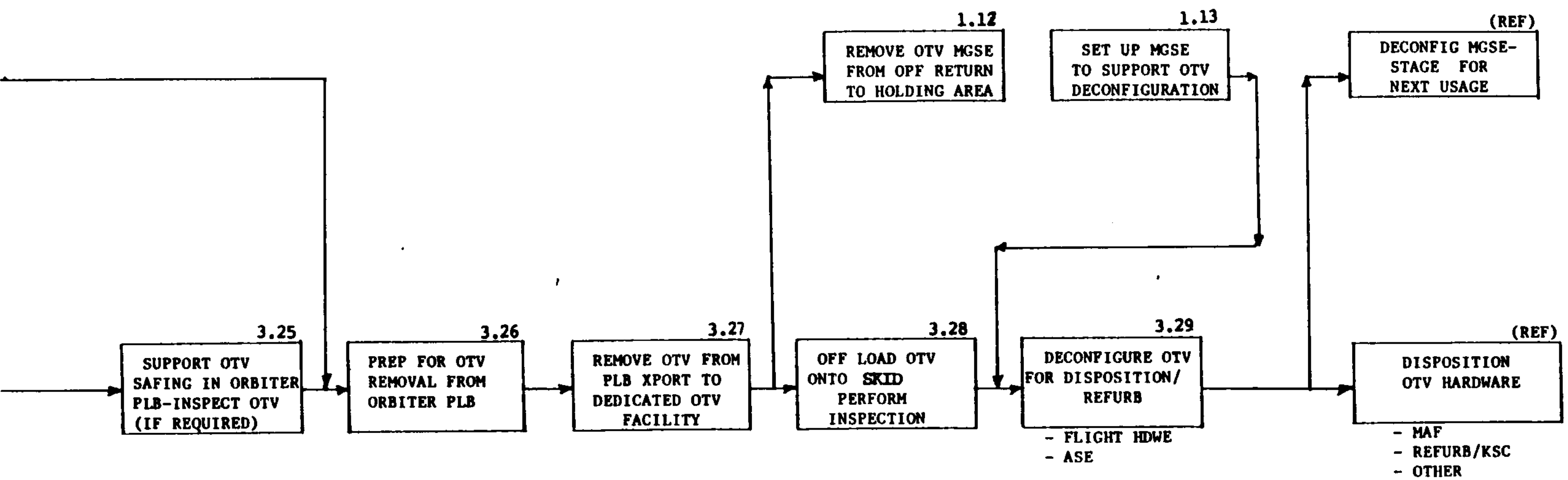


Figure A-3 Space-Based OTV Ground Processing - Vertical (Vertical)

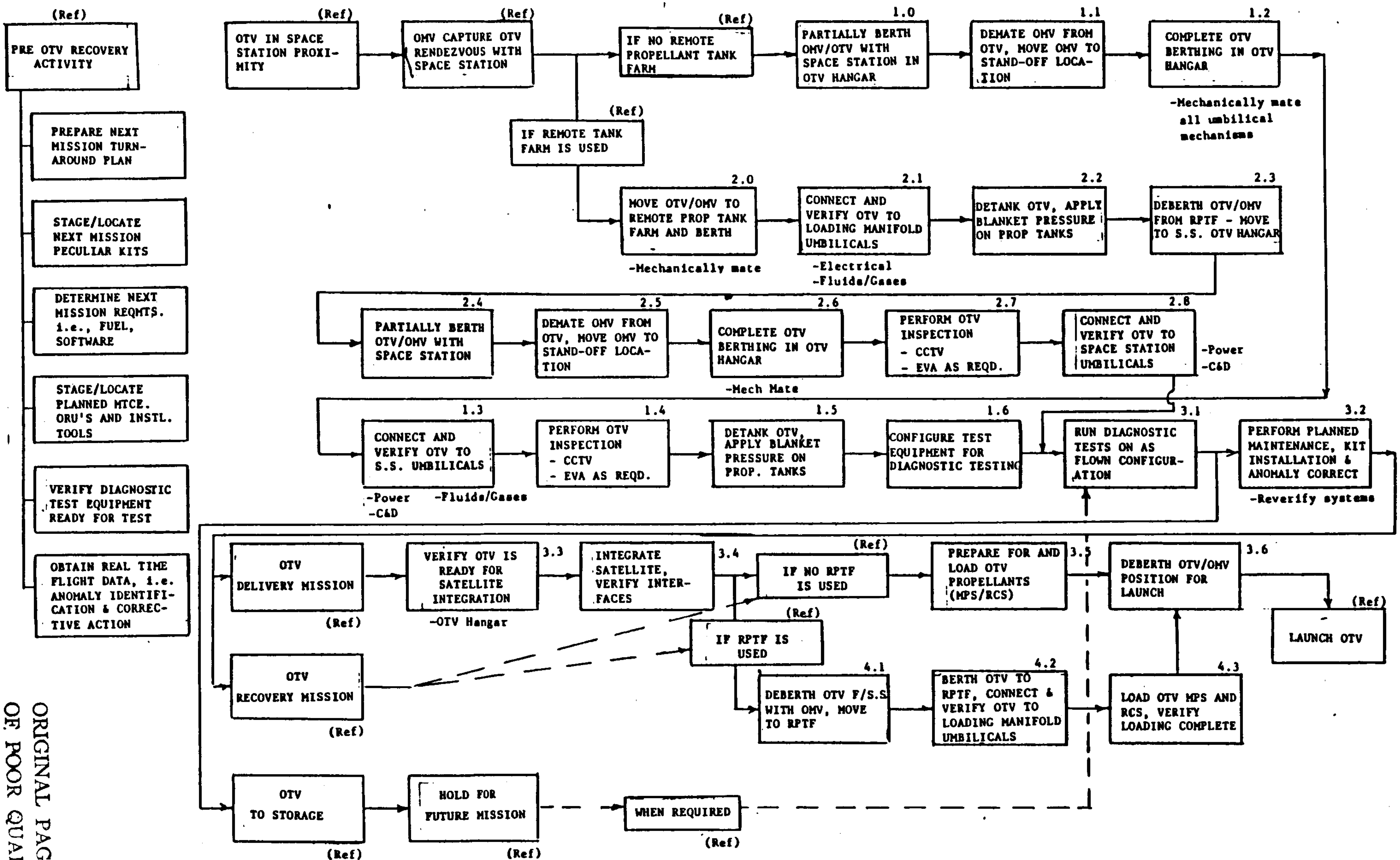


Figure A-4 Space-Based OTV Launch Operations Turnaround Scenario

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APPENDIX B

OTV MISSION TIMELINES

Appendix B contains detailed flight operations timelines for the missions analyzed as driver missions for OTV design. Various OTV hardware components have a mission time dependency because of heat load, power requirements, propellant boiloff, or exposure to meteoroid damage. Definition of the time and operations required for each flight phase allowed the designers to account for the particular space environment or vehicle activity in their design. The data was also used in conjunction with launch processing, recovery and refurbishment timelines to assess fleet size requirements of the OTV to accomplish the projected missions as defined in the OTV mission model. The timelines were originally developed based on the Revision 7 Mission Model and modified where necessary to Revision 8.

Timelines were prepared for each of the Design Reference Missions (DRMs) for both cryo and storable OTV configurations and are included as Tables B-1 through B-16. Based on orbital mechanics, time and delta-V optimization analysis, OTV configurations (where available) and reasonable assumptions where necessary, the timelines specify standard and unique operations required to satisfy the mission objectives. Ground-based missions vary from a minimum of 23.7 hrs for the GEO Delivery Storable (In-Bay) to a maximum of 132.5 hrs for the Cryo Planetary mission. Space-based missions vary from a minimum of 20.0 hrs for the GEO Delivery Storable (Perigee stage) to a maximum of 554.9 hrs for the Lunar Sortie mission.

All operations appear feasible in terms of time and complexity, and have been standardized within one mission and between different missions wherever possible. The following conventions are used in the timelines:

1) Times are in Phased Elapsed Time (PET)
2) Each phase begins with a phase title and the corresponding Mission Elapsed Time (MET)
3) Each phase ends with a phase title and the MET
4) Main Engine delta-V is indicated in fps, and RCS burns are indicated within the event

Ground-Based GEO delivery timelines are based only on MET.

APPENDIX B

Table B-1. GEO Delivery - Ground Based - Storable ACC

(Sheet 1 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	Δ V
00:00:00		Launch		
00:02:12		SRB Separation		
00:02:36		ACC shroud jettison		
00:08:20		MECO	15.8x79.7	
00:08:35		OTV Separation (2.0 fps; Springs provide ΔV)	14.8x79.2	
00:09:05	00:00:6.0	ET Separation; Begin - Z ΔV	(15.8x79.7)	
00:09:11		(4.0 fps) -Z ΔV Complete	(16.2x79.2)	
00:09:35		Deploy Aerobrake		
00:09:50		Activate OTV RCS (Sep distance from Orb=400 ft)		
00:10:00	00:02:00	Begin Maneuver to Orient Brake toward Orb		
00:12:00		End Maneuver		
00:12:20	00:06:44.5	Orbiter OMS-1 Ignition	(16.0x79.1)	(170.4)
00:14:04.9		Orbiter OMS-1 Cut-off	(55.1x130)	
00:33:28.6		OTV Boost-1 Ignition (Sep distance from Orb = 52.34 nmi)	10.5x78.4	227.6
		OTV Boost-1 Cut-off	63.4x150	
00:36:00		Begin OTV Thermal Roll		
00:44:19.7		Orbiter OMS-2 Ignition	(55.1x130)	(135.2)
00:45:41.7		Orbiter OMS-2 Cut-off	(130x130)	
01:02:00	00:23:00	OTV Attitude and State Vector Update		
01:25:13.7		OTV Boost-2 Ignition (Sep distance from Orb = 228.76 nmi)	63.0x140	138.0
		OTV Boost-2 Cut-off	140x140	
04:09:19		Orbiter NH-1 Maneuver	(130x140)	(17.8)
04:54:19		Orbiter NC-3 Maneuver (OTV Leads Orbiter by 10 nmi)	(135x140)	(6.0)
06:24:19		Orbiter NH-2 Maneuver	(140x140)	(11.8)
20:00:00	01:25:00	Orbiter TI Maneuver (From 8 nmi behind to 1000 ft ahead of OTV)		(21.9)
20:30:00		Inhibit/Safe OTV Main Engine(s) prior to 10,000 ft distance		
21:00:00	00:20:00	Payload checkout		
21:25:00		Orbiter TF Maneuver (Null Rate at 1000 ft.) ahead of OTV		
21:30:00	00:30:00	V-bar Prox Ops to 45 ft (when lighting cond correct)		
21:35:00	00:20:00	RMS power up/camera set up		

Table B-1. GEO Delivery - Ground Based - Storable ACC
(Sheet 2 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
22:00:00	00:15:00	Inhibit/Safe OTV RCS and Grapple OTV		
22:15:00	00:10:00	RMS Maneuver OTV		
22:25:00	00:15:00	PIDA unlatch and move to OTV mate position		
22:40:00	00:25:00	Mate OTV to PIDA		
23:05:00	00:30:00	Grapple Payload/Mate to OTV		
23:35:00	00:45:00	OTV Interface checkout & Nav update		
24:20:00*	00:05:00	Release OTV/Payload (Could be delayed up to 12 hours to achieve desired longitude)		
24:25:00*	00:10:00	Orbiter Low Z Separation RCS Maneuver - (0.5 fps)		
24:35:00*	00:48:00	Orbiter RCS Separation Maneuver to safe distance - (1.0 fps)		
24:42:00*		Enable OTV RCS (Orb Dist = 400 ft)		
25:24:00*	00:13:00	Attitude and State Vector Update		
25:30:00*		Enable OTV Main Engine (Orb dist = 10,000 ft)		
25:37:00*	00:03:00	Maneuver to burn attitude		
25:43:00*		OTV Boost-3 Ignition	140x140	8097.3
		OTV Boost-3 Cut-off	140x19323	
26:05:00*		Orbiter OMS-3 Ignition	(140x140)	(17.8)
		Orbiter OMS-3 Cutoff	(130x140)	
26:15:00*	00:08:00	OTV/SC Separation via 1 fps Spring to Reach 400 Dist.		
26:23:00*		OTV Separation Burn; 20 fps RCS		
26:50:00*		Orbiter OMS-3 Ignition	(130x140)	(17.8)
		Orbiter OMS-4 Cutoff	(130x130)	
27:31:00*	00:13:00	Attitude and State Vector Update		
27:44:00*	00:06:00	Maneuver to Burn attitude		
27:50:00*		OTV Deboost Ignition	140x19323	378.4
31:03:45*	00:10:00	SC Apogee Burn		
		OTV Deboost Cut-off	40x19245	

Table B-1. GEO Delivery - Ground Based - Storable ACC
(Sheet 3 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
35:09:00*		Targeting Update		
35:15:00*		Midcourse (RCS), 20 fps		
35:30:00*		Attitude Update		
36:00:00*		State Vector Update		
36:18:00*		Atmospheric Entry (8076 Equiv fps)		
36:22:00*		Atmospheric Exit	40x19245	
36:25:00*		Jettison Aerobrake		
36:34:00*		State Vector Update		
36:49:00*		LEO Reboost #1	115x140	203
37:48:00*		Adjust Inclination	115x140	
37:55:00*	00:23:00	State Vector Update		
38:18:00*		LEO Reboost #2	140x140	45
39:49:00*		Orbiter NH Rendezvous Maneuver	(130x140)	(8.0)
40:39:00*		Orbiter NC Maneuver	(134x140)	(6.0)
41:41:00*		Orbiter TI Maneuver (OTV Ahead of Orbiter 8 nmi)	(138x140)	(11.0)
42:37:00*		Inhibit/Safe OTV Main Engine		
43:11:00*		Orbiter TF Maneuver (Null Rate at 1000 ft.)	140x140	
43:17:00*	00:30:00	V-bar Prox Ops to 45 ft. (when lighting cond. correct)		
43:22:00*	00:20:00	RMS Power Up/Camera Set Up		
43:47:00*	00:15:00	Inhibit OTV RCS; Grapple OTV		
44:02:00*	00:45:00	OTV Stowage Ops		
TBD		Orbiter Deorbit Burn		(235)
			OTV Total	9089.3 fps
			(Orb OMS Total	658.7 fps)

*Add up to 12 additional hours for longitude placement.

Table B-2. GEO Delivery - Ground Based - Storable-in-Bay
(Sheet 1 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
00:00:00		Launch		
00:02:12		SRB Separation		
00:08:20		MECO	(15.8x79.7)	
00:09:05	00:00:6.0	ET Separation; Begin - Z ΔV	(15.8x79.7)	
00:09:11		(4.0 fps) -Z ΔV Complete	(16.2x79.2)	
00:12:20	00:06:44.5	Orbiter OMS-1 Ignition	(16.0x79.1)	(170.4)
00:18:04.5		Orbiter OMS-1 Cut-off	(55.1x130)	
00:44:19.7	00:01:22	Orbiter OMS-2 Ignition	(55.1x130)	(135.2)
00:45:41.7		Orbiter OMS-2 Cut-off	(130x130)	

(   ) Orbiter Values

Table B-2. GEO Delivery - Ground Based - Storable-in-Bay
(Sheet 2 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
03:00:00	00:20:00	Payload checkout		
03:30:00	00:45:00	OTV Interface checkout & Nav update		
04:15:00*		Deploy OTV/Payload (Could be delayed up to 12 hours to achieve desired longitude)		
04:20:00*	00:10:00	Orbiter Low Z Separation RCS Maneuver - (0.5 fps)		
04:30:00*	00:48:00	Orbiter RCS Separation Maneuver to safe distance - (1.0 fps)		
04:37:00*		Enable OTV RCS (Orb Dist = 400 ft)		
05:02:00*	00:23:00	Attitude and State Vector Update		
05:25:00*		Enable OTV Main Engine (Orb dist = 10,000 ft)		
05:32:00*	00:03:00	Maneuver to burn attitude		
05:37:00*		OTV Boost-1 Ignition	130x130	8114.8
TBD		OTV Boost-1 Cut-off	130x19323	
06:15:00*	00:08:00	OTV/SC Separation via 1 fps Spring to Reach 400 ft Dist.		
06:23:00*		OTV Separation Burn; 20 fps RCS		
07:18:45*	00:23:00	Attitude and State Vector Update		
07:41:00*	00:03:00	Maneuver to Burn attitude		
07:44:00*		OTV Deboost Ignition	140x19323	378.4
TBD		OTV Deboost Cut-off	40x19245	
07:50:00*		Begin Thermal Roll		
10:58:45*	00:10:00	SC Apogee Burn		

Table B-3. GEO Delivery - Ground Based - Storable-in-Bay
(Sheet 3 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
14:41:00*	00:23:00	Attitude and State Vector Update		
15:04:00*	00:06:00	Targeting Update		
15:10:00*		Midcourse (RCS), 20 fps		
15:45:00*	00:23:00	Attitude and State Vector Update		
16:13:00*		Atmospheric Entry		
16:17:00*		Atmospheric Exit 8076 fps (equiv)	4x140	
16:17:00	00:03:00	Slew to Jettison Attitude		
16:20:00*		Jettison Aerobrake		
16:21:00*	00:21:00	Attitude and State Vector Update		
16:44:00*		LEO Reboost #1	115x140	203
17:43:00*		Adjust Inclination	115x140	
17:50:00*	00:23:00	Attitude and State Vector Update		
18:13:00*		LEO Reboost #2	140x140	45
19:44:00*		Orbiter NH Rendezvous Maneuver	(130x140)	(8.0)
20:34:00*		Orbiter NC Maneuver	(134x140)	(6.0)
21:36:00*		Orbiter TI Maneuver (OTV Ahead of Orbiter 8 nmi)	(138x140)	(11.0)
22:32:00*		Inhibit/Safe OTV Main Engine		
23:06:00*		Orbiter TF Maneuver (Null Rate at +1000 ft.)	140x140	
23:12:00*	00:30:00	V-bar Prox Ops to 45 ft. (when lighting cond. correct)		
23:17:00*	00:20:00	RMS Power Up/Camera Set Up		
23:42:00*	00:15:00	Inhibit OTV RCS; Grapple OTV		
23:57:00*	00:45:00	OTV Stowage Ops		
TBD		Orbiter Deorbit Burn		(235.0)

OTV Total	8740.4 fps
(Orb OMS Total	565.6 fps)

* Add up to 12 additional hrs for longitude placement

Table B-3. GEO Delivery - Ground Based - Cryo (Sheet 1 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_p x H_A$	ΔV
00:00:00		Launch		
00:02:12		SRB Separation		
00:02:36		ACC shroud jettison		
00:08:20		MECO	15.8x79.7	
00:08:35		OTV Separation (2.0 fps; Springs provide ΔV)	14.8x79.2	
00:09:05	00:00:6.0	ET Separation; Begin - Z ΔV (4.0 fps)	(15.8x79.7)	
00:09:11		-ZΔV Complete	(16.2x79.2)	
00:09:35		Deploy Aerobrake		
00:09:50		Activate OTV RCS (Sep distance from Orb=400 ft)		
00:10:00	00:02:00	Begin Maneuver to Orient Brake toward Orb		
00:12:00		End Maneuver		
00:12:20	00:06:44.5	Orbiter OMS-1 Ignition	(16.0x79.1)	(170.4)
00:18:04.5		Orbiter OMS-1 Cut-off	(55.1x130)	
00:30:00		Begin OTV Engine conditioning (cryo chilldown)		
00:33:28.6	00:00:28.8	OTV Boost-1 Ignition (Sep distance from Orb = 52.34 nmi)	10.5x78.4	227.6
00:33:57.4		OTV Boost-1 Cut-off	63.4x150	
00:36:00		Begin OTV Thermal Roll		
00:44:19.7		Orbiter OMS-2 Ignition	(55.1x130)	(135.2)
00:45:41.7		Orbiter OMS-2 Cut-off	(130x130)	
01:02:13.7	00:23:00	OTV Attitude and State Vector Update		
01:25:13.7	00:00:17.2	OTV Boost-2 Ignition (Sep distance from Orb = 228.76 nmi)	63.0x140	138.0
01:25:30.9		OTV Boost-2 Cut-off	140x140	
04:09:19		Orbiter NH-1 Maneuver	(130.0x140)	(17.8)
04:54:19		Orbiter NC-3 Maneuver (OTV Leads Orbiter by 10 nmi)	(133.5x140)	(6.0)
06:24:19		Orbiter NH-2 Maneuver	(140x140)	(11.8)
20:00:00	01:25:00	Orbiter TI Maneuver (OTV ahead of Orbiter 20 nmi due to differential drag)		(21.9)
20:30:00		Inhibit/Safe OTV Main Engine(s) prior to 10,000 ft distance		
21:00:00	00:20:00	Payload checkout		
21:25:00		Orbiter TF Maneuver (Null Rate at 1000 ft ahead of OTV)		
21:30:00	00:30:00	V-bar Prox Ops to 45 ft (when lighting cond correct)		
21:35:00	00:20:00	RMS power up/camera set up		

( ) Orbiter Values

Table B-3. GEO Delivery - Ground Based - Cryo
(Sheet 2 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_p x H_A$	ΔV
22:00:00	00:15:00	Inhibit/Safe OTV RCS and Grapple OTV		
22:15:00	00:10:00	RMS Maneuver OTV		
22:25:00	00:15:00	PIDA unlatch and move to OTV mate position		
22:40:00	00:25:00	Mate OTV to PIDA		
23:05:00	00:30:00	Grapple Payload/Mate to OTV		
23:35:00	00:45:00	OTV Interface checkout &		
24:20:00*	00:05:00	Release OTV/Payload (Could be delayed up to 12 hours to achieve desired longitude)		
24:25:00*	00:10:00	Orbiter Low Z Separation RCS Maneuver - (0.5 fps)		
24:35:00*	00:48:00	Orbiter RCS Separation Maneuver to safe distance - (1.0 fps)		
24:42:00*		Enable OTV RCS (Orb Dist = 400 ft)		
25:00:00*	00:23:00	Attitude and State Vector Update		
25:23:00*		Enable OTV Main Engine (Orb dist = 10,000 ft)		
25:37:00*	00:03:00	Maneuver to burn attitude		
25:40:00*	00:03:00	Begin engine conditioning (cryo childown)		
25:43:00*	00:17:11	OTV Boost-3 Ignition	140x140	8097.3
26:00:11*		OTV Boost-3 Cut-off	140x19323	
26:02:00*		Begin Thermal Roll		
26:05:00*		Orbiter OMS-3 Ignition	(140x140)	(17.8)
		Orbiter OMS-3 Cutoff	(130x140)	
26:50:00*		Orbiter OMS-4 Ignition	(130x140)	(17.8)
		Orbiter OMS-4 Cutoff	(130x130)	
30:34:45*	00:23:00	Attitude and State Vector Update		
30:57:45*	00:03:00	Maneuver to Burn attitude		
31:00:45*	00:03:00	Begin Engine Conditioning		
31:03:45*	00:07:40	OTV Boost-4 Ignition	140x19323	5834
31:11:25*		OTV Boost-4 Cut-off	19323x19323	
31:41:00*		S/C Checkout & Separation		
54:42:35*	00:23:00	Attitude and State Vector Update		
55:05:35*	00:03:00	Maneuver to Burn Attitude		
55:18:35*	00:03:00	Begin Engine Conditioning		
55:11:37*	00:01:56	OTV Deboost Ignition	19323x19323	6092
55:13:33*		OTV Deboost Cut-off	40x19350	

Table B-3. GEO Delivery - Ground Based - Cryo
(Sheet 3 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
58:46:00*	00:23:00	Attitude and State Vector Update		
59:09:00*	00:06:00	Targeting Update		
59:15:00*		Midcourse (RCS), 20 fps		
59:30:00*	00:23:00	Attitude and State Vector Update		
60:18:00*		Atmospheric Entry		
60:22:00*		Atmospheric Exit (8076 fps equiv)	4x140	
60:22:00*	00:03:00	Slew to Jettison Att		
60:25:00*		Jettison Aerobrake at 1 fps		
60:26:00*	00:16:00	Attitude and State Vector Update		
60:43:00*	00:03:00	Begin Engine Conditioning		
60:47:00*		LEO Reboost #1	115x140	203
61:46:00*		Adjust Inclination	115x140	
61:50:00*	00:23:00	Attitude and State Vector Update		
62:13:00*	00:03:00	Begin Engine Conditioning		
62:16:00*		LEO Reboost #2	140x140	42
62:26:00*		RCS Trim and Residual Dump, 3 fps		
63:57:00*		Orbiter NH Rendezvous Maneuver	(130x140)	(8.0)
64:47:00*		Orbiter NC Maneuver	(134x140)	(6.0)
65:49:21*		Orbiter TI Maneuver (OTV Ahead of Orbiter 8 nmi)	(138x140)	(11.0)
66:45:00*		Inhibit/Safe OTV Main Engine(s) Prior to 10,000 ft Distance		
67:19:00*		Orbiter TF Maneuver (Null Rate at 1000 ft ahead of OTV)	140x140	
67:25:00*	00:30:00	V-bar Prox OPs to 45 ft. (When lighting cond. correct)		
67:30:00*	00:20:00	RMS Power Up/Camera Set Up		
67:55:00*	00:15:00	Inhibit OTV RCS; Grapple OTV		
68:10:00*	03:00:00	OTV Stowage Ops		
TBD		Orbiter Deorbit Burn		(235)
			OTV Total	20633.9 fps
			(Orb OMS Total)	(658.7) fps

* Add up to 12 additional hours for longitude placement

Table B-4. Planetary - Ground Based - Storable In Bay
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	LAUNCH		MET: 00:00:00	
00:00:00		Launch		
00:02:12		SRB Separation		
00:08:20		MECO	(15.8x79.7)	
00:09:05	00:00:6.0	ET Separation; Begin - ZΔV	(15.8x79.7)	
00:09:11		(4.0 fps) -ZΔV Complete	(16.2x79.2)	
00:12:20	00:06:44.5	Orbiter OMS-1 Ignition	(16.0x79.1)	(170.4)
00:18:04.5		Orbiter OMS-1 Cut-off	(55.1x130)	
00:44:19.7	00:01:22	Orbiter OMS-2 Ignition	(55.1x130)	(135.2)
00:45:41.7		Orbiter OMS-2 Cut-off	(130x130)	
03:00:00	00:20:00	Payload checkout		
03:30:00	00:45:00	OTV Interface checkout & Nav update		
PHASE:	END LAUNCH		MET: 4:15:00	

(   ) Orbiter Values

Table B-4. Planetary - Ground Based - Storable In Bay
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	ORBITER OPS AND SEPARATION		MET - 4:15:00	
00:00:00		Deploy OTV/Payload		
00:05:00	00:10:00	Orbiter Low Z Separation RCS Maneuver - (0.5 fps)		
00:15:00	00:48:00	Orbiter RCS Separation Maneuver to safe distance - (1.0 fps)		
00:22:00		Enable OTV RCS (Orb Dist = 400 ft)		
00:47:00	00:23:00	Attitude and State Vector Update		
01:10:00		Enable OTV Main Engine (Orb dist = 10,000 ft)		
PHASE:	END ORBITER OPS AND SEPARATION		MET - 5:25:00	
PHASE:	OTV DELIVERY AND RETURN		MET - 5:25:00	
00:07:00	00:03:00	Maneuver to burn attitude		
00:12:00		OTV Boost-1 Ignition	130x130	
		OTV Boost-1 Cut-off	130xHyperbolic	
00:32:00	00:08:00	OTV/SC Separation via 1 fps Spring to Reach 400 ft Dist.		
00:40:00	00:08:00	OTV Separation Burn; 20 fps RCS to reach 10,000 ft dist.		
00:45:00	00:03:00	Maneuver to Burn attitude		
00:48:00		OTV Deboost Ignition	130xHyperbolic	
		OTV Deboost Cut-off	130x107929	
23:43:00	00:23:00	Attitude and State Vector Update		
23:06:00	00:06:00	Targeting Update		

Table B-4. Planetary - Ground Based - Storable In Bay
(Sheet 3 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
23:12:00		Midcourse (RCS)		
47:43:00	00:23:00	Attitude and State Vector Update		
48:06:00	00:06:00	Targeting Update		
48:12:00		OTV Apogee Deboost Ignition	130x107929	
		OTV Apogee Deboost Cutoff	40x107929	
94:40:00	00:23:00	Attitude and State Vector Update		
95:03:00	00:06:00	Targeting Update		
95:09:00		Midcourse (RCS), 20 fps		
95:44:00	00:23:00	Attitude and State Vector Update		
96:12:00		Atmospheric Entry		
96:16:00		Atmospheric Exit	4x140	
96:16:00	00:03:00	Slew to Jettison Attitude		
96:19:00		Jettison Aerobrake		
96:20:00	00:21:00	Attitude and State Vector Update		
96:41:00		LEO Reboost #1	115x140	203
97:40:00		Adjust Inclination	115x140	
97:47:00	00:23:00	Attitude and State Vector Update		
98:10:00		LEO Reboost #2	140x140	45
98:11:00		Inhibit/Safe OTV Engines		
PHASE:	END OTV DELIVERY AND RETURN		MET - 103:36:00	
PHASE:	ORBITER RENDEZVOUS AND RETRIEVAL		MET - 103:36:00	
01:31:00		Orbiter NH Rendezvous Maneuver	(130x140)	(8.0)
02:21:00		Orbiter NC Maneuver	(134x140)	(6.0)
03:23:00		Orbiter TI Maneuver (OTV Ahead of Orbiter 8 nmi)	(138x140)	(11.0)
04:53:00		Orbiter TF Maneuver (Null Rate at +1000 ft.)	(140x140)	
04:59:00	00:30:00	V-bar Prox Ops to 45 ft. (when lighting cond. correct)		
05:04:00	00:20:00	RMS Power Up/Camera Set Up		
05:29:00	00:15:00	Inhibit OTV RCS; Grapple OTV		
05:44:00	00:45:00	OTV Stowage Ops		
		(Orbiter Deorbit Burn)		(235.0)
PHASE:	END ORBITER RENDEZVOUS AND RETRIEVAL		MET - 110:05:00	

OTV Total fps
(Orbiter OMS Total 565.6 fps)

Table B-5. Planetary - Ground Based - Cryo
(Sheet 1 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	LAUNCH		MET: 00:00:00	
00:00:00		Launch		
00:02:12		SRB Separation		
00:02:36		ACC shroud jettison		
00:08:20		MECO	15.8x79.7	
00:08:35		OTV Separation (2.0 fps; Springs provide ΔV)	14.8x79.2	
00:09:05	00:00:6.0	ET Separation; Begin - Z ΔV (4.0 fps)	(15.8x79.7)	
00:09:11		-Z ΔV Complete	(16.2x79.2)	
00:09:35		Deploy Aerobrake		
00:09:50		Activate OTV RCS (Sep distance from Orb=400 ft)		
00:10:00	00:02:00	Begin Maneuver to Orient Brake toward Orb		
00:12:00		End Maneuver		
00:12:20	00:06:44.5	Orbiter OMS-1 Ignition	(16.0x79.1)	(170.4)
00:18:04.5		Orbiter OMS-1 Cut-off	(55.1x130)	
00:30:00		Begin OTV Engine conditioning (cryo chilldown)		
00:33:28.6	00:00:28.8	OTV Boost-1 Ignition (Sep distance from Orb = 52.34 nmi)	10.5x78.4	227.6
00:33:57.4		OTV Boost-1 Cut-off	63.4x150	
00:36:00		Begin OTV Thermal Roll		
00:44:19.7		Orbiter OMS-2 Ignition	(55.1x130)	(135.2)
00:45:41.7		Orbiter OMS-2 Cut-off	(130x130)	
01:02:00	00:23:00	OTV Attitude and State Vector Update		
01:25:13.7	00:00:17.2	OTV Boost-2 Ignition (Sep distance from Orb = 228.76 nmi)	63.0x140	138.0
01:25:30.9		OTV Boost-2 Cut-off	140x140	
PHASE:	END LAUNCH		MET: 01:25:30.9	
PHASE:	ORBITER OPS AND SEPARATION		MET - 01:25:30.9	

(   ) Orbiter Values

Table B-5. Planetary - Ground Based - Cryo
(Sheet 2 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
00:00:00		Orbiter Phasing Coast		
02:55:00		Orbiter NH-1 Maneuver	(130.0x140)	(17.8)
03:29:19		Orbiter NC-3 Maneuver (OTV Leads Orbiter by 10 nmi)	(133.5x140)	(6.0)
04:59:00		Orbiter NH-2 Maneuver	(140x140)	(11.8)
18:35:00	01:25:00	Orbiter TI Maneuver (OTV ahead of Orbiter 20 nmi due to diff drag)		(21.9)
19:05:00		Inhibit/Safe OTV Main Engine(s) prior to 10,000 ft distance		
19:35:00	00:20:00	Payload checkout		
20:00:00		Orbiter TF Maneuver (Null Rate at 1000 ft ahead of OTV)		
20:05:00	00:30:00	V-bar Prox Ops to 45 ft (when lighting cond correct)		
20:10:00	00:20:00	RMS power up/camera set up		
20:35:00	00:15:00	Inhibit/Safe OTV RCS and Grapple OTV		
20:50:00	00:10:00	RMS Maneuver OTV		
21:00:00	00:15:00	PIDA unlatch and move to OTV mate position		
21:15:00	00:25:00	Mate OTV to PIDA		
21:40:00	00:30:00	Grapple Payload/Mate to OTV		
22:10:00	00:45:00	OTV Interface checkout & Nav update		
22:55:00		Deploy OTV/Payload		
23:00:00	00:10:00	Orbiter Low Z Separation RCS Maneuver - (0.5 fps)		
23:10:00	00:48:00	Orbiter RCS Separation Maneuver to safe distance - (1.0 fps)		
23:17:00		Enable OTV RCS (Orb Dist = 400 ft)		
23:42:00	00:23:00	Attitude and State Vector Update		
24:05:00		Enable OTV Main Engine (Orb dist = 10,000 ft)		

PHASE: END ORBITER OPS AND SEPARATION MET - 25:30:00

Table B-5. Planetary - Ground Based - Cryo
(Sheet 3 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	OTV DELIVERY AND RETURN		MET - 25:30:00	
00:04:00	00:03:00	Maneuver to burn attitude		
00:07:00	00:03:00	Begin Engine Conditioning		
00:12:00		OTV Boost-1 Ignition	270x270	
		OTV Boost-1 Cut-off	270x Hyperbolic	
00:32:00	00:08:00	OTV/SC Separation via 1 fps Spring to Reach 400 ft Dist.		
00:40:00	00:08:00	OTV Separation Burn; 20 fps RCS to reach 10,000 ft dist.		
00:42:00	00:03:00	Maneuver to Burn attitude		
00:45:00	00:03:00	Begin Engine Conditioning		
00:48:00		OTV Deboost Ignition	270xHyperbolic	
		OTV Deboost Cut-off	270x107989	
01:00:00		Orbiter OMS-3 Ignition	(140x140)	(17.8)
		Orbiter OMS-3 Cutoff	(130x140)	
01:45:00		Orbiter OMS-4 Ignition	(130x140)	(17.8)
		Orbiter OMS-4 Cutoff	(130x130)	
23:43:00	00:23:00	Attitude and State Vector Update		
23:06:00	00:06:00	Targeting Update		
23:12:00		Midcourse (RCS)		
47:43:00	00:23:00	Attitude and State Vector Update		
48:06:00	00:06:00	Targeting Update		
48:12:00		OTV Apogee Deboost Ignition	270x107989	
		OTV Apogee Deboost Cutoff	40x107989	
94:40:00	00:23:00	Attitude and State Vector Update		
95:03:00	00:06:00	Targeting Update		
95:09:00		Midcourse (RCS), 20 fps		
95:44:00	00:23:00	Attitude and State Vector Update		
96:12:00		Atmospheric Entry		
96:16:00		Atmospheric Exit	4x140	
96:16:00	00:03:00	Slew to Jettison Attitude		
96:19:00		Jettison Aerobrake		
96:20:00	00:21:00	Attitude and State Vector Update		
96:41:00		LEO Reboost #1	115x140	203
97:40:00		Adjust Inclination	115x140	
97:47:00	00:23:00	Attitude and State Vector Update		
98:10:00		LEO Reboost #2	140x140	42
98:20:00		RCS Trim and Residual Dump, 3 fps		
PHASE:	END OTV DELIVERY AND RETURN		MET - 123:50:00	

Table B-5. Planetary - Ground Based - Cryo
(Sheet 4 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_p x H_A$	ΔV
PHASE:	ORBITER RENDEZVOUS AND RETRIEVAL		MET - 123:50:00	
01:31:00		Orbiter NH Rendezvous Maneuver	(130x140)	(8.0)
02:21:00		Orbiter NC Maneuver	(134x140)	(6.0)
03:23:00		Orbiter TI Maneuver (OTV Ahead of Orbiter 8 nmi)	(138x140)	(11.0)
04:19:00		Inhibit/Safe OTV Main Engine(s) Prior to 10,000 ft Distance		
04:53:00		Orbiter TF Maneuver (Null Rate at 1000 ft ahead of OTV)	(140x140)	
04:59:00	00:30:00	V-bar Prox OPs to 45 ft. (When lighting cond. correct)		
05:04:00	00:20:00	RMS Power Up/Camera Set Up		
05:29:00	00:15:00	Inhibit OTV RCS; Grapple OTV		
05:44:00	03:00:00	OTV Stowage Ops		
		Orbiter Deorbit Burn		(235)
PHASE:	END ORBITER RENDEZVOUS AND RETRIEVAL		MET - 132:34:00	

OTV Total
(Orb OMS Total 658.7)

Table B-6. High Inclination - Ground Based - Storable In Bay
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: LAUNCH			MET - 00:00:00	
00:00:00		Launch		
00:02:12		SRB Separation		
00:08:20		MECO	(15.8x79.7)	
00:09:05	00:00:6.0	ET Separation; Begin - Z ΔV	(15.8x79.7)	
00:09:11		(4.0 fps) -Z ΔV Complete	(16.2x79.2)	
00:12:20	00:06:44.5	Orbiter OMS-1 Ignition	(16.0x79.1)	(170.4)
00:18:04.5		Orbiter OMS-1 Cut-off	(55.1x130)	
00:44:19.7	00:01:22	Orbiter OMS-2 Ignition	(55.1x130)	(135.2)
00:45:41.7		Orbiter OMS-2 Cut-off	(130x130)	
03:00:00	00:20:00	Payload checkout		
03:30:00	00:45:00	OTV Interface checkout & Nav update		
PHASE: END LAUNCH			MET - 04:15:00	
PHASE: ORBITER OPS AND SEPARATION			MET - 04:15:00	
00:00:00		Deploy OTV/Payload (Could be delayed up to 12 hours to achieve desired longitude)		
00:05:00	00:10:00	Orbiter Low Z Separation RCS Maneuver - (0.5 fps)		
00:15:00	00:48:00	Orbiter RCS Separation Maneuver to safe distance - (1.0 fps)		
00:22:00		Enable OTV RCS (Orb Dist = 400 ft)		
00:47:00	00:23:00	Attitude and State Vector Update		
01:10:00		Enable OTV Main Engine (Orb dist = 10,000 ft)		
PHASE: END ORBITER OPS AND SEPARATION			MET - 05:25:00	

( ) Orbiter Values

Table B-6. High Inclination - Ground Based - Storable In Bay
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 05:25:00	
00:07:00	00:03:00	Maneuver to burn attitude		
00:12:00		OTV Boost-1 Ignition	130x130	6737
		OTV Boost-1 Cut-off	130x10898	
00:32:00		Begin Thermal Roll		
02 46:00	00:23:00	Attitude and State Vector Update		
03:09:00		OTV Boost-2 Ignition	130x10898	4673
		OTV Boost-2 Cutoff	10898x10898	
03:24:00	00:08:00	OTV/GPS-1 Separation Via 1 fps Spring to Reach 400 ft Dist.		
03:32:00		OTV Separation Burn; 20 fps RCS		
09:09:00		OTV Boost-3 Ignition (4.9 Deg RAAN Plane Change)	10898x10898	2032
		OTV Boost-3 cutoff	10898 22148	
18:59:00		OTV Boost-4 Ignition (38.6 Deg RAAN Plane Change)	10898x22148	5338
		OTV Boost-4 Cutoff	10898 22148	
28:48:00		OTV Boost-5 Ignition (4.9 Deg RAAN Plane Change)	10898x22148	2032
		OTV Boost-5 Cutoff	10898x10898	
29:03:00	00:08:00	OTV/GPS-2 Separation via 1 fps Spring to Reach 400 Ft Distance		
29:11:00		OTV Separation Burn; 10 fps RCS		
30:00:00		OTV Shuttle Phasing Maneuver		
83:46:00	00:23:00	Attitude and State Vector Update		
84:09:00	00:03:00	Maneuver to Burn attitude		
84:12:00		OTV Deboost Ignition (34.8 Deg RAAN Plane Change)	10898x10898	7643
		OTV Deboost Cut-off	40x10898	
85:39:00	00:23:00	Attitude and State Vector Update		
86:02:00	00:06:00	Targeting Update		
86:08:00		Midcourse (RCS), 20 fps		
86:40:00	00:23:00	Attitude and State Vector Update		
87:08:00		Atmospheric Entry		
87:12:00		Atmospheric Exit	4x140	
87:12:00	00:03:00	Slew to Jettison Attitude		
87:15:00		Jettison Aerobrake		
87:16:00	00:21:00	Attitude and State Vector Update		

Table B-6. High Inclination - Ground Based - Storable In Bay
(Sheet 3 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
87:37:00		LEO Reboost #1	115x140	203
88:36:00		Adjust Inclination	115x140	
88:43:00	00:23:00	Attitude and State Vector Update		
89:06:00		LEO Reboost #2	140x140	45
PHASE: END OTV DELIVERY AND RETURN			MET - 94:31:00	
PHASE: ORBITER RENDEZVOUS AND RETRIEVAL			MET - 94:31:00	
01:31:00		Orbiter NH Rendezvous Maneuver	(130x140)	(8.0)
02:21:00		Orbiter NC Maneuver	(134x140)	(6.0)
03:23:00		Orbiter TI Maneuver (OTV Ahead of Orbiter 8 nmi)	(138x140)	(11.0)
04:19:00		Inhibit/Safe OTV Main Engine		
04:53:00		Orbiter TF Maneuver (Null Rate at +1000 ft.)	(140x140)	
04:59:00	00:30:00	V-bar Prox Ops to 45 ft. (when lighting cond. correct)		
05:04:00	00:20:00	RMS Power Up/Camera Set Up		
05:29:00	00:15:00	Inhibit OTV RCS; Grapple OTV		
05:44:00	00:45:00	OTV Stowage Ops (Orbiter Deorbit Burn)		(235.0)
PHASE: END ORBITER RENDEZVOUS AND RETRIEVAL			MET - 101:00:00	

OTV Total 28703 fps
(Orb OMS Total 565.6 fps)

Table B-7. GEO Delivery - Space-Based - Storable
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	Δ V
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity at	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RLS		
01:43:00		OMV return maneuver		
02:31:20		OTV Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

Table B-7. GEO Delivery - Space-Based - Storable
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	OTV DELIVERY AND RETURN		MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for nodal crossing		
00:47:00		OTV Boost-1 Ignition	270x270	7774.8
		OTV Boost-1 Cut-off	270x19323	
01:06:00		Begin Thermal Roll		
04:24:00	00:23:00	Attitude and State Vector Update		
04:47:00	00:08:00	OTV Separation via 1 fps Spring to Reach 400 ft Dist.		
04:55:00		OTV Separation Burn; 20 fps RCS		
05:56:45	00:03:00	OTV Maneuver to Aeroshield Protect Attitude		
05:59:45	00:10:00	SC Apogee Burn		
06:09:45	00:23:00	Attitude and State Vector Update		
06:32:45	00:03:00	Maneuver to Burn Attitude		
06:35:00		OTV Deboost Ignition	270x19323	
		OTV Deboost Cut-off	40x19350	
10:05:00	00:23:00	Attitude and State Vector Update		
10:28:00	00:06:00	Targeting Update		
10:34:00		Midcourse (RCS), 20 fps		
11:04:00	00:23:00	Attitude and State Vector Update		
11:34:00		Atmospheric Entry		
11:38:00		Atmospheric Exit (8076 fps equiv)	4x245	
11:40:00	00:23:00	Attitude and State Vector Update		
12:03:00		LEO Reboost #1	245x245	427
12:53:00		Adjust Inclination	245x245	
13:17:00	00:23:00	State Vector Update Update		
13:40:00		LEO Reboost #2	245x270	42
14:27:00		LEO Reboost #3	270x270	42
14:45:00		RCS Trim		
14:45:00		Inhibit/Safe OTV Main Engine(s)		
PHASE:	END OTV DELIVERY AND RETURN		MET - 17:16:20	

Table B-7. GEO Delivery - Space-Based - Storable
(Sheet 3 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS RENDEZVOUS - CAPTURE			MET - 17:16:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE: END OTV/SS RENDEZVOUS - CAPTURE			MET - 19:59:20	
		OTV TOTAL		fps

Table B-8. GEO Delivery - Space-Based - Cryo
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity at	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RLS		
01:43:00		OMV return maneuver		
02:31:20		OTV Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

Table B-8. GEO Delivery - Space-Based - Cryo
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	H_PxH_A	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for nodal crossing		
00:44:00	00:03:00	Begin engine conditioning (cryo chilldown)		
00:47:00		OTV Boost-1 Ignition	270x270	7774.8
		OTV Boost-1 Cut-off	270x19323	
01:06:00		Begin Thermal Roll		
05:38:45	00:23:00	Attitude and State Vector Update		
06:01:45	00:03:00	Maneuver to Burn attitude		
06:04:45		Begin Engine Conditioning		
06:07:45		OTV Boost-2 Ignition	270x19323	5964.6
		OTV Boost-2 Cut-off	19323x19323	
06:45:00		S/C Checkout & Separation		
29:12:00	00:23:00	Attitude and State Vector Update		
29:35:00	00:03:00	Maneuver to Burn Attitude		
29:38:00	00:03:00	Begin Engine Conditioning		
29:41:00	00:01:56	OTV Deboost Ignition	19323x19323	6049.6
29:42:56		OTV Deboost Cut-off	40x19350	
33:22:00	00:23:00	Attitude and State Vector Update		
33:45:00	00:06:00	Targeting Update		
33:51:00		Midcourse (RCS), 20 fps		
34:06:00	00:23:00	Attitude and State Vector Update		
34:54:00		Atmospheric Entry		
34:58:00		Atmospheric Exit	4x245	
35:01:00		Open Brake Door(s)		
35:02:00	00:21:00	Attitude and State Vector Update		
35:22:00	00:03:00	Begin Engine Conditioning		
35:25:00		LEO Reboost #1	245x245	427
36:12:00		Adjust Inclination	245x245	
36:33:00	00:23:00	State Vector Update		
36:56:00	00:03:00	Begin Engine Conditioning		
36:59:00		LEO Reboost #2	245x270	42
37:46:00		LEO Reboost #3	270x270	42
37:52:00		RCS Trim		
37:53:00		Inhibit/Safe OTV Main Engine(s)		
PHASE: END OTV DELIVERY AND RETURN			MET - 40:24:20	

Table B-8. GEO Delivery - Space-Based - Cryo
(Sheet 3 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS RENDEZVOUS - CAPTURE			MET - 40:24:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE: END OTV/SS RENDEZVOUS - CAPTURE			MET - 43:07:20	
			OTV TOTAL	20300 fps

Table B-9. Planetary - Space-Based - Storable
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_p x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV return maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for C_3 vector crossing		
00:44:00		OTV Boost-1 Ignition	270x270	
		OTV Boost-1 Cut-off	270xHyperbolic	
01:04:00	00:08:00	OTV/SC Separation via 1 fps Spring to reach 400 ft Dist.		
01:12:00	00:08:00	OTV separation burn; 20 fps RCS to reach 10,000 ft dist.		
01:17:00	00:03:00	Maneuver to Burn Attitude		
01:20:00		OTV Deboost Ignition	270xHyperbolic	
		OTV Deboost Cut-off	270x107789	
23:28:00	00:23:00	Attitude and State Vector Update		
23:51:00	00:06:00	Targeting Update		
23:57:00		Midcourse (RCS)		

Table B-9. Planetary - Space-Based - Storable
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	OTV DELIVERY AND RETURN		MET - 02:31:20	
48:15:00	00:23:00	Attitude and State Vector Update		
48:38:00	00:06:00	Targeting Update		
48:44:00		OTV Apogee Deboost Ignition	130x107929	
		OTV Apogee Deboost Cutoff	40x107929	
95:12:00	00:23:00	Attitude and State Vector Update		
95:33:00	00:06:00	Targeting Update		
95:41:00		Midcourse (RCS), 20 fps		
96:16:00	00:23:00	Attitude and State Vector Update		
96:44:00		Atmospheric Entry		
96:48:00		Atmospheric Exit	4x245	
96:49:00	00:21:00	Attitude and State Vector Update		
97:13:00		LEO Reboost #1	245x245	427
98:00:00		Adjust Inclination	245x245	
98:24:00	00:23:00	Attitude and State Vector Update		
98:47:00		LEO Reboost #2	245x270	42
99:34:00		LEO Reboost #3	270x270	42
99:40:00		RCS Trim (10 fps)		
99:41:00		Inhibit/Safe OTV Main Engine(s)		
PHASE:	END OTV DELIVERY AND RETURN		MET - 102:12:20	

Table B-9. Planetary - Space-Based - Storable
(Sheet 3 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS RENDEZVOUS - CAPTURE			MET - 102:12:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE: END OTV/SS RENDEZVOUS - CAPTURE			MET - 104:55:20	
		OTV TOTAL		fps

Table B-10. Hyperbolic Planetary - Space-Based - Cryo
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_p x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV return maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

Table B-10. Hyperbolic Planetary - Space-Based - Cryo
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	OTV DELIVERY AND RETURN		MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for C_3 Vector crossing		
00:44:00	00:03:00	Begin engine conditioning (cryo chilldown)		
00:47:00		OTV Boost-1 Ignition (Hyperbolic inject)	270x270	TBD
		OTV Boost-1 Cut-off	270xHyperbolic	
01:07:00		S/C Separation to 400 ft		
01:15:00		OTV separation burn; 20 fps RCS to 10,000 ft dist.		
01:17:00	00:03:00	Maneuver to Burn Attitude		
01:20:00	00:03:00	Begin Engine Conditioning		
01:23:00		OTV Deboost Ignition	270xHyperbolic	
		OTV Deboost Cut-off	270x107789	
23:31:00	00:23:00	Attitude and State Vector Update		
23:54:00	00:06:00	Targeting Update		
24:00:00		Midcourse (RCS)		
48:18:00		Attitude and State Vector Update		
48:41:00		Targeting Update		
48:47:00		OTV Apogee Deboost Ignition	270x107789	
		OTV Apogee Deboost Cutoff	40x107789	
95:15:00	00:23:00	Attitude and State Vector Update		
95:38:00	00:06:00	Targeting Update		
95:44:00		Midcourse (RCS), 20 fps		
96:19:00	00:23:00	Attitude and State Vector Update		
96:47:00		Atmospheric Entry		
96:51:00		Atmospheric Exit	4x245	
96:52:00	00:21:00	Attitude and State Vector Update		
97:13:00	00:03:00	Begin Engine Conditioning		
97:16:00		LEO Reboost #1	245x245	427
98:03:00		Adjust Inclination	245x245	
98:24:00	00:23:00	Attitude and State Vector Update		
98:47:00	00:03:00	Begin Engine Conditioning		
98:50:00		LEO Reboost #2	245x270	42
99:37:00		LEO Reboost #3	270x270	42
99:43:00		RCS Trim, 10 fps		
99:44:00		Inhibit/Safe OTV Main Engine(s)		
PHASE:	END OTV DELIVERY AND RETURN		MET - 102:15:20	

Table B-10. Hyperbolic Planetary - Space-Based - Cryo
(Sheet 3 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS RENDEZVOUS - CAPTURE			MET - 102:15:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE: END OTV/SS RENDEZVOUS - CAPTURE				MET - 104:58:20
			OTV TOTAL	fps

Table B-11. Low G GEO Delivery - Space-Based - Storable
(Sheet 1 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV return maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

Table B-11. Low G GEO Delivery - Space-Based - Storable
(Sheet 2 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for nodal crossing		
00:47:00	TBD	OTV Boost-1 Ignition	270x270	
TBD		OTV Boost-1 Cut-off		
01:06:00		Begin Thermal Roll		
		Begin Thermal Roll		
	00:03:00	Maneuver to Burn attitude		
	TBD	OTV Boost-2 Ignition		
TBD		OTV Boost-2 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
	TBD	OTV Boost-3 Ignition		
TBD		OTV Boost-3 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
	TBD	OTV Boost-4 Ignition		
TBD		OTV Boost-4 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
	TBD	OTV Boost-5 Ignition		
TBD		OTV Boost-5 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		

B-11. Low G GEO Delivery - Space-Based - Storable
(Sheet 3 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
	00:03:00	Maneuver to Burn attitude		
	TBD	OTV Boost-6 Ignition		
TBD		OTV Boost-6 Cut-off	270x____	
	00:03:00	Maneuver to Burn attitude		
	TBD	OTV Boost-7 Ignition		
19:04:00		OTV Boost-7 Cut-off	270x____	
19:10:00	00:30:00	S/C Separation		
19:40:00		OTV Separation Burn RCS 10fps		
23:42:00	00:23:00	Attitude and State Vector Update		
24:05:00	00:03:00	Maneuver to Burn Attitude		
24:08:00		OTV Deboost-8 Ignition	270x____	
		OTV Deboost-8 Cutoff	40x____	
27:36:00	00:23:00	Attitude and State Vector Update		
27:59:00	00:06:00	Targeting Update		
28:05:00		Midcourse (RCS), 20 fps		
28:32:00	00:23:00	Attitude and State Vector		
		OTV Deboost Cut-off	40x19350	
29:08:00		Atmospheric Entry		
29:12:00		Atmospheric Exit	4x245	
29:18:00	00:21:00	Attitude and State Vector Update		
29:39:00		LEO Reboost #1	245x245	427
30:26:00		Adjust Inclination	245x245	
30:50:00	00:23:00	State Vector Update		
31:13:00		LEO Reboost #2	245x270	42
32:00:00		LEO Reboost #3	270x270	42
32:06:00		RCS Trim		
32:07:00		Inhibit/Safe OTV Main Engine(s)		

PHASE: END OTV DELIVERY AND RETURN MET - 34:38:20

Table B-11. Low G GEO Delivery - Space-Based - Storable
(Sheet 4 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	OTV/SS RENDEZVOUS - CAPTURE		MET - 34:38:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE:	END OTV/SS RENDEZVOUS - CAPTURE		MET - 37:21:20	
		OTV TOTAL		

Table B-12. Low G GEO Delivery - Space-Based - Cryo

(Sheet 1 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV return maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

Table B-12. Low G GEO Delivery - Space-Based - Cryo
(Sheet 2 of 4)

PET (HMS)	DURATION (HMS)	EVENT	H_PxH_A	ΔV
PHASE:	OTV DELIVERY AND RETURN		MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for nodal crossing		
00:44:00	00:03:00	Begin engine conditioning (cryo childown)		
00:47:00	TBD	OTV Boost-1 Ignition	270x270	
TBD		OTV Boost-1 Cut-off	270x____	
01:06:00		Begin Thermal Roll		
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
		Begin Engine Conditioning		
	TBD	OTV Boost-2 Ignition		
TBD		OTV Boost-2 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
		Begin Engine Conditioning		
	TBD	OTV Boost-3 Ignition		
TBD		OTV Boost-3 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
		Begin Engine Conditioning		
	TBD	OTV Boost-4 Ignition		
TBD		OTV Boost-4 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		
	00:03:00	Maneuver to Burn attitude		
		Begin Engine Conditioning		
	TBD	OTV Boost-5 Ignition		
TBD		OTV Boost-5 Cut-off	270x____	
		Begin Thermal Roll		
	00:23:00	Attitude and State Vector Update		

Table B-12. Low G GEO Delivery - Space-Based - Cryo
(Sheet 3 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
	00:03:00	Maneuver to Burn attitude		
		Begin Engine Conditioning		
	TBD	OTV Boost-6 Ignition		
TBD		OTV Boost-6 Cut-off	270x____	
	00:03:00	Maneuver to Burn attitude		
		Begin Engine Conditioning		
	TBD	OTV Boost-7 Ignition		
TBD		OTV Boost-7 Cut-off	270x____	
00:03:00		Maneuver to Burn Attitude		
00:03:00		Begin Engine Conditioning		
		OTV Boost-8 Ignition		
		OTV Boost-8 Cutoff	19323x19323	
24:48:00		S/C Separation		
48:18:00	00:23:00	Attitude and State Vector Update		
48:41:00	00:03:00	Maneuver to Burn Attitude		
48:44:00	00:03:00	Begin Engine Conditioning		
48:47:00		OTV Deboost Ignition	19323x19323	6049.6
		OTV Deboost Cut-off	40x19350	
52:27:00	00:23:00	Attitude and State Vector Update		
52:50:00	00:06:00	Targeting Update		
52:56:00		Midcourse (RCS), 20 fps		
53:11:00	00:23:00	Attitude and State Vector Update		
53:54:00		Atmospheric Entry		
54:03:00		Atmospheric Exit	4x245	
54:06:00	00:21:00	Attitude and State Vector Update		
54:27:00	00:03:00	Begin Engine Conditioning		
54:30:00		LEO Reboost #1	245x245	427
55:17:00		Adjust Inclination	245x245	
55:38:00	00:23:00	State Vector Update		
56:01:00	00:03:00	Begin Engine Conditioning		
56:04:00		LEO Reboost #2	245x270	42
56:51:00		LEO Reboost #3	270x270	42
56:57:00		RCS Trim		
56:58:00		Inhibit/Safe OTV Main Engine(s)		
PHASE: END OTV DELIVERY AND RETURN			MET - 59:29:20	

Table B-12. Low G GEO Delivery - Space-Based - Cryo
(Sheet 4 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE:	OTV/SS RENDEZVOUS - CAPTURE		MET - 59:29:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE:	END OTV/SS RENDEZVOUS - CAPTURE		MET - 62:12:20	
		OTV TOTAL		

Table B-13. GEO Manned Servicing+ - Space-Based - Storable (Sheet 1 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV return maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

+ Unmanned Mission is 192 hrs (8 days) shorter in OTV delivery and return phase.

Table B-13. GEO Manned Servicing - Space-Based - Storable
(Sheet 2 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV-S1 (Stage 1) Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for nodal crossing		
00:47:00		OTV-S1 Boost Ignition	270x270	7774.8
		OTV-S1 Boost Cut-off	270x19323	
		OTV-S1 Separation		
		OTV-S1 20 fps retro sep Burn		
01:06:00		Begin Thermal Roll		
05:37:00	00:23:00	OTV-S1 Attitude and State Vector Update		
06:00:00	00:03:00	OTV S-1 Maneuver to Burn Attitude		
06:03:00		OTV-S1 Deboost Ignition	19323x19323	6049.6
		OTV-S1 Deboost Cut-off	40x19350	
05:42:00	00:23:00	OTV-S2 Attitude and State Vector Update		
06:05:00	00:03:00	OTV-S2 Maneuver to Burn attitude		
06:08:00		OTV-S2 Boost Ignition	270x19323	5964.6
		OTV-S2 Boost Cut-off	19323x19323	
06:31:00		OTV-S2/Servicing Module Separation		
		On-Orbit Servicing Begins		
09:29:00	00:23:00	OTV-S1 Attitude and State Vector Update		
09:52:00	00:06:00	OTV-S1 Targeting Update		
09:58:00		OTV-S1 Midcourse (RCS), 20 fps		
10:36:00	00:23:00	OTV-S1 Attitude and State Vector Update		
11:02:00		OTV-S1 Atmospheric Entry		
11:06:00		OTV-S1 Atmospheric Exit	4x245	
11:10:00	00:23:00	OTV-S1 Attitude and State Vector Update		
11:33:00		OTV-S1 LEO Reboost #1	245x245	427
12:20:00		OTV-S1 Adjust Inclination	245x245	

Table B-13. GEO Manned Servicing - Space-Based - Storable (Sheet 3 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN				
12:39:00	00:23:00	OTV-S1 State Vector Update		
13:07:00		OTV-S1 LEO Reboost #2	245x270	42
13:54:00		LEO Reboost #3	270x270	42
14:00:00		OTV-S1 RCS Trim		
14:01:00		Inhibit/Safe OTV-S1 Main Engine(s)		10
439:00:00		Servicing Module Rendezvous with OTV-S2		
440:00:00	00:30:00	Servicing Module Mates with OTV-S2		
441:20:00	00:23:00	OTV-S2 Attitude and State Vector Update		
441:43:00	00:03:00	OTV-S2 Maneuver to Burn Attitude		
441:46:00*		OTV-S2 Deboost Ignition (when Coplanar with SS)	19323x19323	6049.6
		OTV-S2 Deboost Cut-off	40x19350	
445:15:00	00:23:00	OTV-S2 Attitude and State Vector Update		
445:38:00	00:06:00	OTV-S2 Targeting Update		
445:44:00		OTV-S2 Midcourse (RCS), 20 fps		
446:21:00	00:23:00	OTV-S2 Attitude and State Vector Update		
446:47:00		OTV-S2 Atmospheric Entry		
446:51:00		OTV-S2 Atmospheric Exit	4x245	
446:55:00	00:23:00	OTV-S2 Attitude and State Vector Update		
447:18:00		OTV-S2 LEO Reboost #1	245x245	427
448:05:00		OTV-S2 Adjust Inclination	115x270	
448:29:00	00:23:00	OTV-S2 Attitude and State Vector Update		
448:52:00		OTV-S2 LEO Reboost #2	245x270	42
449:39:00		LEO Reboost #3	270x270	42
449:45:00		OTV-S2 RCS Trim, 10 fps		
449:46:00*		Inhibit/Safe OTV-S2 Main Engine(s)		
PHASE: END OTV DELIVERY AND RETURN			MET - 452:17:20*+	

Table B-13. GEO Manned Servicing - Space-Based - Storable
(Sheet 4 of 4)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV-S1/SS RENDEZVOUS - CAPTURE			MET - 00:16:32:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV-S1		
00:29:30		OTV-S1 Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV-S1		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV-S1/OMV Grappled by SS Crane		
PHASE: END OTV-S1/SS RENDEZVOUS - CAPTURE			MET - 00:19:15:20	
PHASE: OTV-S2/SS RENDEZVOUS - CAPTURE			MET - 452:17:20*+	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV-S2/Servicing Module		
00:29:30		OTV-S2 Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV-S2/Servicing Module		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV-S2/Servicing Module/OMV Grappled by SS Crane		
PHASE: END OTV-S2/SS RENDEZVOUS - CAPTURE			MET - 455:00:20+	

+ Unmanned mission is 192 hrs (8 days) shorter;
  Total mission duration: 263:00:20

Table B-14. GEO Manned+ Servicing - Space-Based Cryo

(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV return maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

\+ Unmanned Servicing Mission is 192 hrs (8 days) shorter in OTV delivery and return phase.

Table B-14. GEO Manned Servicing - Space-Based Cryo
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV Main Engine		
00:26:00	00:03:00	Maneuver to Burn Attitude		
00:29:00	00:15:00	Wait for Nodal Crossing		
00:44:00	00:03:00	Begin Engine Conditioning (Cryo Childown)		
00:47:00		OTV Boost-1 Ignition	270x270	7774.8
		OTV Boost-1 Cut-off	270x19323	
01:06:00		Begin Thermal Roll		
05:39:00	00:23:00	Attitude and State Vector Update		
06:02:00	00:03:00	Maneuver to Burn attitude		
06:05:00		Begin Engine Conditioning		
06:08:00		OTV Boost-2 Ignition	270x19323	5964.6
		OTV Boost-2 Cut-off	19323x19323	
06:10:00		Servicing Module Separation		
06:10:00		Onorbit Servicing Begins		
439:00:00		Servicing Module Rendezvous with OTV		
440:00:00		Servicing Module Mates with OTV		
441:17:00	00:23:00	Attitude and State Vector Update		
441:40:00	00:03:00	Maneuver to Burn Attitude		
441:43:00	00:03:00	Begin Engine Conditioning		
441:46:00*	00:01:56	OTV Deboost Ignition	19323x19323	6049.6
		OTV Deboost Cut-off	40x19350	
445:15:00	00:23:00	Attitude and State Vector Update		
445:38:00	00:06:00	Targeting Update		
445:44:00		Midcourse (RCS), 20 fps		
446:21:00	00:23:00	Attitude and State Vector Update		
446:47:00		Atmospheric Entry		
446:51:00		Atmospheric Exit	4x245	
446:54:00		Open Brake Door(s)		
446:55:00	00:21:00	Attitude and State Vector Update		
447:15:00	00:03:00	Begin Engine Conditioning		
447:18:00		LEO Reboost #1	245x245	427
448:05:00		Adjust Inclination	245x245	
448:26:00	00:23:00	State Vector Update		
448:49:00	00:03:00	Begin Engine Conditioning		

Table B-14. GEO Manned Servicing - Space-Based Cryo
(Sheet 3 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
448:52:00		LEO Reboost #2	245x270	42
449:39:00		LEO Reboost #3	270x270	42
449:45:00		RCS Trim		
449:46:00*		Inhibit/Safe OTV Main Engine(s)		

PHASE: END OTV DELIVERY AND RETURN MET - 452:17:20+

PHASE: OTV/SS RENDEZVOUS - CAPTURE MET - 452:17:20+

Note: OTV at 25 nmi from SS

00:00:00	00:30:00	OMV Begins Final Approach to OTV
00:29:30		OTV Inhibits/Safes RCS Engines
00:30:00		OMV Attaches to OTV/Servicing Module
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position
02:43:00		OTV/OMV Grappled by SS Crane

PHASE: END OTV/SS RENDEZVOUS - CAPTURE MET - 455:00:20+

OTV TOTAL 20268 fps

\+ Unmanned MIssion is 192 hrs (8 days) shorter;
Total mission duration: 263:00:20

Table B-15. High Inclination - Space-Based
(Sheet 1 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity at	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RLS		
01:43:00		OMV return maneuver		
02:31:20		OTV Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

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Table B-15. High Inclination - Space-Based
(Sheet 2 of 3)

PET (HMS)	DURATION (HMS)	EVENT	$H_p x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:07:00	00:03:00	Maneuver to burn attitude		
00:12:00		OTV Boost-1 Ignition (3.3 Deg Inc Change)	270x270	6696
		OTV Boost-1 Cut-off	270x10898	
00:32:00		Begin Thermal Roll		
02:48:00	00:23:00	Attitude and State Vector Update		
03:11:00		OTV Boost-2 Ignition (23.2 Deg Inc Change)	270x10898	6131
		OTV Boost-2 Cutoff	10898x10898	
03:26:00	00:08:00	OTV/GPS-1 Separation Via 1 fps Spring to Reach 400 ft Dist.		
03:34:00		OTV Separation Burn; 20 fps RCS		
09:11:00		OTV Boost-3 Ignition (4.9 Deg RAAN Plane Change)	10898x10898	2032
		OTV Boost-3 cutoff	10898 22148	
19:01:00		OTV Boost-4 Ignition (38.6 Deg RAAN Plane Change)	10898x22148	5338
		OTV Boost-4 Cutoff	10898 22148	
28:50:00		OTV Boost-5 Ignition (4.9 Deg RAAN Plane Change)	10898x22148	2032
		OTV Boost-5 Cutoff	10898x10898	
29:05:00	00:08:00	OTV/GPS-2 Separation via 1 fps Spring to Reach 400 Ft Distance		
29:13:00		OTV Separation Burn; 10 fps RCS		
30:02:00		OTV Station Phasing Maneuver	10898x10898	100
209:36:00	00:23:00	Attitude and State Vector Update		
209:59:00	00:03:00	Maneuver to Burn attitude		
210:02:00		OTV Deboost Ignition	10898x10898	6624
		OTV Deboost Cut-off	40x10898	
212:58:00	00:23:00	Attitude and State Vector Update		
213:21:00	00:06:00	Targeting Update		
213:27:00		Midcourse (RCS)		
213:59:00	00:23:00	Attitude and State Vector Update		
214:27:00		Atmospheric Entry		
214:31:00		Atmospheric Exit	4x245	
214:35:00	00:23:00	Attitude and State Vector Update		

Table B-15. High Inclination - Space-Based
(Sheet 3 of 3)

TIME (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
214:58:00		LEO Reboost #1	245x245	427
215:45:00		Adjust Inclination	245x245	
216:09:00	00:23:00	Attitude and State Vector Update		
216:32:00		LEO Reboost #2	245x270	42
217:19:00		LEO Reboost #3	270x270	42
217:25:00		RCS Trim 10 fps		
217:26:00		Inhibit/safe OTV Main Engine(s)		
PHASE: END OTV DELIVERY AND RETURN			MET - 219:57:20	
PHASE: OTV/SS RENDEZVOUS - CAPTURE			MET - 219:57:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV		
00:29:30		OTV Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV/OMV Grappled by SS Crane		
PHASE: END OTV/SS RENDEZVOUS - CAPTURE			MET - 222:40:20	

OTV TOTAL 29464 fps

Table B-16. Lunar - Space-Based - Cryo
(Sheet 1 of 5)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV/SS SEPARATION			MET - 00:00:00	
00:00:00		OTV/Payload/OMV Receives 1 fps Velocity	270 x 270	
00:55:00		OTV clears SS Zone 1, 3280 ft		
00:58:20		OMV RCS Separation, 7 fps Retro burn		
01:00:00		OMV separation from OTV/Payload		
01:10:00		Activate OTV RCS		
01:43:00		OMV Return Maneuver		
02:31:20		OTV/Payload Clears SS Zone 2 SS Dist 20 nmi		
PHASE: END OTV/SS SEPARATION			MET - 02:31:20	

Table B-17. Lunar - Space-Based - Cryo
(Sheet 2 of 5)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV DELIVERY AND RETURN			MET - 02:31:20	
00:00:00	00:23:00	Attitude and State Vector Update		
00:23:00		Enable OTV-S1 (Stage 1) Main Engine		
00:26:00	00:03:00	Maneuver to burn attitude		
00:29:00	00:15:00	Wait for nodal crossing		
00:43:00	00:03:00	Begin Engine Conditioning		
00:47:00		OTV-S1 Boost Ignition	270x270	4984
		OTV-S1 Boost Cut-off	270x6081	
		OTV-S1 Separation		
01:30:00		OTV-S1 20 fps retro sep Burn		
01:36:00		Begin Thermal Roll		
02:03:00	00:23:00	OTV-S1 Attitude and State Vector Update		
02:10:00	00:23:00	OTV-S2 Attitude and State Vector Update		
02:29:00	00:03:00	OTV-S1 Maneuver to Burn Attitude		
02:32:00	00:03:00	Begin Engine Conditioning		
02:33:00	00:03:00	OTV-S2 Maneuver to Burn attitude		
02:35:00		OTV-S1 Deboost Ignition	270x6081	
		OTV-S1 Deboost Cut-off	40x6081	
02:37:00	00:03:00	Begin Engine Conditioning		
02:40:00		OTV-S2 Boost Ignition	270x6081	5366
		OTV-S2 Boost Cut-off	19323xLunar Inject	
04:48:00	00:23:00	OTV-S1 Attitude and State Vector Update		
05:11:00	00:06:00	OTV-S1 Targeting Update		
05:17:00		OTV-S1 Midcourse (RCS)		

Table B-16. Lunar - Space-Based - Cryo
(Sheet 3 of 5)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
05:51:00	00:23:00	OTV-S1 Attitude and State Vector Update		
06:17:00		OTV-S1 Atmospheric Entry		
06:21:00		OTV-S1 Atmospheric Exit	4x245	
06:25:00	00:23:00	OTV-S1 Attitude and State Vector Update		
06:48:00		OTV-S1 LEO Reboost #1	245x245	427
07:35:00		OTV-S1 Adjust Inclination	245x245	
07:59:00	00:23:00	OTV-S1 State Vector Update		
08:22:00	TBD	OTV-S1 LEO Reboost #2	245x270	42
09:09:00		OTV-S1 LEO Reboost #3	270x270	42
09:15:00		OTV-S1 RCS Trim (10 fps)		
09:16:00		Inhibit/Safe OTV-S1 Main Engine(s)		
44:11:00	00:23:00	OTV-S2 Attitude and State Vector Update		
44:34:00	00:06:00	OTV-S2 Targeting Update		
44:40:00		OTV-S2 Midcourse		180
86:08:00	00:23:00	OTV-S2 Attitude and State Vector Update		
86:31:00	00:06:00	OTV-S2 Targeting Update		
86:37:00	00:03:00	Begin Engine Conditioning		
86:40:00		OTV-S2 Lunar Insertion Burn Ignition	270xLunar Inject	2690
		OTV-S2 Burn Cutoff	Lunar Orbit	
87:00:00		OTV-S2/Lunar Module Separation		
460:00:00		Lunar Module Rendezvous with OTV-S2		
461:00:00	00:30:00	Lunar Module Mates with OTV-S2		
462:11:00	00:23:00	OTV-S2 Attitude and State Vector Update		
462:34:00	00:03:00	OTV-S2 Maneuver to Burn Attitude		
462:37:00	00:03:00	Begin Engine conditioning		
462:40:00		OTV-S2 Deboost Ignition	Lunar Orbit	2690
		OTV-S2 Deboost Cut-off	40xLunar	
504:11:00	00:23:00	OTV-S2 Attitude and State Vector Update		
504:34:00	00:06:00	OTV-S2 Targeting Update		
504:40:00		OTV-S2 Midcourse #1		180
545:11:00	00:23:00	OTV-S2 Attitude and State Vector Update		
545:34:00	00:06:00	OTV-S2 Targeting Update		
545:40:00		OTV-S2 Midcourse #2		310

Table B-16. Lunar - Space-Based - Cryo
(Sheet 4 of 5)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
546:14:00	00:23:00	OTV-S2 Attitude and State Vector Update		
546:40:00		OTV-S2 Atmospheric Entry		
546:44:00		OTV-S2 Atmospheric Exit	4x245	
546:48:00	00:23:00	OTV-S2 Attitude and State Vector Update		
547:11:00		OTV-S2 LEO Reboost #1	245x245	427
547:58:00		OTV-S2 Adjust Inclination	245x245	
548:22:00	00:23:00	OTV-S2 Attitude and State Vector Update		
548:45:00	TBD	OTV-S2 LEO Reboost #2	245x270	42
549:32:00		OTV-S2 LEO Reboost #3	270x270	42
549:38:00		OTV-S2 RCS Trim (10 fps)		
549:39:00		Inhibit/Safe OTV-S2 Main Engine(s)		

PHASE: END OTV DELIVERY AND RETURN — MET - 551:18:20

PHASE: OTV-S1/SS RENDEZVOUS - CAPTURE — MET - 11:47:20

Note: OTV at 25 nmi from SS

00:00:00	00:30:00	OMV Begins Final Approach to OTV-S1
00:29:30		OTV-S1 Inhibits/Safes RCS Engines
00:30:00		OMV Attaches to OTV-S1
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position
02:43:00		OTV-S1/OMV Grappled by SS Crane

PHASE: END OTV-S1/SS RENDEZVOUS - CAPTURE — MET - 14:30:20

Table B-16. Lunar - Space-Based - Cryo
(Sheet 5 of 5)

PET (HMS)	DURATION (HMS)	EVENT	$H_P x H_A$	ΔV
PHASE: OTV-S2/SS RENDEZVOUS - CAPTURE			MET - 552:10:20	
Note: OTV at 25 nmi from SS				
00:00:00	00:30:00	OMV Begins Final Approach to OTV-S2/Servicing Module		
00:29:30		OTV-S2 Inhibits/Safes RCS Engines		
00:30:00		OMV Attaches to OTV-S2/Servicing Module		
00:40:00	01:33:00	OMV Approach to SS via 6 fps Retro Burn		
02:13:00	00:30:00	OMV Brake Burn and V-Bar Prox Ops to Grapple Position		
02:43:00		OTV-S2/Servicing Module/OMV Grappled by SS Crane		
PHASE: END OTV-S2/SS RENDEZVOUS - CAPTURE			MET - 554:53:20	