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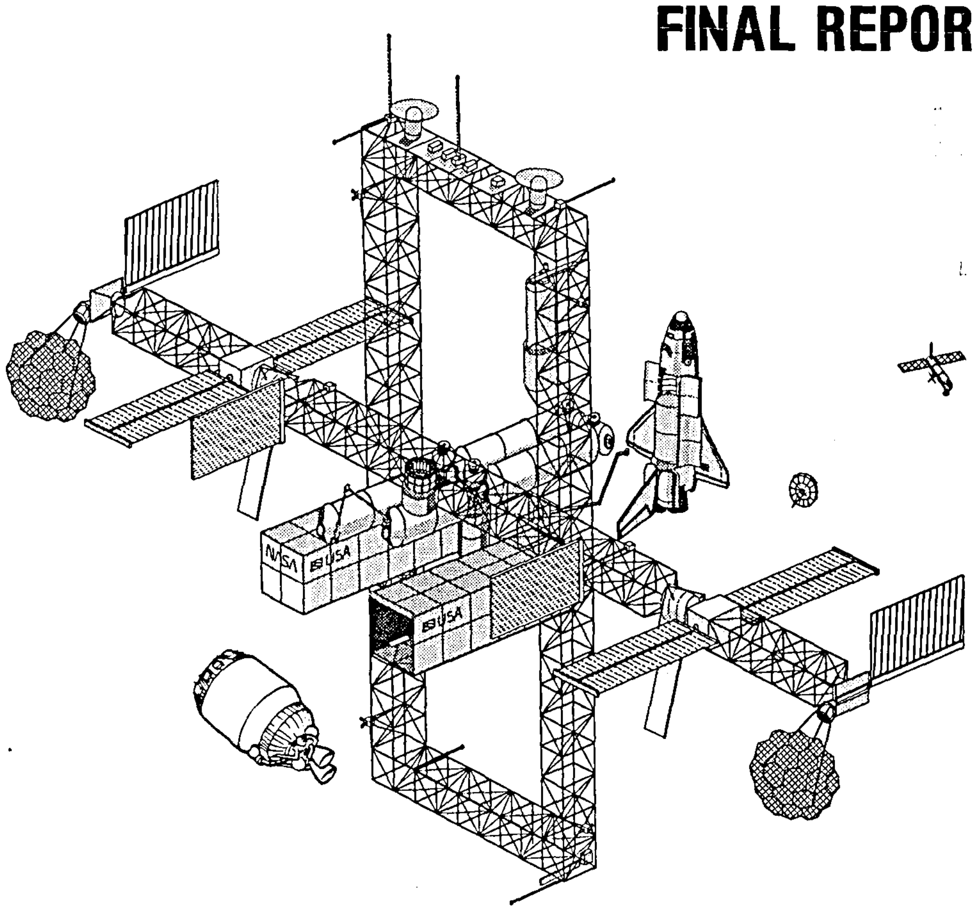
GDSS-SP-87-003
CONTRACT NAS3-24900

CENTAUR OPERATIONS AT THE SPACE STATION FINAL REPORT



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Project Managers: Donald F. Schultz, Robert R. Corban
NASA Lewis Research Center

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CENTAUR OPERATIONS AT THE SPACE STATION

FINAL REPORT

15 FEBRUARY 1987

Prepared for
NASA-Lewis Research Center
Cleveland, Ohio

Prepared by
GENERAL DYNAMICS SPACE SYSTEMS DIVISION
San Diego, California

ACKNOWLEDGEMENTS

I am indebted to Frank Bennett, Walter Thompson, Kevin Woolworth, Eric Hogan, and Jeff Holdridge, without whose dedication and volunteer work this study could not have been done. Thanks also go to Bob Sharp, Charly Combs, and Reid Wronski, all of whom made significant contributions.

John Porter
Study Manager

FOREWORD

This final report was prepared by General Dynamics Space Systems Division (GDSS) under contract NAS3-24900 "Centaur Operations at the Space Station." It encompasses the work under the first phase of the program (Tasks 1 to 4) from September 1986 through February 1987.

Contract NAS3-24900 was sponsored by the National Aeronautics and Space Administration, Lewis Research Center (NASA/LeRC). Donald Schultz of NASA/LeRC was the technical manager for the program with the assistance of Bob Corban.

The GDSS Program Manager was John Porter. Frank Bennett, Walter Thompson, Kevin Woolworth, Eric Hogan, Jeff Holdridge, Bob Sharp, Charly Combs, and Reid Wronski all contributed to the technical effort.

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ACRONYMS AND ABBREVIATIONS

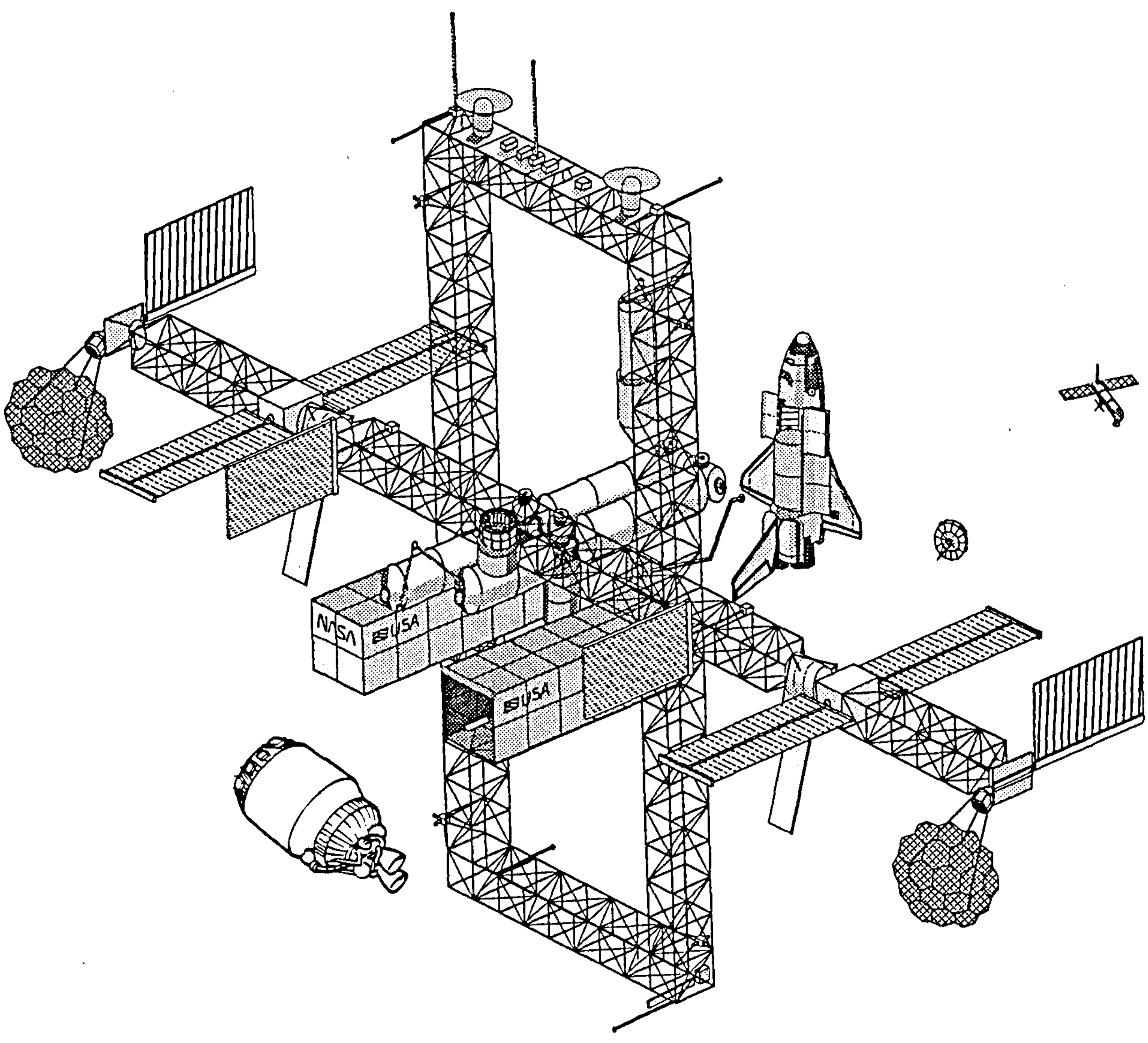
A&O	Accommodations and Operations
ANT	Antenna
AP	Attach Points
APCS	Automatic Pressurization and Control System
BBU	Battery Busing Unit
CCA	Centaur CISS Assembly
CCLS	Computer-Controlled Launch Set
CELV	Complementary Expendable Launch Vehicle
CFMFE	Cryogenic Fluid Management Flight Experiment
CISS	Centaur Integrated Support System
COP	Co-Orbiting Platform
CPOCC	Centaur Payload Operations Control Center
CU	Control Unit
DCU	Digital Computer Unit
DoD	Department of Defense
DUFTAS	Dual Failure Tolerant Arm/Safe Sequencer
ELV	Expendable Launch Vehicle
ENC	Encrypter
EP	Electrical Panel Disconnects
EVA	Extra-Vehicular Activity
FCP	Flight Control Processor
FIB	Forward Instrument Box
FSS	Flight Support System
GFE	Government Furnished Equipment
GHe	Gaseous Helium
GEO	Geosynchronous Earth Orbit
GNC	Guidance, Navigation, and Control
GPS	Global Positioning System
IMG	Inertial Measurement Group
IOC	Initial Operational Capability
IRU	Inertial Reference Unit
IVA	Inter-Vehicular Activity

ACRONYMS AND ABBREVIATIONS, Contd

KHB	Kennedy Handbook
LAD	Liquid Acquisition Device
LV	Launch Vehicle
MCCH	Mission Control Center Houston
MCDS	Multifunction CRT Display System
MDU	Master Data Unit
MES	Main Engine Start
MLI	Multilayer Insulation
MMI	Mixer Motor Inverter
MPA	Multiple Payload Adapter
MRDW	Mission Requirements Database Worksheets
MRMS	Mobile Remote Manipulating System
MSC	Mobile Servicing Center
MVB	Main Vehicle Battery
N_2H_4	Hydrazine
NHB	NASA Handbook
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replaceable Unit
OTV	Orbital Transfer Vehicle
PCDU	Power Control and Distribution Unit other Antennas
PICU	Pyro Initiator Control Unit
PLB	Payload Battery
POCC	Payload Operations Control Center
PP	Pneumatic Panel
PTU	Power Transfer Unit
RCS	Reaction Control System
RDU	Remote Data Unit
RF	Radio Frequency Transponder
RMU	Remoter Multiplex Unit
S/C	Spacecraft
SC	Signal Conditioner
SCU	Sequence Control Unit

ACRONYMS AND ABBREVIATIONS, Contd

SEU	System Electronics Unit
SIU	Servo Inverter Unit
SS	Space Station
SPF	Spacecraft Processing Facility
ST	Startracker
STS	Space Transportation System
TDM	Technology Demonstration Mission
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TIU	Telemetry Interface Unit
TRA	Telerobotic Arm
TVS	Thermodynamic Vent System
TWTA	Traveling Wave Tube Amplifier
UPA	Universal Payload Adapter
WBS	Work Breakdown Structure
XMTR	Transmitter



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SECTION 1

SUMMARY

The Centaur Operations at the Space Station Study generated five experiments and drills, collectively into two Technology Demonstration Missions (TDMs). They would be performed at the Space Station, using a Centaur rocket, over a 9-month period. Specifically these TDMs are as follows:

1) ACCOMMODATIONS TDM

   - Berthing
   - Checkout, Maintenance, and Servicing
   - Payload Integration

2) OPERATIONS TDM
   - Cryogenic Propellant Resupply
   - Centaur Deployment

The TDMs would be the substance of the Centaur at Space Station Program defined by the study. Their purpose is to develop and demonstrate accommodations and operations required by an orbital transfer vehicle (OTV) at the Space Station, using Centaur as an OTV simulator.

At the start of the program, the Centaur would be carried to the Station "dry" (no loaded "cryogens") in the Shuttle cargo bay. The Centaur's propellant tanks would be pressurized with 2-5 psig of gaseous helium (GHe) to maintain shape and stability. The Shuttle's mobile remote manipulating system (MRMS) would lift Centaur out of its cargo bay, and hand it off to the telerobotic arms (TRAs) of the Centaur hangar. The hangar would have been constructed a month or more before Centaur's arrival by the Berthing element TDM.

The Berthing element constructs a 10m x 10m x 20m hangar attached to the Space Station. This is identical to the size now in the Space Station data base for the planned Spacecraft Servicing Facility hangar. It will provide micrometeoroid protection and an unpressurized environment for Centaur storage and servicing. The station will supply "utilities" like GHe, electrical power, data, and communication transmission "utilities."

The Checkout, Maintenance, and Servicing element develops procedures and equipment for contingency service and drills. Batteries and avionics boxes will be installed and removed, propellant tank GHe pressurization and temperatures will be monitored, etc.

The Payload Integration element will drill the mounting, swapping, and systems checkout of single and multiple payloads. Dummy payload simulators will be used which will incorporate the circuits to simulate checkout responses. The last payload integration of the program will mate real multiple payloads for an actual Centaur launch during the Deployment element.

The Cryogenic Propellant Resupply element will assess three different procedures to childown, fill, and drain LO_2 and LH_2 propellants to and from Centaur. These operations will be done 100 n.mi. away from the Space Station on a co-orbiting platform (COP). The avionics and solar power core of this platform will be the U.S.-reference COP anticipated by JSC 30000. The propellant depot hardware will be a large version of LeRC's cryogenic fluid management facility experiment (CFMFE), with any appropriate modifications. The COP will be unmanned. It will have resident automated functions of a computer-controlled launch set (CCLS) to control tanking and detanking operations automatically. Both the Space Station and a ground station will monitor events at manned CCLS control panels through the tracking and data relay satellite system (TDRSS). Either station can override automated COP CCLS actions. A fourth tanking at the end of the program will prepare Centaur for an actual launch in the Deployment element.

The Centaur Deployment element will develop procedures to launch Centaur from the COP. Payload mating and Centaur/CISS and payload systems checkout will be done on a dry Centaur in the Space Station hangar. The Centaur/CISS assembly (CCA) with payload will be transferred to the COP with the orbital maneuvering vehicle (OMV). The COP's CCLS functions will control propellant tanking. The Space Station OMV control room controls launch and mission monitoring. The deployment will carry multiple payloads into geosynchronous orbit and/or escape trajectories.

To facilitate the TDMs, the following five precursor technologies should be demonstrated:

- Construction of the Spacecraft Processing Facility on Space Station
- Vehicle on-orbit replaceable unit development
- Universal spacecraft interface development
- Spacecraft maneuvering and grappling techniques
- CFMFE

Figure 1-1 shows the overall timing of the program. It includes precursors, TDM operations, and significant milestones for perspective.

To implement the Centaur Operations at the Space Station program, some structural and electronic "scars" or modifications must be added to both Centaur and the Space Station.

Centaur structural and electronic "scarring" to support the program are as follows:

- Avionics upgrades to allow guidance calibration and alignment in space
- Structural additions to allow grasping and attaching to Shuttle MRMS, OMV, hangar fixtures, and COP
- Propellant tank modifications to allow zero-gravity, no-vent tanking and detanking
- Software changes as necessary

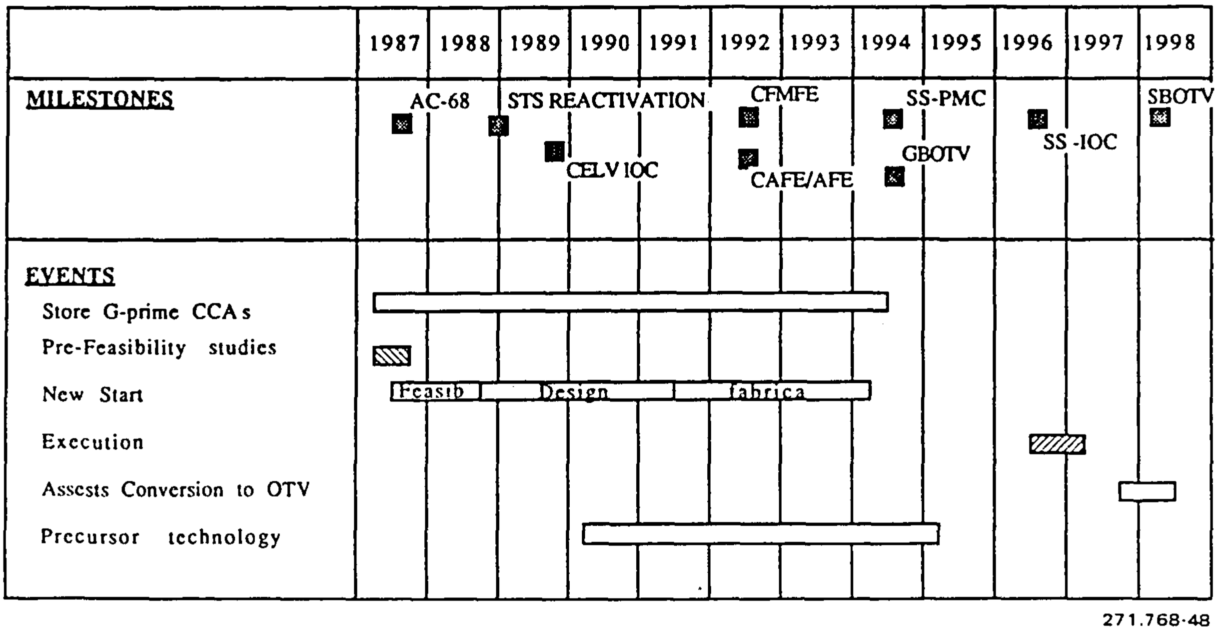


Figure 1-1. The Overall Program Schedule for the NASA-Lewis Space Station TDM Program

Space Station structural and electronic "scarring" to support the program are as follows:

- Hangar interface panel for Station-supplied utilities
- Hangar attach fittings at Space Station structural nodes
- OMV control facility software changes to accommodate Centaur launch and monitoring
- Addition of CCLS equivalent hardware and software to Space Station
- Construction of a COP to accommodate propellant transfer and Centaur deployment operations

These scars were incorporated into the Space Station data base as one of the tasks of this study. Payload customer revenue from the Deployment element should reduce the net program cost. At the conclusion of the program, hardware and data bases would be converted for subsequent use of OTV servicing facilities. The Centaur hangar would remain at the Space Station to accommodate future expendable launches, as provided for by the Space Station baseline configuration document, JSC 30000.

Figure 1-2 illustrates the major elements of the program architecture.

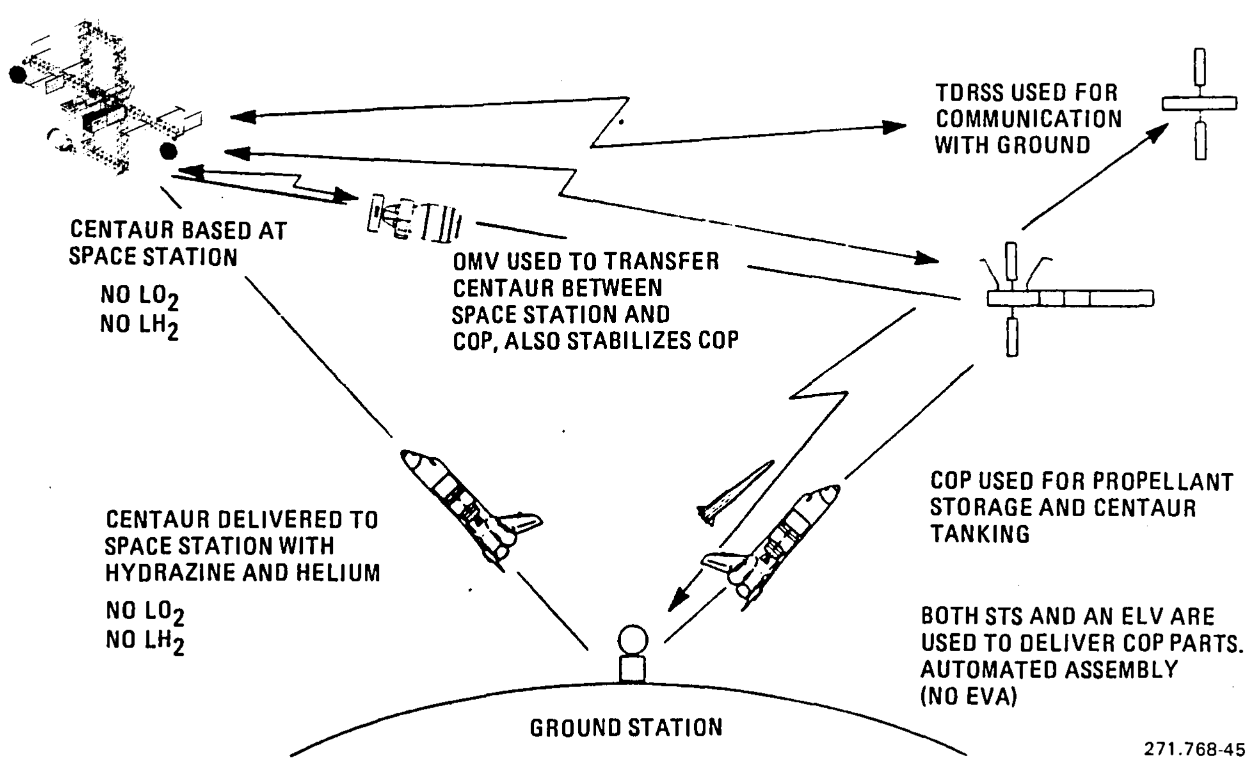
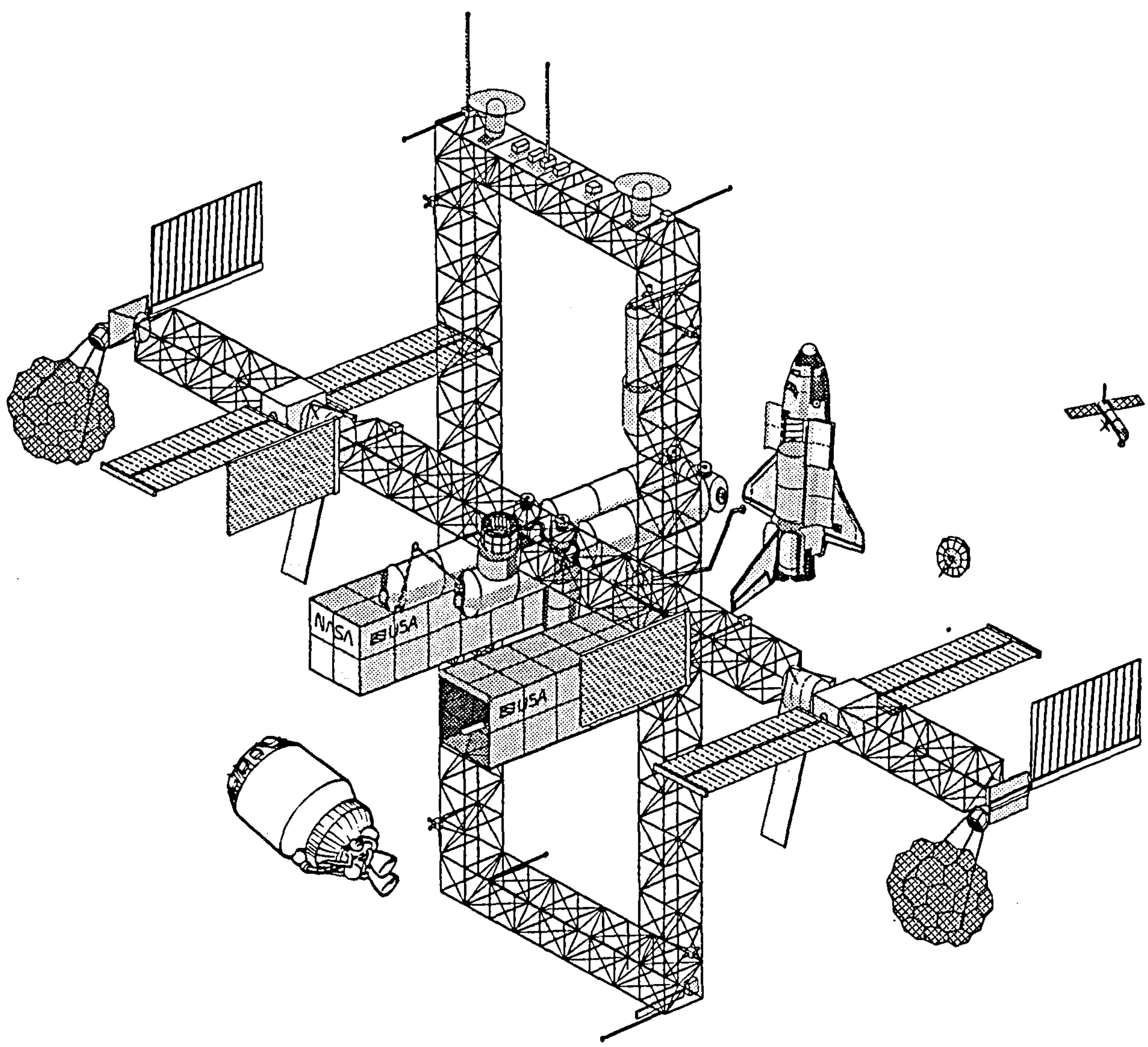


Figure 1-2. The Roles of Elements of the Space Station TDM Program Are Well Defined

Study budget constraints would not allow credible economic analysis, but intuitively, the program could save significant OTV development monies. A feasibility study will be needed to perform optimization trades, establish hardware and software engineering criteria, define program costs, and determine specific value and savings to NASA.

It is recommended that NASA fund follow-on studies to determine economic values and costs, Centaur G-prime payload and mission capabilities from the Space Station, and Program Feasibility Study to set engineering design criteria and justify a new start.



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SECTION 2
INTRODUCTION

This final report documents approximately 5 months of technical work on the Centaur Operations at the Space Station Study (NAS3-24900).

2.1 BACKGROUND

Coordinated planning efforts are currently underway within NASA to establish mission guidelines and accommodations for the Space Station which will be operational in the early 1990s. Proposed missions have been solicited from the science, technology, and commercial communities. A preliminary data base has been established which defines the mission requirements. Included in this data base are Technology Demonstration Missions (TDMs) which would provide a technological basis for building and operating advanced space stations, or which might lead to utilization of the space environment for advanced Earth and space-based applications.

The scope of the TDMs is broad, covering many different technologies. However, they all share the following common characteristics:

- They require the unique environment offered by the Space Station for long periods
- They involve technologies which are projected to be required in the 1990s and beyond.

TDMs may be performed within a pressurized module, attached to the Space Station, or on a free-flying platform.

The Space Station will serve as a transportation node starting in the mid 1990s for the Space Shuttle. This will involve the use of an Orbit Maneuvering Vehicle (OMV) and an Orbital Transfer Vehicle (OTV). The NASA Marshall Space Flight Center has recently completed OTV Phase A studies. Four major consistent conclusions can be identified: 1) for the return leg of the mission, the OTV would require an aerobrake for energy dissipation in the Earth's atmosphere to reduce propellant requirements, 2) the vehicle would use cryogenic fuel for the main propulsion, 3) the Space Station would have some degree of accommodation and operations for the OTV, and 4) further study of OTV accommodations and operations at the Space Station is required to adequately define the propellant management facility and the hangar and servicing facility(s) which will be required.

In connection to the third and fourth conclusions, there is an approach with potentially significant cost, schedule, and risk benefits. OTV development and Space Station evaluation could include utilization of an existing upper stage vehicle at the Space Station to develop and demonstrate many of the operational requirements for an OTV. NASA LeRC is proposing TDMs which will utilize the Centaur G-prime to develop and demonstrate accommodations and operations required for Space Station and OTV integration. The Centaur is a cryogenic upper stage that has many common features to proposed OTV concepts. Currently, two Centaur G-primes exist as "paid for" government assets. They have no mission assignments. Thus, they are excellent candidates for demonstration activities relating to the Space Station and OTV integration.

2.2 OBJECTIVES

The objectives of this study were to: 1) define Space Station TDMs, and 2) assess and document their operational impacts and scarring requirements on the Space Station. Additionally, study progression added two consequent objectives: 1) to define Centaur modifications required, and 2) to suggest follow-on studies to determine the potential value of Centaur TDMs to the OTV development program.

2.3 SCOPE

The scope of the work was for General Dynamics Space Systems (GDSS) to supply all personnel, services, materials, and facilities needed to perform the study's objectives. The following points were adhered to:

- Only the G-prime Centaur was to be considered in the study.
- Mission Requirements Data Base (MRDW) forms were to be used to document Space Station scarring.
- Propellant resupply operations were restricted to a co-orbiting platform (COP).

2.4 APPROACH

The study was structured into four technical tasks, as shown in Figure 2-1, and one reporting task. Task outlines follow.

- Task 1 - Identify critical Space Station OTV accommodations and operations needs. These would become TDMs in Task 2.
- Task 2 - Determination of TDM requirements. TDM concepts developed from identified needs. Then Space Station support and Centaur modifications required for the TDMs were defined.
- Task 3 - Documentation of TDM requirements. This was done using the NASA Mission Data Requirements Data Base.
- Task 4 - Generate Preliminary Program Plan. This plan combines a schedule of Centaur TDMs with precursor technology development schedules and program development activities.
- Task 5 - Monthly reports, task review briefings, and final report generation were scheduled and monitored under this task.

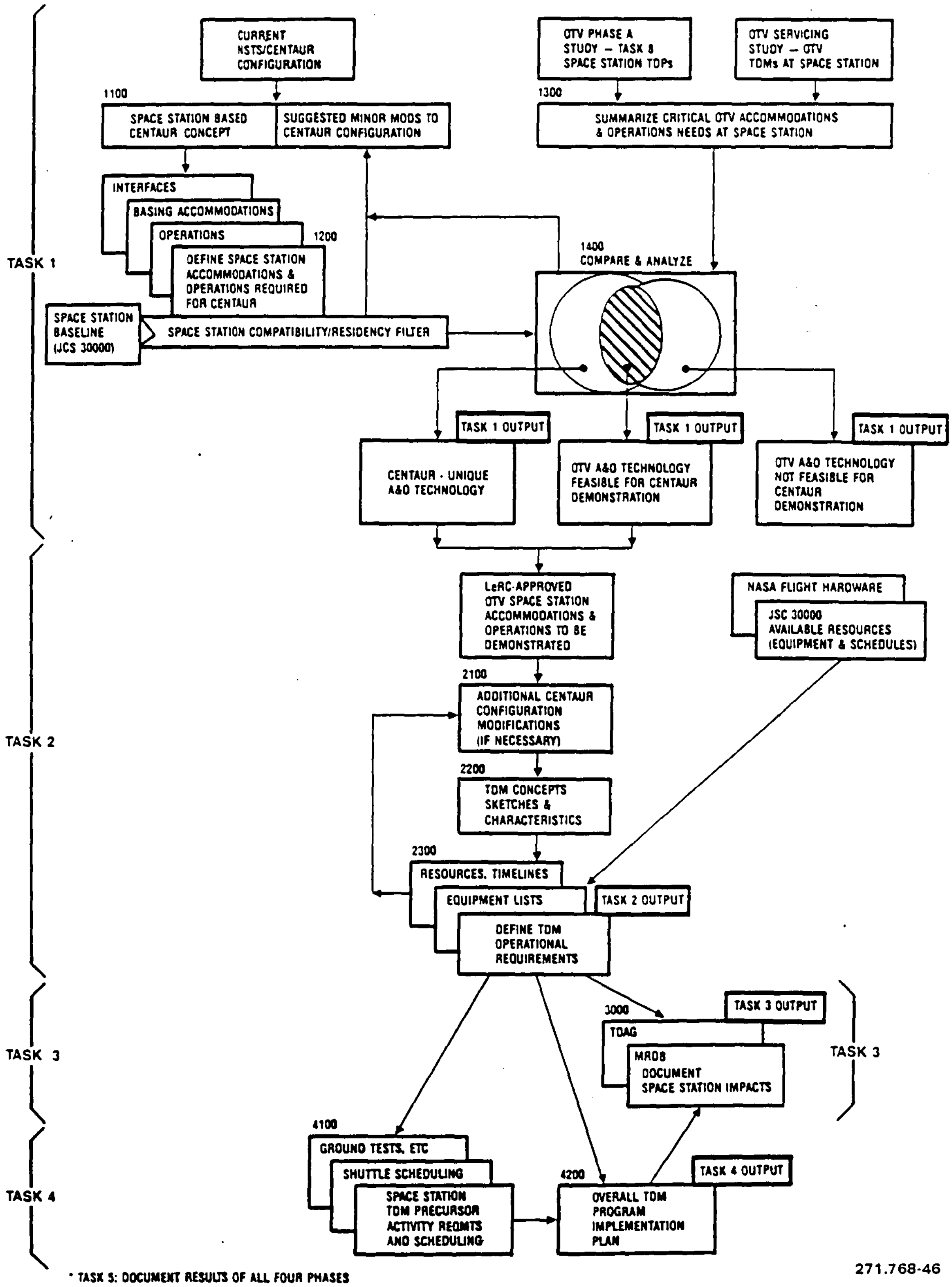


Figure 2-1. Study Work Organized for Effective Performance

Figure 2-2 shows the program schedule of Figure 2-1 task events as they actually occurred.

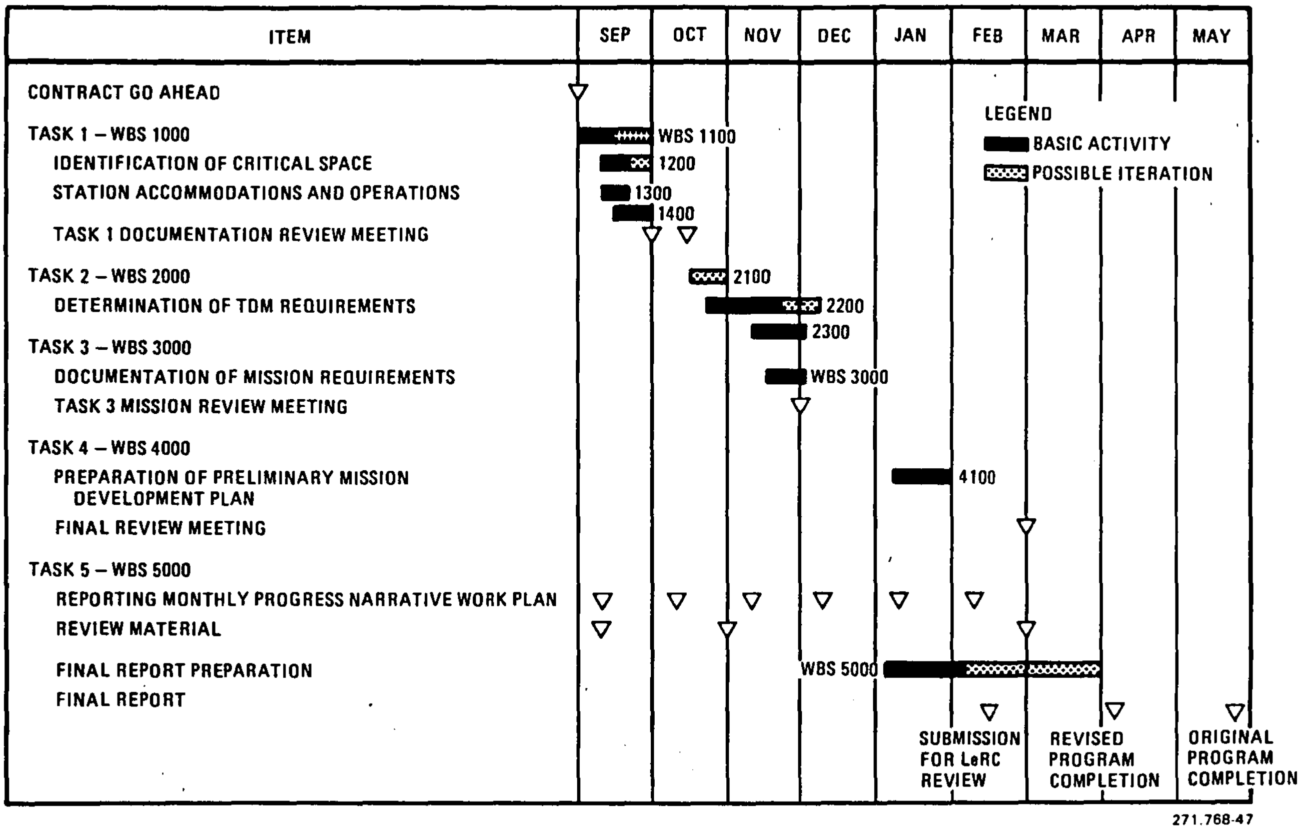
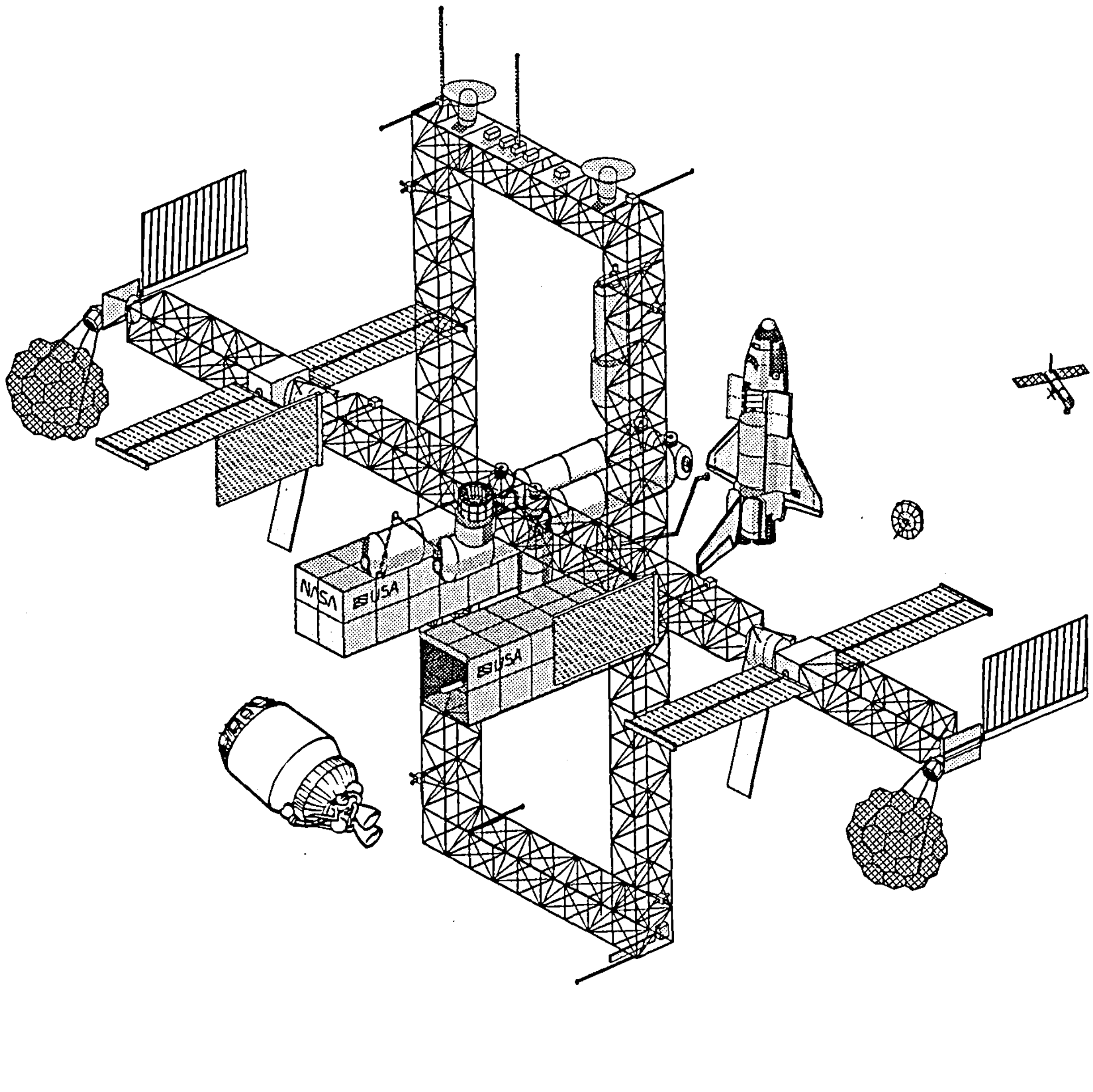


Figure 2-2. Program Schedule Was Revised to Reflect Completion 1 Month Early



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SECTION 3
OVERALL PROGRAM IMPLEMENTATION

A first cut at the Overall Program Implementation Plan is shown in Figure 3-1. Milestones are shown to relate the program to more familiar events. The following two key tasks must start in 1987 if the program is to succeed:

- One or both Centaur G-prime/CISSs owned by NASA LeRC must be designed for storage and use in the program
- A program Feasibility Study must be funded and begun

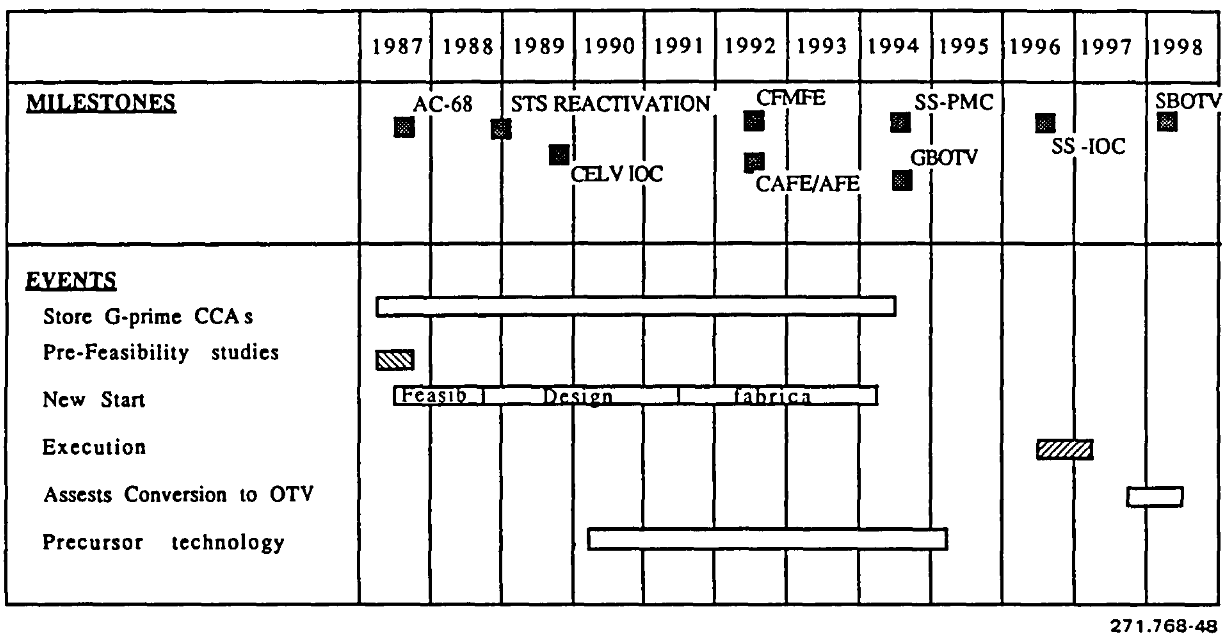


Figure 3-1. The Overall Program Schedule for the LeRC TDM Program

Figure 3-2 gives more detail of program events between 1987 and 1990. This includes ground or flight demonstrations of more general technologies (called precursor technologies) that support program events. Also shown are key early program studies.

Figure 3-3 gives more detail of Technology Demonstration Mission (TDM) scheduling during the program's 9-month execution between 1996 and 1997. Tasks of individual TDMs are detailed in Section 5.

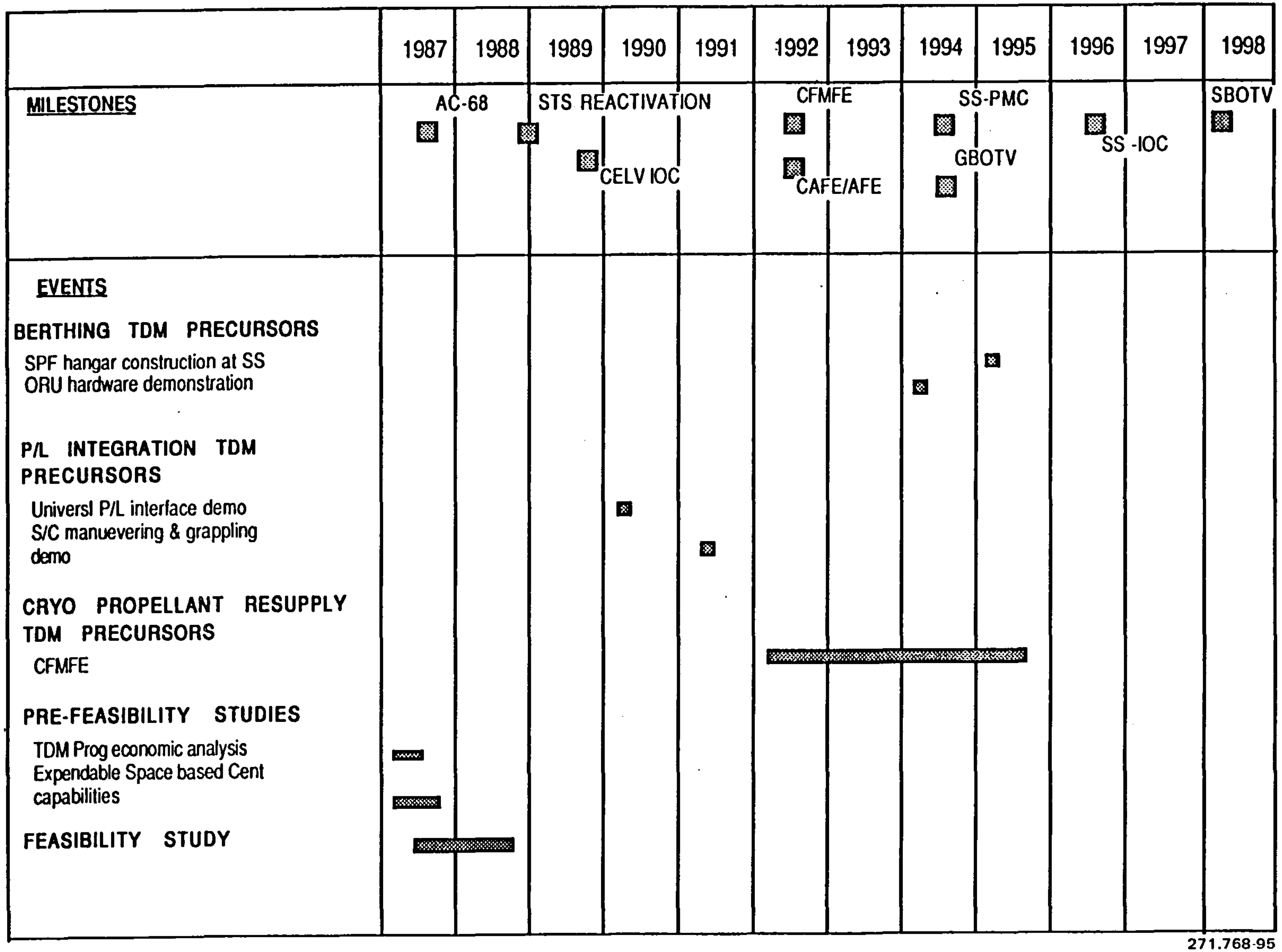


Figure 3-2. Key Program Activities Need 1987 Support

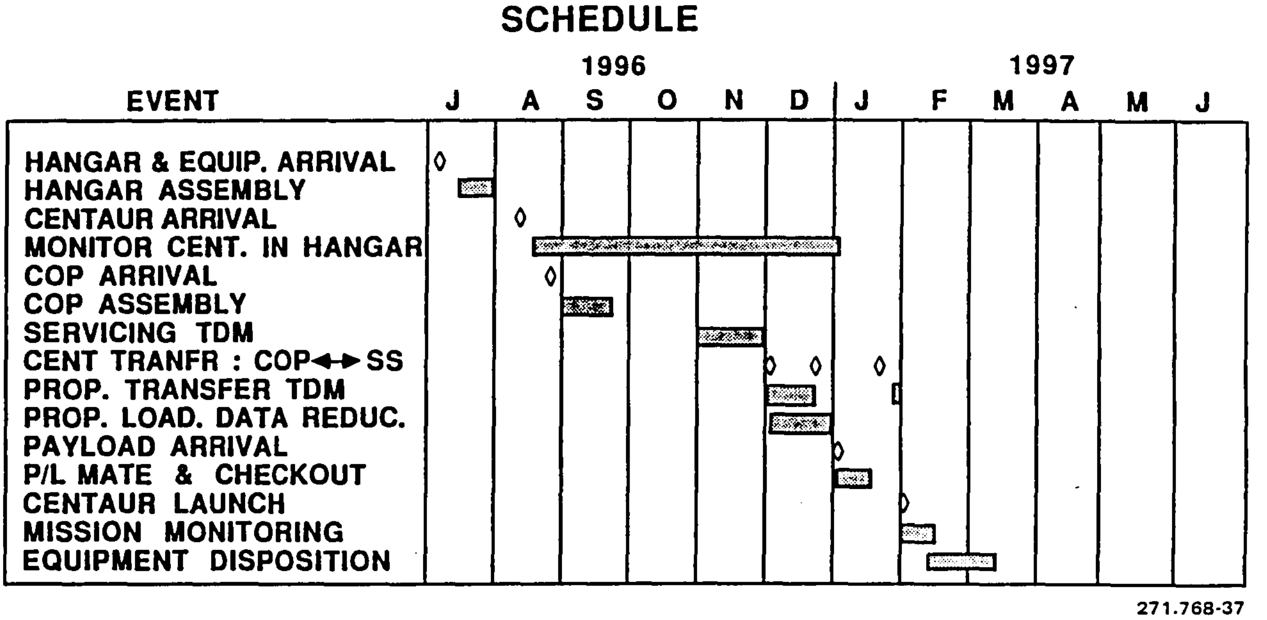


Figure 3-3. Centaur Operations at the Space Station Will Span 9 Months

The next level of detail, sequence charts, and detailed timelines for each TDM, are given in the appropriate parts of Section 5. For the sake of example, Figure 3-4 is a closeup of the Centaur Deployment TDM. See Section 5.4 for specifics on this TDM. Tables 3-1 and 3-2 are detailed timelines prepared for Berthing activities. Table 3-1 (robotics intensive) compared to Table 3-2 (EVA intensive) shows the advantage of using robotics for hangar assembly.

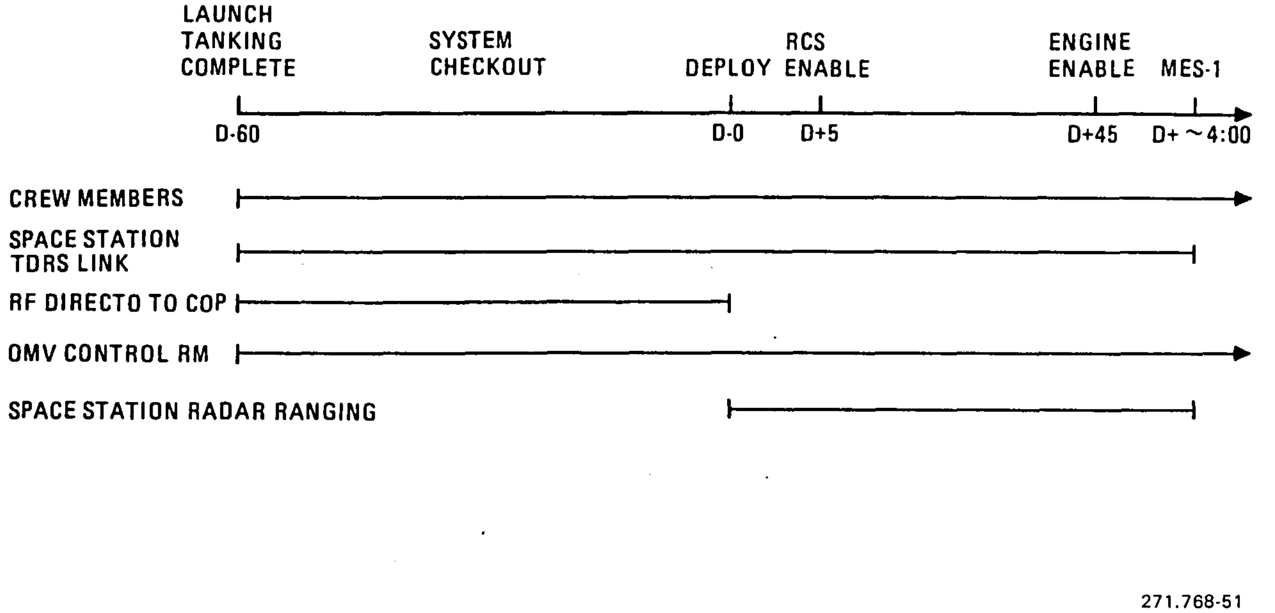


Figure 3-4. Centaur Engine Start Delayed 4 Hours 45 Minutes to Clear COP

Table 3-1. EVA Requires Three People: Two EVA Plus One Inside Station for Monitoring and Control

Maintenance Timeline
(Alternate Battery Replacement Using EVA)

Event Description	Start	Duration	Finish
Donn suit and check out EVA	0:00:00	0:30:00	0:30:00
Depressurize and exit airlock	0:30:00	0:10:00	0:40:00
Translate on MSC to storage	0:40:00	0:05:00	0:45:00
Move batteries to hangar	0:45:00	0:10:00	0:55:00
Stow batteries on wall	0:55:00	0:10:00	1:05:00
Position foot restraint for each crewman	1:05:00	0:20:00	1:25:00
Two-man relay to exchange batteries (3)	1:25:00	0:30:00	1:55:00
Move old batteries to storage	1:55:00	0:15:00	2:10:00
Translate to airlock	2:10:00	0:05:00	2:15:00
Enter airlock and repressurize	2:15:00	0:05:00	2:20:00
Doff EVA suit and stow	2:20:00	0:10:00	2:30:00

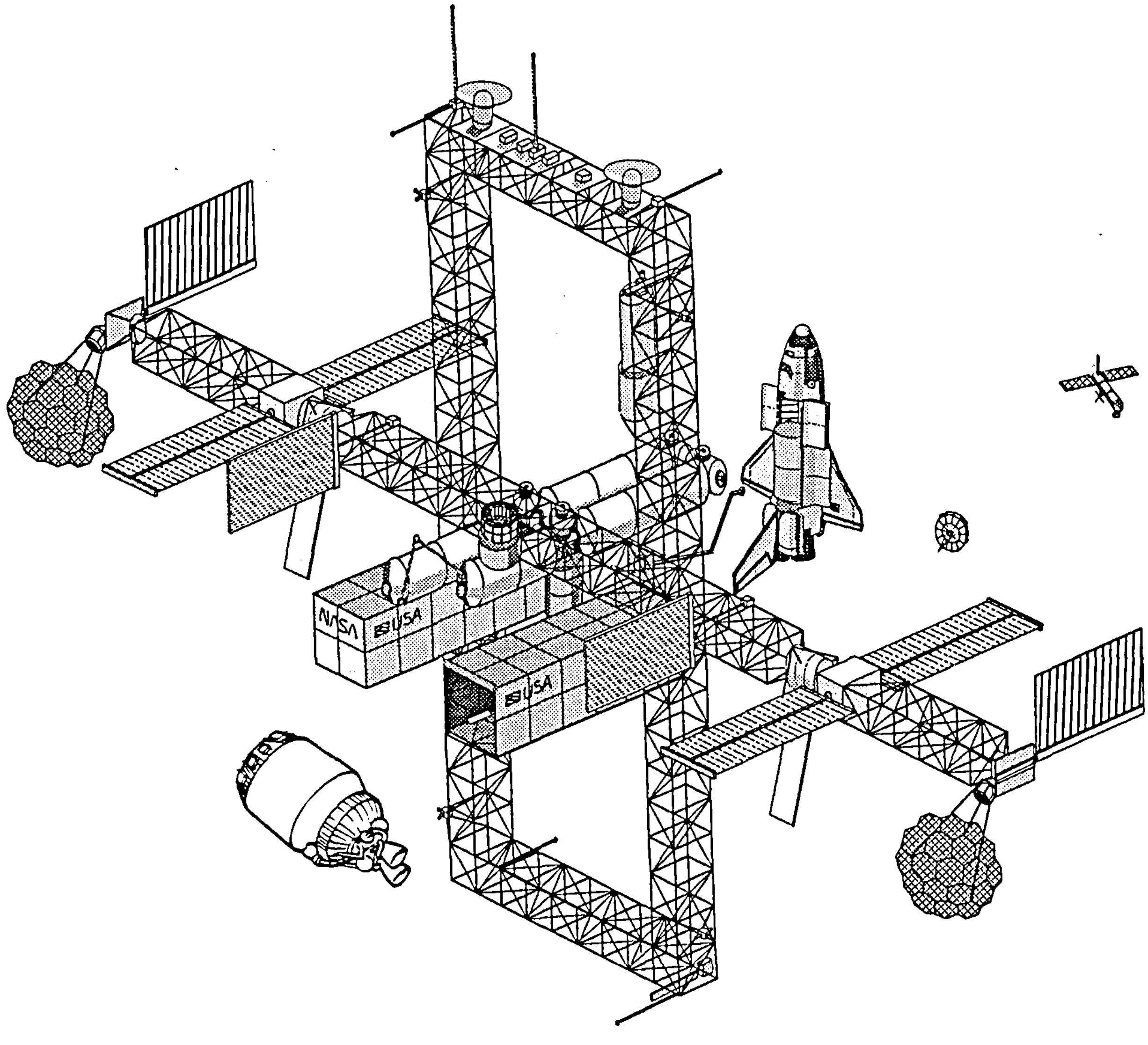
Total manhours = 2:30:00 x 3 = 7:30:00

Table 3-2. Telerobotics Uses One-Tenth the Total Manhours Required for EVA

Maintenance Timeline
(Battery Replacement Using Telerobotics)

Event Description	Start	Duration	Finish
Unstow from storage spare batteries (IVA)	0:00:00	0:05:00	0:05:00
Translate to hangar, attach to hangar wall	0:05:00	0:05:00	0:10:00
TRA remove old battery from Centaur and stow	0:10:00	0:05:00	0:15:00
Detach new battery, attach to Centaur	0:15:00	0:05:00	0:20:00
Replace two other batteries in same manner	0:20:00	0:20:00	0:40:00
Verify battery functioning	0:40:00	0:01:00	0:41:00
Transfer old batteries to storage	0:41:00	0:05:00	0:46:00

Advantage over EVA 7:30:00 : 0:46:00 approximately = 10:1



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SECTION 4

TASK 1 - OTV SPACE STATION ACCOMMODATIONS AND OPERATIONS TECHNOLOGY

Recently completed orbital transfer vehicle (OTV) Phase A studies by Marshall Space Flight Center (MSFC) identified the following OTV-critical Space-Station-related technologies that could be demonstrated using Centaur:

- Rendezvous and docking
- Berthing
- Payload integration
- Vehicle and payload checkout
- Propellant resupply

In the first task of our study, these accommodations and operations (A&O) technologies plus launching, aerobrake maintenance, and tank set and engine replacement were analyzed for suitability for Centaur demonstration. Contract ground rules required that only minor modifications to Centaur be considered, and that no economic analysis be done. Therefore, suitability criteria included the extensiveness and intuitive cost of modifications required to Centaur for demonstration.

Listings of suitable and not-suitable technologies were made. Modifications to Centaur for space-based survival and to perform Technology Development Missions (TDMs) were concept designed. A&O required only for Centaur survival, and not necessarily for TDMs, were identified as Centaur-unique A&O required.

4.1 OTV A&O SUITED FOR CENTAUR DEMONSTRATION

Based on MSFC OTV studies, the following A&O technologies are critical to OTV and were candidates for Centaur demonstration:

- Rendezvous and docking
- Vehicle and payload checkout, maintenance, and servicing
- Aerobrake maintenance and handling
- Geosynchronous earth orbit (GEO) to lower earth orbit (LEO) control and communications
- Spare parts depot operations
- Payload integration
- Berthing
- Cryogenic propellant resupply
- Modular tank set operations

- Crew facilities
- Launch operations

This list was filtered by preliminary mission analysis, intuitive cost effectiveness, and the ground rule that only "minor modifications to the flight vehicle" should be considered. The result was the following list of OTV A&O technologies suited for Centaur demonstration as a TDM:

- Berthing
- Vehicle and payload checkout, maintenance, and servicing
- Payload integration
- Launch operations

We also recommended that cryogenic propellant resupply be selected for demonstration even though it would require major Centaur propellant tank modifications.

In the following sections, the analyses for each selected OTV technology is summarized in a uniform format. The major elements of the technology are described and defined. Then, the rationale for considering the particular technology as critical to OTV, the performance criteria for a technology experiment, and the justification for establishing the criteria are given. Next, a gross assessment is made of the impact on the Space Station and Centaur of potential modifications if a TDM is created to demonstrate and develop the OTV technology utilizing a Centaur at the Space Station. Lastly, any significant issues regarding a potential TDM, if they exist, are presented.

4.1.1 BERTHING. We interpret berthing as securing an OTV vehicle to the Space Station during storage, protecting it from harsh environment, and monitoring its condition. This in general requires a hangar, OTV-to-Space-Station interfaces, and leak detection (see Figure 4-1 and Tables 4-1 and 4-2).

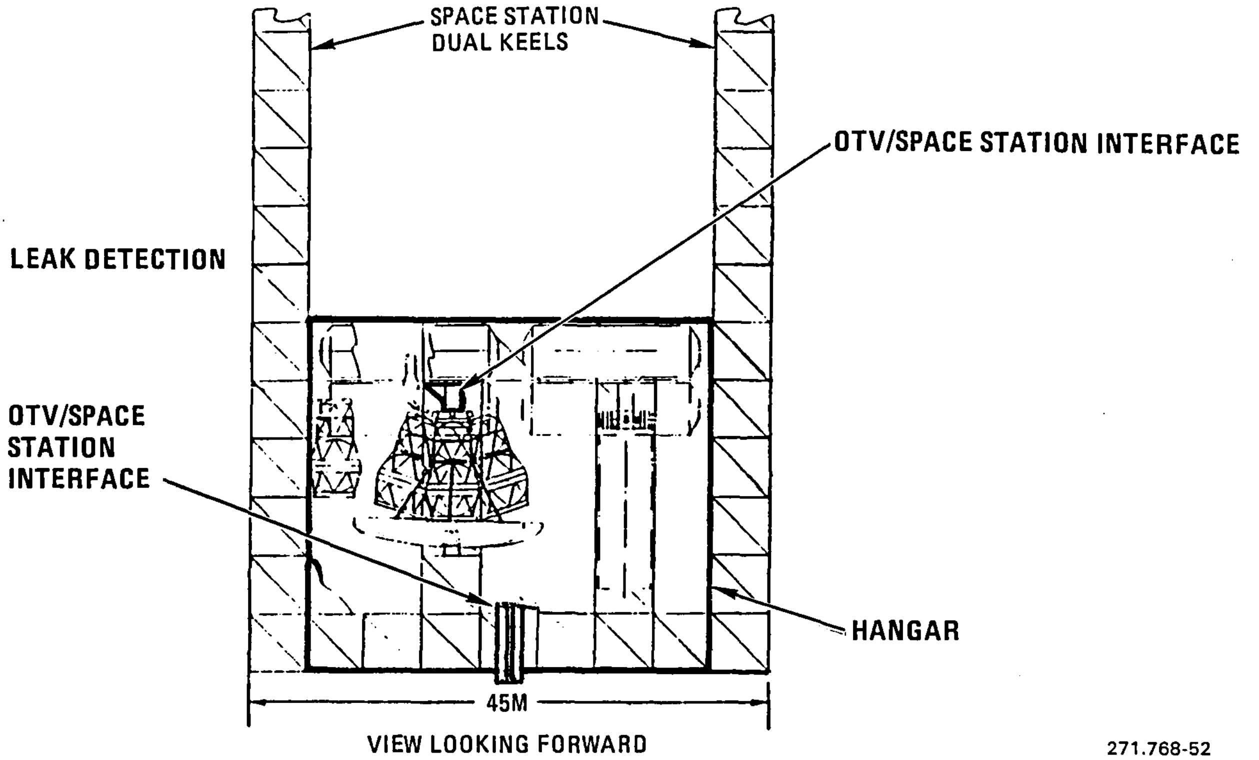


Figure 4-1. OTV Space Station Berthing Has Three Major Elements

Table 4-1. Impact on Space Station of TDM Elements for Berthing

Element	Space Station Impact
Hangar Structure	Minor, build to design
Hangar Protective System	Minor, undeveloped technology
Berthing Structure	Minor, build to design
Berthing Interface Panel	Minor, undergoing development
Leak Detection System	Minor, undefined at this time
EVA Equipment	Minor, planned Space Station asset
Manipulator Foot Restraint	Minor, asset exists
RMS (Mobile)	Minor, planned Space Station asset
Control Station	Minor, planned Space Station asset
TV and Lighting System	Minor, planned Space Station asset

Table 4-2. Impact on Centaur of TDM Elements for Berthing

Element	Centaur Impact
Hangar Construction	No impact identified
OTV/Space Station Interface	Minor, build to design
Leak Detection System	No impact identified

- Hangar

Rationale:	Space-based OTV requires micrometeoroid and debris protection on orbit. Protection is provided by hangar. Hangar bulk materials handling, construction techniques, tools, and operations require verification at Space Station
Performance:	99.5% probability of no penetration over 10 years
Justification:	MSFC-derived specification

- OTV/Space Station Interface

Rationale:	Space Station and vehicle interfaces require automatic engagement devices to allow efficient OTV operations.
Performance:	Structural and fluid interconnect integrity (no leak)
Justification:	Identified during OTV study

- Leak Detection

Rationale:	Safety, contamination, and operational considerations require leak detection for OTV at the Space Station
Performance:	As defined by JSC 30000
Justification:	Space Station baseline requirements

4.1.2 CHECKOUT, MAINTENANCE, AND SERVICING. Efficient maintenance of an OTV at the Space Station requires the removal and replacement of On-orbit Replaceable Units (ORUs) to ensure an operational status and adequate reliability level. The ORUs currently scheduled to be replaced on OTV include avionics, fuel cell, tank set, engines, reaction control system (RCS), and aerobrake thermal protection system. The component replacement equipment and operations techniques must be demonstrated at the Space Station, along with the capability to load software and checkout the vehicle using automatic routines and built-in tests (see Figure 4-2 and Tables 4-3 and 4-4).

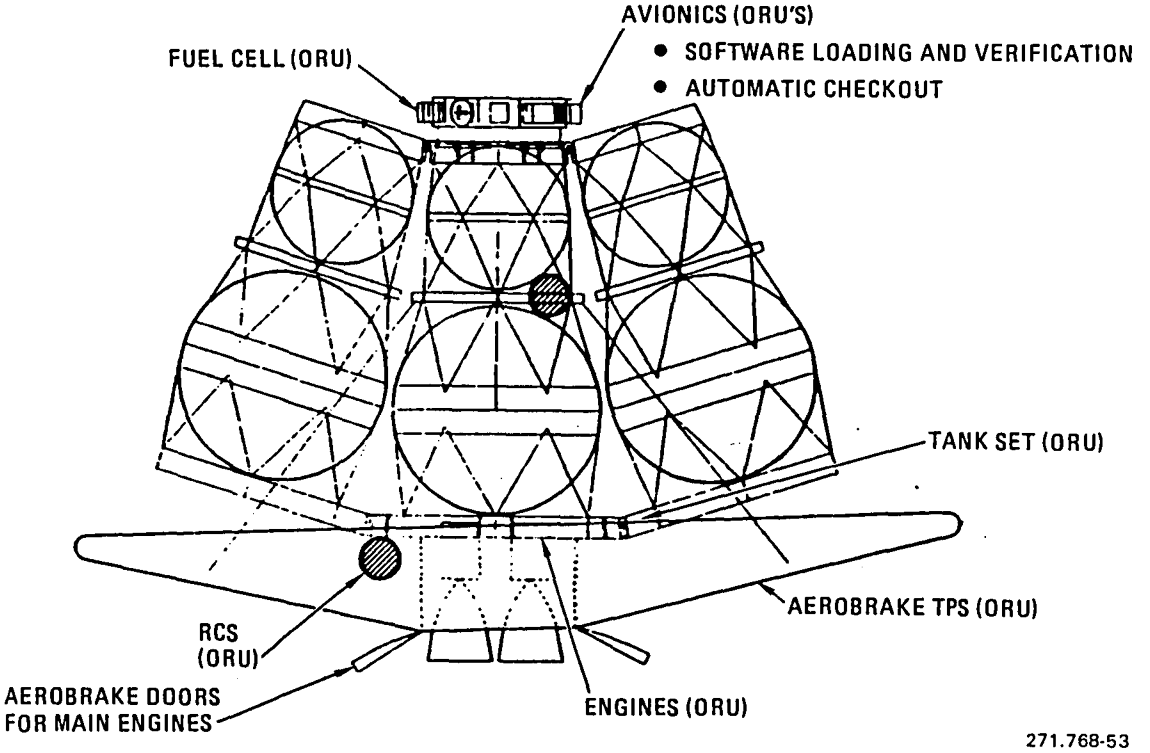


Figure 4-2. OTV Checkout and Maintenance Requires Removal and Replacement of ORUs

Table 4-3. Impact on Space Station of TDM Elements for OTV Checkout and Maintenance

Element	Space Station Impact
Remove and Replace ORUs	
• Avionics	Minor, planned Space Station assets
• Fuel Cell/Battery	Minor, planned Space Station assets
• ENGINE	Minor, planned Space Station assets
• RCS	Minor, planned Space Station assets
Handling Operations	
• Berthing Operations	Minor, interface needs design structure needs design other Space Station assets planned
• Hangar/OTV Operations	Minor, build hangar to design other Space Station assets planned

Table 4-4. Impact on Centaur of TDM Elements for OTV Checkout and Maintenance

Element	Centaur Impact
Remove and Replace ORUs	
• Avionics	Minor, build to design
• Fuel cell/battery	Minor, build to design
• Engine	Major, undergoing development
• RCS	Minor, build to design
Handling Operations	
• Berthing operations	Minor, interface needs design
• Hangar/OTV operations	Minor, build to design

- Removal and Replacement of ORUs

  Rationale: Restores OTV to a operational mode and an acceptable reliability status

  Performance: Operations time (detailed on following charts)

  Justification: ORU replacement times established during OTV studies

- Handling Operations

  Rationale: Provides for OTV mobility at the Space Station

  Performance: Operations time (detailed on following charts)

  Justification: Handling operations times established during OTV studies

- Removal and Replacement of ORUs

  Avionics

  Computing Unit
  Performance: Operations time - EVA = 4:20 hr
  Remote = 2:55 hr

  RF Unit
  Performance: Operations time - EVA = 4:20 hr
  Remote = 2:55 hr

  Fuel Cell/Battery
  Performance: Operations time - EVA = 5:05 hr
  Remote = 3:15 hr

  Engine (One)
  Performance: Operations time - EVA = 9:30 hr
  Remote = 8:30 hr

  Tank Set
  Performance: Operations time - EVA = 10:10 hr
  Remote = 6:49 hr

  RCS
  Performance: Operations time - EVA = 3:40 hr
  Remote = 2:10 hr

  Aerobrake
  Performance: Operations time - EVA = 13:15 hr
  Remote = 10:22 hr

  Aerobrake TPS
  Performance: Operations time - EVA = 18:56 hr

- Handling Operations

  Berthing Operations.
  Performance:
  - Operations time - remote = :30 hr
  - No leak disconnects
  - Equipment compatibility

  Hangar/OTV Operations
  Performance:
  - Operations time - remote = TBD hr
  - Adequate accessibility for maintenance
  - Equipment compatibility
  - Collision avoidance

4.1.3 CRYOGENIC PROPELLANT RESUPPLY. A space-based OTV will require propellant management systems capable of operating in a zero-gravity environment, particularly for tanking and detanking. Highly efficient thermal control systems will be required to accommodate some of the longer missions to GEO. Finally, efficient vehicle operations in space will only be possible if large quantities cryogenic propellants can be delivered to and stored on the Space Station. The major elements are new propellant tank devices, and a separate propellant depot.

Space-basing of the OTV will require a number of changes to the propellant management systems used on current cryogenically fueled vehicles, such as the Centaur. The primary driver is the requirement that the vehicle be capable of operating in a zero-gravity environment. This means that special propellant tank devices will be needed to fill and drain the vehicle, and to control tank pressures. A number of these devices are illustrated in Figure 4-3. A total communication liquid acquisition device (LAD) will be included to drain propellants back into the storage depot at the station, while a separate, high-flow outlet will be provided for engine feed when the liquids are settled. A bubbler pressurization system is shown for flight operations of the oxygen tank, while a diffuser located in the ullage is proposed for use during draining. The multilayer insulation (MLI) system may double as a micrometeoroid protection system with a reflective solar coating. Here a tank wall-mounted thermodynamic vent system (TVS) is illustrated to avoid venting liquid when the fluid is not settled.

The propellant depot shown in Figure 4-4 will contain many of the propellant management subsystems in Figure 4-3 for the vehicle. In addition, it may include a boiloff reliquefaction system to avoid having to dispose of vaporized propellants that may cost $1500/lb to transport to orbit. Another new system is the vapor-cooled shield which routes cold boiloff vapor through a heat exchanger in the MLI. Boiloff reductions of over 50 percent are achievable with these shields. They also add flexibility by allowing tailoring of the relative hydrogen and oxygen boiloff rates. Figure 4-4 shows a 100,000-lbm capacity tank set configured to be launched empty in the Shuttle cargo bay (see also Tables 4-5 through 4-7).

The rationale for space testing the major zero-gravity propellant management systems, together with performance criteria and justification for those criteria follows.

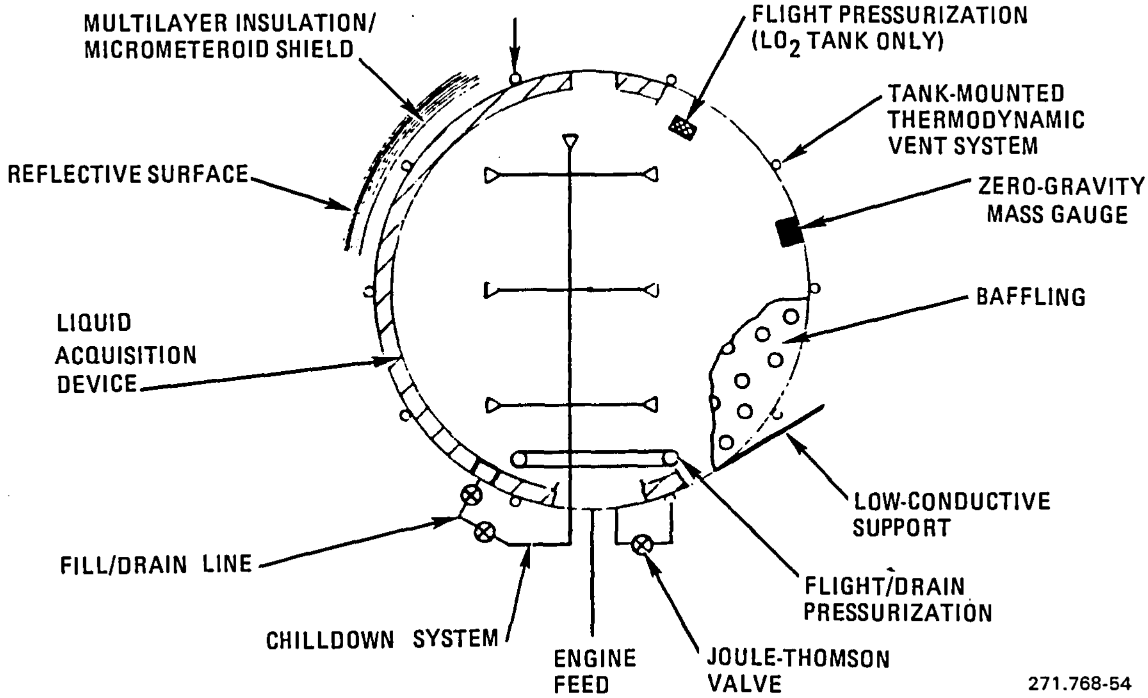


Figure 4-3. There Are Several Elements to OTV Propellant Management

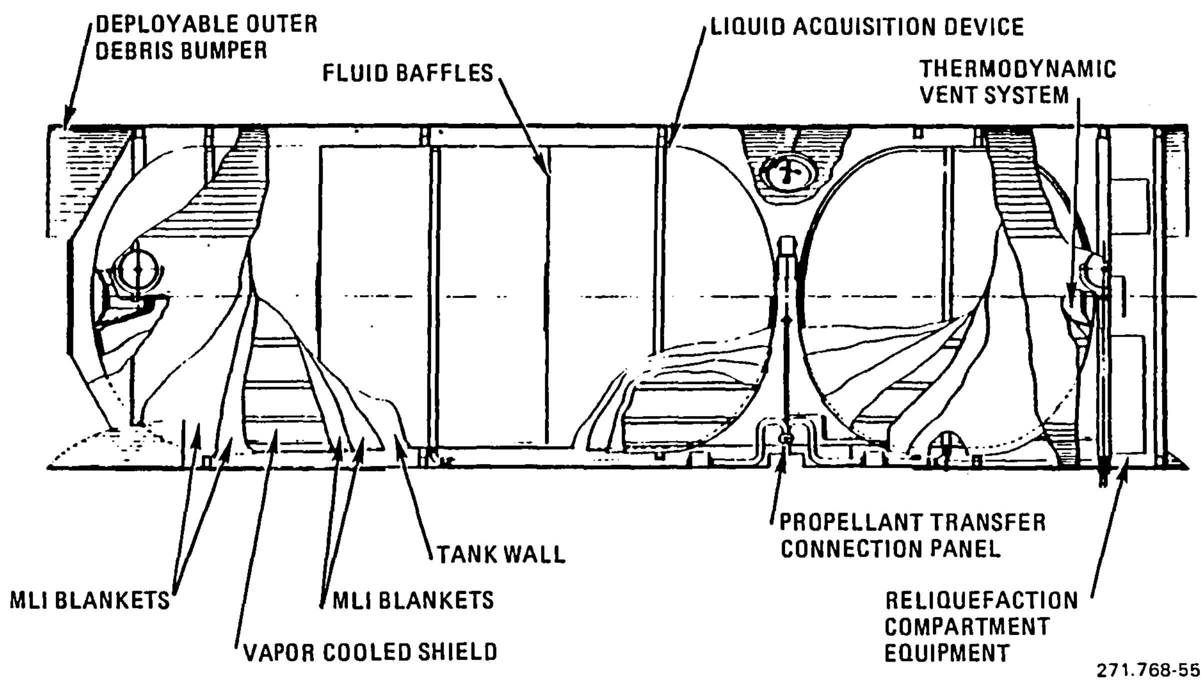


Figure 4-4. Depot Tank Will Contain Many of the Propellant Management Systems Also in the OTV Tanks

Table 4-5. Cryogenic Resupply

Mass Gauging	
Rationale:	Conventional means are inoperative in zero-gravity. Required for tanking, detanking, and determining fluid quantities.
Performance Target:	Accuracy to within $\pm 1\%$ of the LH_2 and LO_2 tank capacity.
Justification:	Prevent over-pressurization during no-vent fill.
Liquid Acquisition System	
Rationale:	Required to transfer liquid in zero-gravity.
Performance Target:	No breakdown during quiescent periods. Residuals $\leq 1/2\%$.
Justification:	Minimize propellant resupply quantities.
Childown/No-Vent Fill	
Rationale:	Required to minimize liquid loss.
Performance Target:	$\leq 1/2\%$ loss during chilldown and fill cycle.
Justification:	Reduce propellant loss. Could contaminate Space Station.
Pressure Control (Pressurization/Venting)	
Rationale:	Minimize pressurant "collapse" and quantity required. To avoid expelling liquid.
Performance Target:	Pressurization - collapse factors <2. Venting - zero liquid expulsion.
Justification:	Minimize pressurant usage and heat addition. Minimize propellant resupply quantities.
Quick Disconnects	
Rationale:	Avoid liquid loss and environmental contamination.
Performance Target:	Zero leakage to environment.
Justification:	Potentially hazardous and could contaminate the Space Station.

Table 4-5. Cryogenic Resupply, Contd

Leak Detection Methodology	
Rationale:	Required for early detection.
Performance Target:	As defined by JSC 30000.
Justification:	Space Station baseline requirements.
Cryogenic Liquid Transfer Pumps	
Rationale:	Depot required pumps with low net positive suction head (MPSH) and low flow rates
Performance Target:	$\leq$3 years mean time between failure (MTBF)
Justification:	Minimize on-orbit service requirements.
Boiloff Accumulation System Compressors	
Rationale:	To avoid venting boiloff.
Performance Target:	$\leq$3 years MTBF.
Justification:	Minimize on-orbit service requirements.
Micrometeoroid/Debris Shielding	
Rationale:	Penetration could have severe safety and cost impact.
Performance Target:	99.5% probability of no penetration in 10 years.
Justification:	MSFC derived specification for Long-Term Cryogenic Storage Facility System Study.
Fluid Baffling	
Rationale:	Demonstrate motion control of liquid mass.
Performance Target:	$\leq$0.01g acceleration level imposed on Space Station.
Justification:	Minimum disturbance of microgravity experiments.

Table 4-5. Cryogenic Resupply, Contd

Thick Multilayer Insulation	
Rationale:	Demonstrate ≥3 in. of MLI to achieve boiloff rates.
Performance Target:	≤1% per month boiloff.
Justification:	Minimize propellant resupply quantities.
Thermal Control Coatings	
Rationale:	Required to achieve low absorptivity/emissivity.
Performance Target:	Replacement interval ≤10 years.
Justification:	Minimize extra-vehicular activity (EVA) for shield replacement.
MLI/Vapor Cooled Shield/Structural System Integration	
Rationale:	Minimize boiloff loss, minimize load on reliquefaction system.
Performance Target:	≥50% boiloff improvement over MLI alone.
Justification:	Minimize propellant resupply quantities.
Low Conductance Penetration	
Rationale:	Minimize heat flow to liquid.
Performance Target:	≤5% of total tank heat leak.
Justification:	Minimize propellant resupply quantities.
Para/Ortho Hydrogen Converter	
Rationale:	Increase boiloff vapor heat sink capacity.
Performance Target:	Replacement interval ≥5 years.
Justification:	Minimize EVA for converter replacement.
Active Cooling System	
Rationale:	Reliquefaction of boiloff.
Performance Target:	≥3 years MTBF.
Justification:	Minimize EVA to refurbish.

Table 4-5. Cryogenic Resupply, Contd

Fluid Condenser	
Rationale:	Demonstrate reliquefaction condensers in zero-gravity.
Performance Target:	1g performance.
Justification:	Minimize size and weight of unit.

Table 4-6. Impact on Space Station of TDM Elements for Propellant Resupply

Element	Space Station Impact
Micrometeoroid Shield	Minor, uncertain requirement
Fluid Baffling	Minor, build into design
Thick MLI	Minor, undergoing development
Thermal Control Coating	Minor, undeveloped technology
MLI/VCS Integration	Minor, undeveloped technology
Low Conductance Penetration	Minor, current technology
Para/Ortho Converter	Minor, current technology
Active Cooling System	Major, new technology for space
Fluid Condenser	Minor, undeveloped technology
Mass Gauging	Minor, undergoing development
Liquid Acquisition	Minor, new technology
Chilldown/No-Vent Fill	Minor, undemonstrated technology
Pressure Control	Minor, current technology
Quick Disconnect	Minor, build into design
Leak Detection in Space	Minor, current technology
Transfer Pump	Major, new technology for space
Vapor Compressor	Major, new technology for space

Table 4-7. Impact on Centaur of TDM Elements for Propellant Resupply at the Space Station

Technology	Centaur Impact
Low-Gravity Mass Gauging	Minor, change current components
Low-Gravity Liquid Acquisition	Major, new tank structure and undeveloped technology
Childown/No-Vent Fill	Major, new internal structure
Pressure Control	Minor, current technology
Add Quick Disconnect Panel	Minor, redesign of panels
Leak Detection in Space	Minor, current technology
Fluid Baffling	Major, new internal structure
Thermal Control Coating	Minor, undeveloped technology
Low Conductance Penetration	Minor, current technology

Duplicating OTV propellant transfer in a zero-gravity environment will obviously require similar major propellant management system modifications to the Centaur G-prime vehicle. These are shown in Figure 4-5. Zero-gravity mass gauges, currently under development by NASA/JSC, are added to each tank. Channel-type total communication LADs are required to drain the tanks at the Space Station in the event of a shortened or aborted mission. The LADs will also be used to achieve efficient tank chilldown with minimum liquid loss, and a thermodynamic vent system with mixer is added to the oxygen tank to increase agitation during chilldown and no-vent fill, as well as provide for liquid-free venting. A diffuser/dissipator is also added to the oxygen tank for zero-gravity draining (see also Table 4-8).

An assessment of the impact on Space Station and Centaur of these changes and additions to develop a TDM, and of relevant major issues regarding this technology follows.

4.1.4 PAYLOAD INTEGRATION. This technology must provide simple and adequate interfaces between OTV and payload. The goal is to allow efficient payload mating with a minimum of expensive, time-consuming EVA. The mating operations for OTV would include both large single, and multiple small payloads. Figure 4-6 illustrates the OTV operation that a TDM would model. Major element test rationale, performance criteria, and criteria justification are as follows:

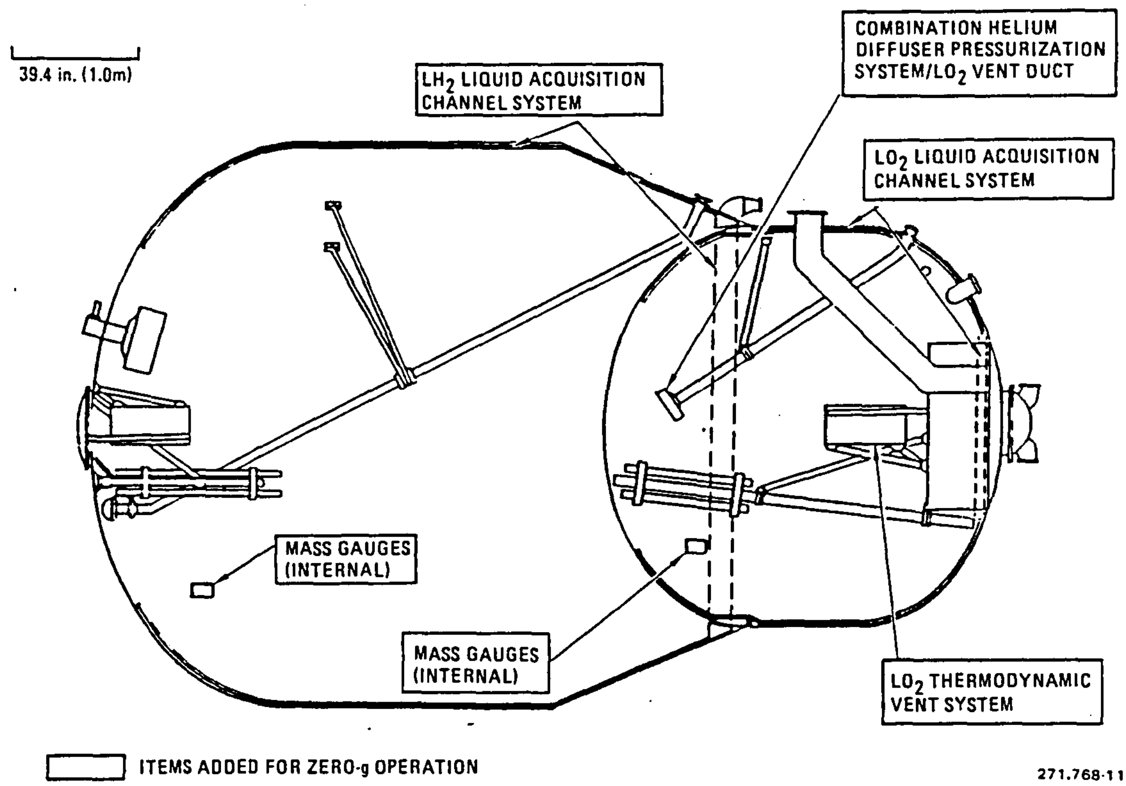


Figure 4-5. Centaur Will Require Propellant Management System Modifications for Zero-Gravity Operation

Table 4-8. Propellant Resupply TDM Issues

Fluid System Modifications	Without major fluid systems modifications, propellant settling would be required (CO-ORBITING PLATFORM (COP) with rotation or tethering) for transfer and tanking for Centaur mission.
TDM Location	Substantial mass may limit possible locations on the Space Station.
Safety	Will require single failure operational/dual failure safe systems, leak-before-burst design of pressure vessels. May need: 1) emergency jettison system for Centaur or 2) COP for propellant transfer.
Power and Heat Rejection	Will require interface with Space Station power and heat rejection systems. Needs are minimal to operate components other than reliquefaction system.
Monitoring	Will require automated statusing and automated propellant transfer system with astronaut override.

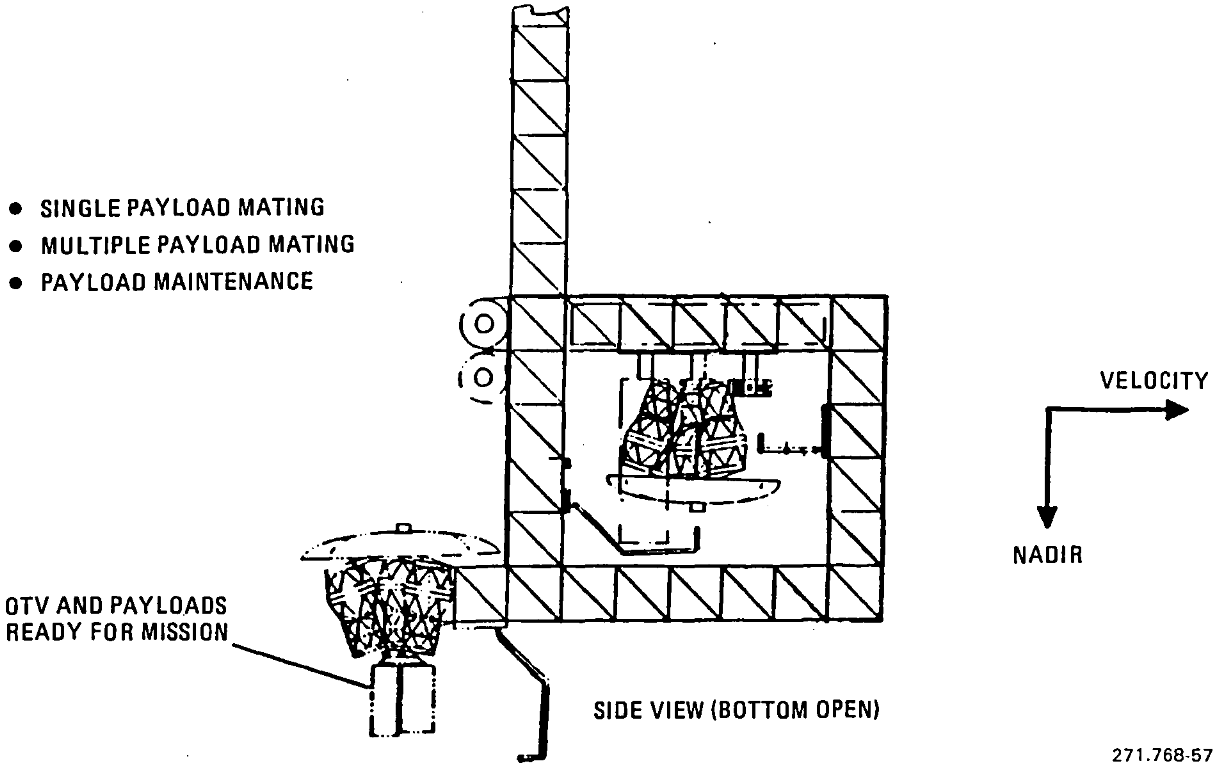


Figure 4-6. OTV Can Mate Single or Multiple Payloads

CENTAUR OPERATIONS AT THE SPACE STATION

- Mate payload to OTV

Rationale:	Space-based OTV requires efficient payload mating hardware and operations at the Space Station
Performance:	Operations elapsed time = 8 hr
Justification:	Operations analyses during OTV studies established payload mating times

- Payload maintenance

Rationale:	Contingency maintenance operations on payloads while mated to the OTV requires demonstration to reduce number of unplanned mating operations
Performance:	Operations elapsed time = 2 hr
Justification:	Operations analyses during OTV studies established payload maintenance (removal and replacement) times

Impacts on Space Station and Centaur of changes necessary for a TDM are presented in Tables 4-9 through 4-11.

Table 4-9. Impact on Space Station of TDM Element Operations for Payload Integration

Element	Space Station Impact
Single Payload Mating	Minor, planned Space Station assets
Multiple Payload Mating	Minor, planned Space Station assets
Payload Maintenance	Minor, planned Space Station assets

Table 4-10. Impact on Space Station of TDM Elements for OTV Payload Integration

Element	Space Station Impact
Payload	Minor, planned Space Station asset
Payload Storage Fixture	Minor, planned asset for payload TDM
Manipulator Foot Restraint	Minor, asset exists
RMS (Mobile)	Minor, planned Space Station asset
EVA Equipment	Minor, planned Space Station asset
Payload ORU	Minor, planned Space Station asset
Control Station	Minor, planned Space Station asset
TV and Lighting System	Minor, planned Space Station asset

Table 4-11. Impact on Centaur of TDM Element Operations for Payload Integration

Element	Centaur Impact
Single Payload Mating	Minor, build to design
Multiple Payload Mating	Minor, build to design
Payload Maintenance	No impact identified

4.1.5 <u>CENTAUR DEPLOYMENT (LAUNCH OPERATIONS)</u>. The point of the OTV is to launch with payloads from the Space Station, deploy those payloads in GEO or higher orbits, then return to the Space Station. This requires extensive communication and control interfaces between OTV, tracking and data relay satellites (TDRS), orbital maneuvering vehicle (OMV), Earth Ground stations, and the Space Station. It is these communication links, and launch operations that would be demonstrated in this TDM. Figure 4-7 illustrates the links and operations to be tested. Rationale, performance criteria, criteria justification, Space Station and Centaur impact, see Tables 4-12 through 4-14, and issue assessments are as follows:

- Rationale: The mission of OTV is to launch from the Space Station, deploy payloads in GEO, or higher orbits, or escape trajectories; and return to Space Station for reuse
- Performance: Demonstrate coordinated communications and control between Space Station, Earth stations, TDRS, and OMU to support a multiple payload (expendable) launch
- Justification: Centaur can be recovered without major modifications

Table 4-12. Impact on Space Station of TDM Elements for Launch Operations

Element	Space Station Impact
COP for fueling and launch	Medium. COP is in JSC 30000 baseline, but would be specially modified for Centaur - would be reused for OTV.
OMV control room used to control launch	Minor.
TDRS and Ground station communication and	Minor. Elements will already be in place with Initial Operational Capability (IOC)

Table 4-13. Impact on Centaur of TDM Elements for Launch Operations

Element	Centaur Impact
Zero-gravity propellant management	Major. Accomplished in cryogenic resupply TDM.
Software changes	Minor.
Grappling and handling changes	Minor.

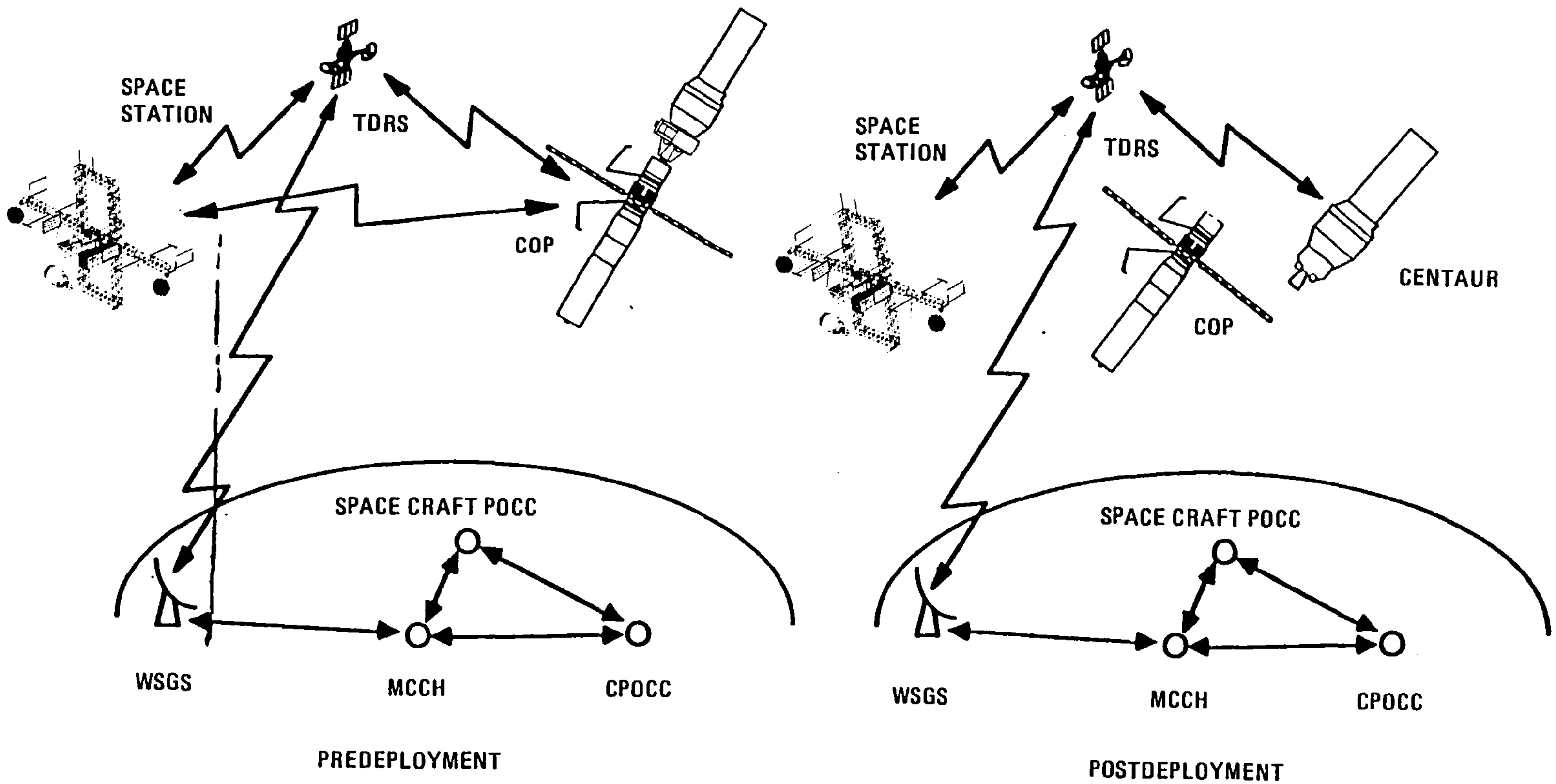


Figure 4-7. Like OTV, Centaur Deployment Communications and Control Has Several Elements

Table 4-14. Launch Operations Issues

- Insurance for multipayload launch
- Transportation to station (baseline assumption is Shuttle cargo bay with empty Centaur propellant tanks)
- COP cost and construction
- Hangar construction
- Unforeseen safety issues

4.2 OTV A&O NOT SUITED FOR CENTAUR DEMONSTRATION

The technologies from Section 4.1 that Centaur could not cost-effectively demonstrate are listed here with reasons (see Tables 4-15 and 4-16).

Table 4-15. Critical OTV Space Station A&O Technology That Centaur Cannot Do

Technology	Reason
Modular tank set operations	Major changes required
GEO to LEO control and communication	Centaur does not return after mission
Crew facilities	Centaur is unmanned

Table 4-16. OTV-Related Space Station Technology Outside Scope of Contract

Technology	Comment
Aerobrake maintenance and handling	Critical capability for OTV.
Space Station refuse removal	Critical Space Station need. Might be used for nonserviceable OTVs
Spare parts depot	OTV critical but not feasible TDM

4.3 CENTAUR MODIFICATIONS REQUIRED FOR SPACE BASING

4.3.1 SUMMARY. Centaur G-prime and its Centaur Integrated Support System (CISS) were modified for Space Station basing. The changes were consistent with the following assumptions:

- The Centaur/CISS Assembly (CCA) would be mated on the ground using Super-Zip and separation springs as currently done, and would remain mated for up to a 1-year period of technology demonstrations at the Space Station.
- The Centaur would be transported to the Space Station "dry" (i.e., no cryogens in the Shuttle).
- The CCA would be deployed on a multiple payload geosynchronous mission after its Space Station residency.
- The CCA would contain no cryogens at Space Station. Cryogenic propellant tanking, detanking, and launch deployment would take place from a COP depot.
- The OMV would transport the CCA between Space Station and COP.

Modifications were made to avionics, payload integration hardware, vehicle structure, fluid management systems, and electric power components.

4.3.2 SPACE TEST RATIONALE AND OBJECTIVES. Space Station basing was the goal of the modifications. These modifications were done to allow Centaur to serve as an OTV surrogate for Space Station A&O Technology. Objectives were as follows:

- To make CCA systems compatible with Space Station, OMV, and COP A&O
- To retain deployment capability after up to 1-year at Space Station
- To make a dry CCA compatible with, and space removable from, the Shuttle.

4.3.3 ARCHITECTURE. As depicted in Figure 1-2, the CCA will be delivered to the Space Station by the Shuttle. The CCA would be transported between the Space Station and the COP by the OMV.

4.3.4 COMMUNICATIONS AND CONTROL. The CCA will have continuous monitoring. While in the Shuttle, it will have no cryogens and no main vehicle batteries (MVBs). It will have its normal charges of hydrazine and helium. The CISS Dual Failure Tolerant systems will monitor and control minimum helium stabilization pressures (4-5 psig in LO_2, and 2-3 psig in LH_2 tanks). Any unlikely helium venting would be done in the Shuttle cargo bay. The CCA will have electrical interfaces allowing monitoring during berthing and transfers with the telerobotic arms of the Shuttle and the Space Station hangar.

4.3.5 SYSTEMS AND SUBSYSTEMS

4.3.5.1 Avionics. Figures 4-8 and 4-9 show avionics modifications on the forward and aft ends of Centaur. The current inertial measurement group, inertial reference unit, and systems electronics unit are replaced by an inertial measurement unit (a ring laser gyro) and a startracker to allow calibration and alignment in space at zero-gravity conditions. As the current 16K digital computer unit was not compatible with the inertial measurement unit, it was replaced and upgraded with a 128K flight control processor. In addition the signal conditioner and remote multiplexer unit were replaced with a master data unit. The master data unit performs telemetry formatting previously done in the digital computer unit (and not available in the flight control processor) and facilitates easier, more comprehensive vehicle checkout. A remote data unit is aft mounted to support the master data unit. Two additional MVBs and a battery bussing unit have been added as support and backup for a geosynchronous mission. Up to three Payload Batteries and a power transfer unit can be added to support payload spacecraft. These avionics changes are consistent with an advanced launch vehicle avionics system that has already been designed for Centaur. Specifications to these new units exist.

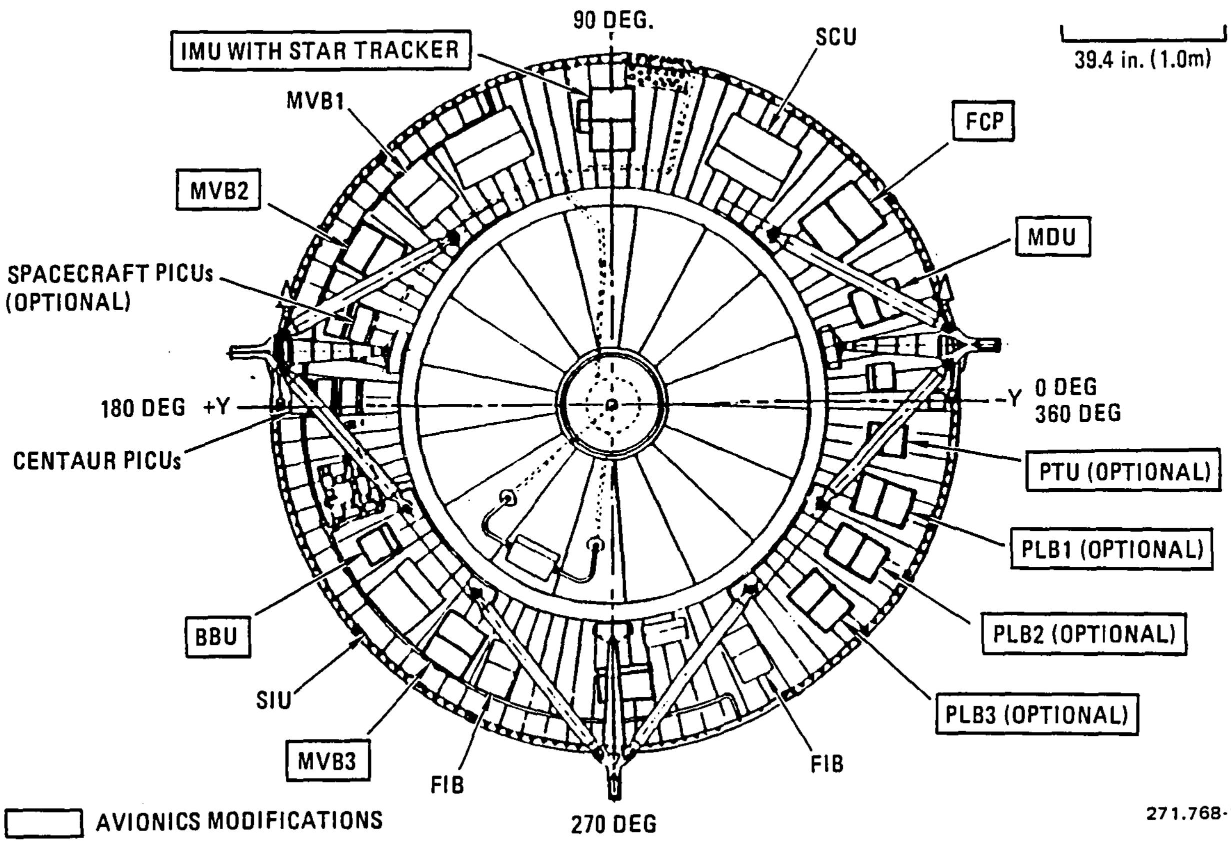


Figure 4-8. Centaur Forward End (View Looking Aft) Shows Avionics Modifications

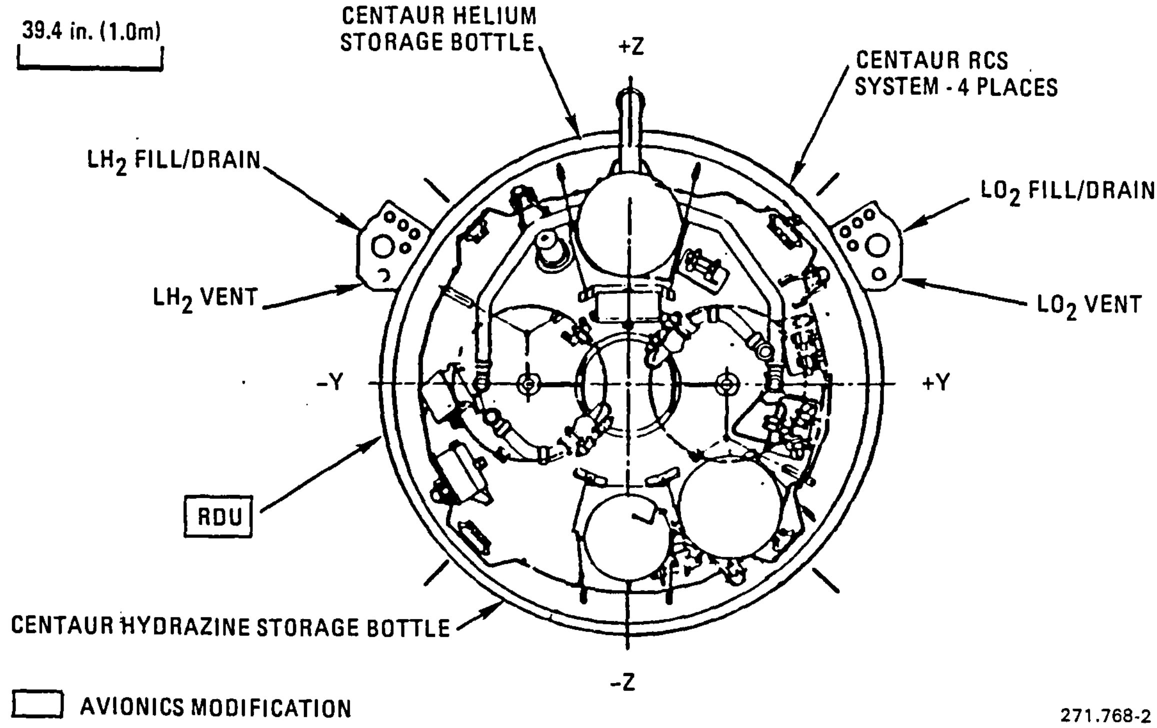


Figure 4-9. Centaur Aft End (Support Structure Removed) Shows Remote Data Unit Avionics Additions

The Centaur will be at the Space Station 9 months. Battery servicing will be necessary because of the 2-month shelf-life limitation of Centaur's present silver-zinc batteries. Installation and replacement will be done by EVA inside a special Centaur hangar at the Space Station. Battery replacement modules will be equipped with "pip pin" latching mechanisms and an electrical connector (see Figure 4-10). Pip pins are standard on both commercial and military aircraft.

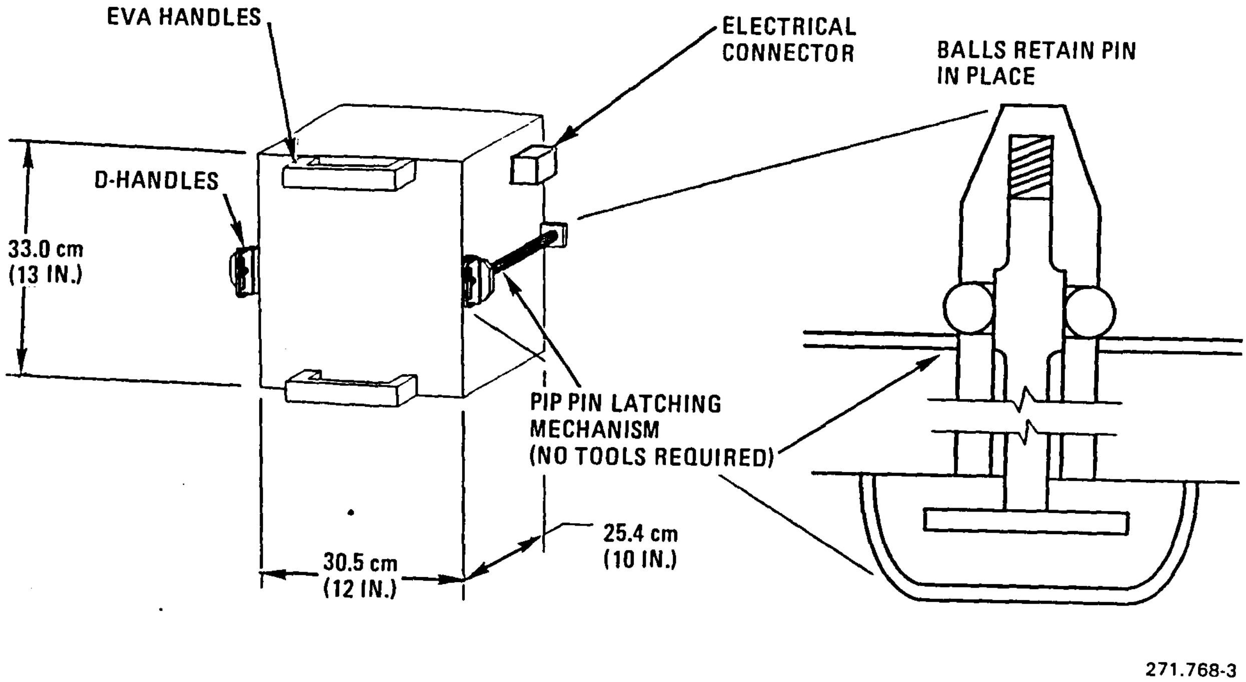


Figure 4-10. Battery Module Connection Concept Uses Pip Pin EVA Handles for Removal

4.3.5.2 Payload Integration. The Centaur will use an OTV prototype Universal Payload Adapter (UPA) to allow evaluation of single payload integration activities. A Multiple Payload Adapter (MPA) will also be tested. It will allow several payloads to be carried simultaneously on individual UPAs. This commonality and modularization will allow quick changeout and replacement of payloads for optimum flexibility.

The UPA is for single spacecraft mating to Centaur. The adapter is mounted on the forward end of the Centaur while on the ground and delivered with Centaur to the Space Station. Figure 4-11 shows the single payload system.

The UPA has three payload latch mechanisms and an electrical umbilical actuator. Details are shown in Figure 4-12. The latch secures the payload to the UPA. A preliminary OTV payload latch design shown in Figure 4-13 was chosen. It is an electrically actuated trunnion lock-down device. Its spring supplies the force for clamping and deployment.

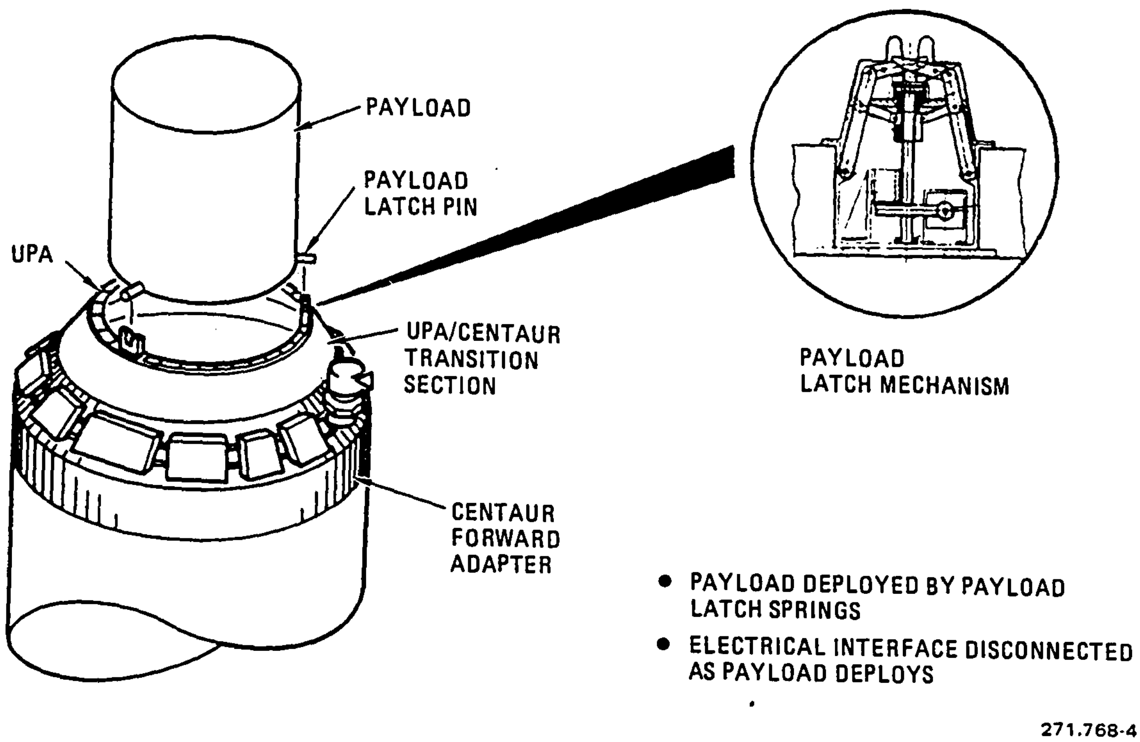
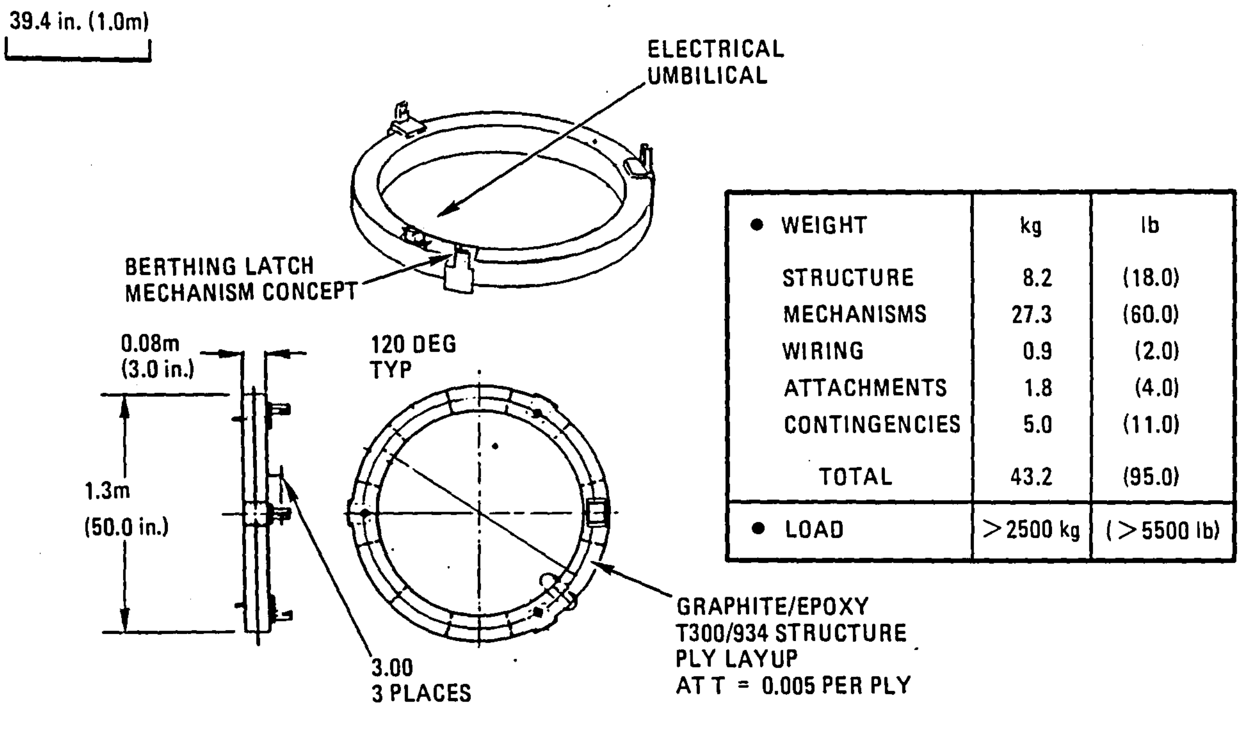


Figure 4-11. Payload Deployed by Payload Latch Mechanism Springs



• WEIGHT	kg	lb
STRUCTURE	8.2	(18.0)
MECHANISMS	27.3	(60.0)
WIRING	0.9	(2.0)
ATTACHMENTS	1.8	(4.0)
CONTINGENCIES	5.0	(11.0)
TOTAL	43.2	(95.0)
• LOAD	>2500 kg	(>5500 lb)

Figure 4-12. The Universal Payload Adapter (UPA) Designed for OTV Will Be Used in Centaur Payload Integration TDM

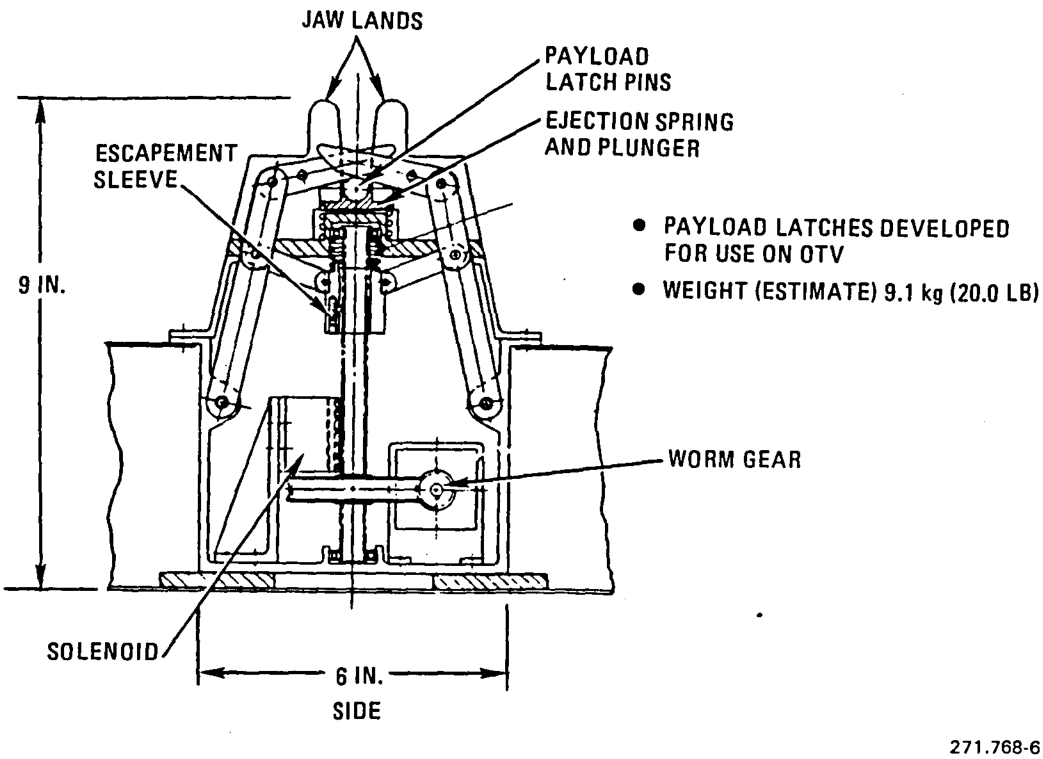
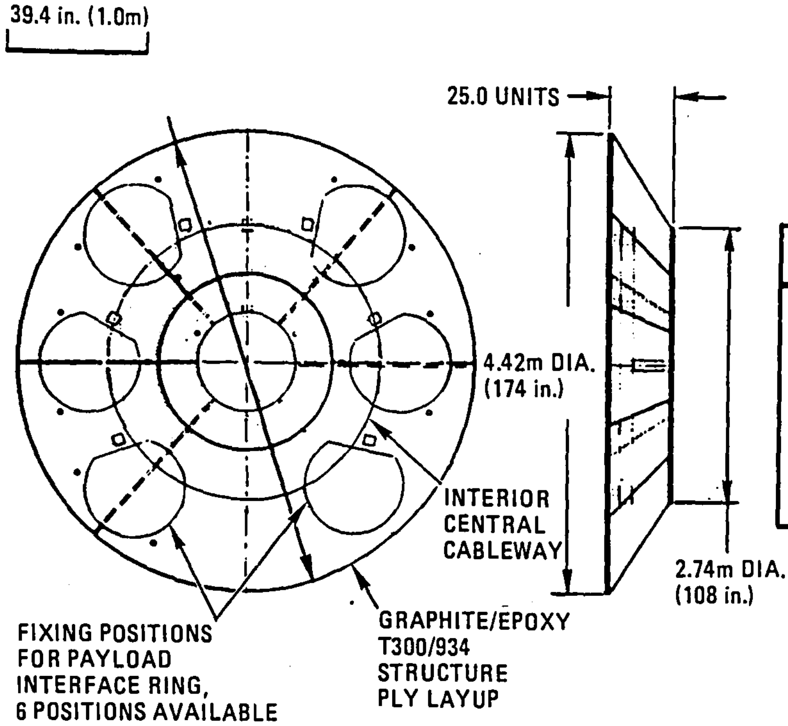


Figure 4-13. Payload Latch Ejects Payload With a Spring

The MPA mounts two to six individual UPAs to accommodate a variety of payloads. It is the dish-like structure illustrated in Figure 4-14. The MPA mounts to the forward end of the Centaur on another UPA as can be seen in Figure 4-15.



SPACE INTEGRATED MULTIPLE PAYLOAD CARRIER DEVELOPED FOR USE ON OTV

WEIGHT	kg	lb
STRUCTURE	105.0	(230.0)
MECHANISMS	164.0	(360.0)
WIRING	18.0	(40.0)
CONTINGENCY	43.0	(95.0)
TOTAL	330.0	(725.0)

271.768-7

Figure 4-14. The Multiple Payload Adapter (MPA) is a Mount to Integrate Up to Six UPAs

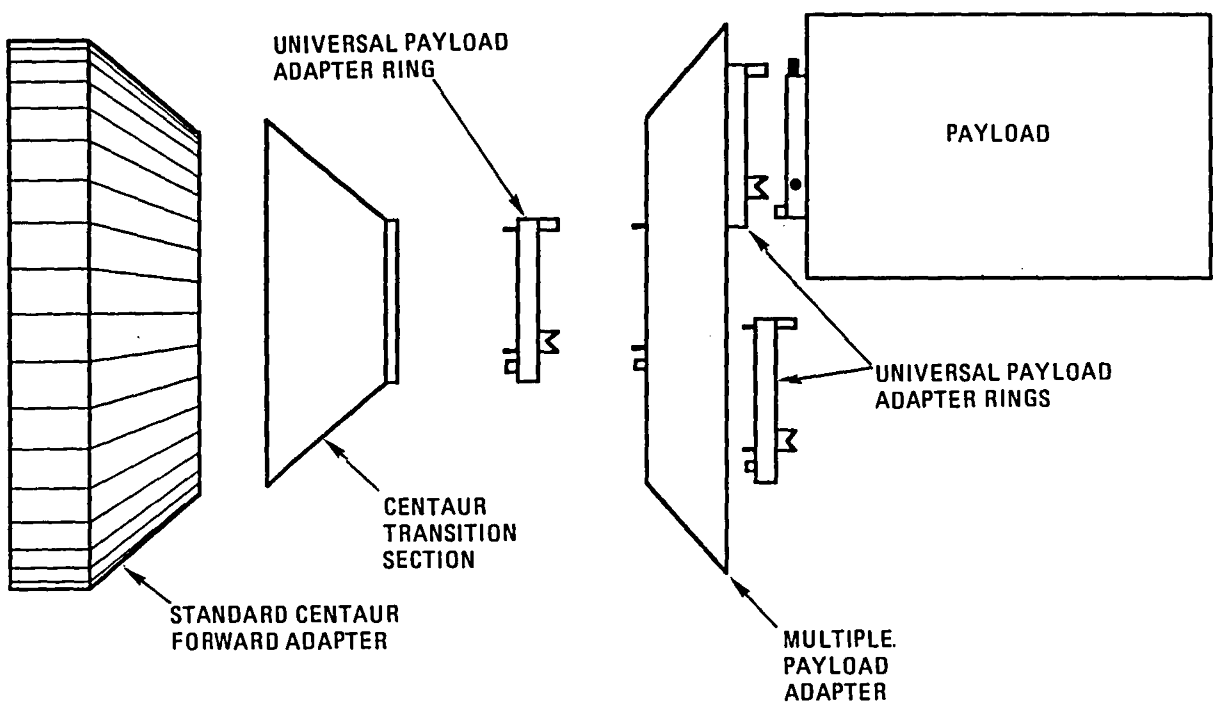


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Figure 4-15. The MPA Mates to Centaur Through a Single UPA

4.3.5.3 Structures. The Centaur space handling fixture is the means for extracting the CCA from the Orbiter cargo bay while minimizing changes to the Centaur. The handling fixture provides a standard grapple fixture for use with the Space Station mobile remote manipulator system (MRMS) and Centaur berthing hangar telerobotic arm. The handling fixture is an aluminum truss attached to the top left and right sides of the CISS. It can be seen in Figure 4-16.

Another added structure is the Centaur space berthing fixture. It is the means for securing Centaur in its Space Station hangar, and for attachment to the OMV and COP. It is a boron-aluminum truss interface structure added to the rear of the CISS. It offers five secure attach points: four trunnions and a standard grapple fixture. This is illustrated in Figure 4-17.

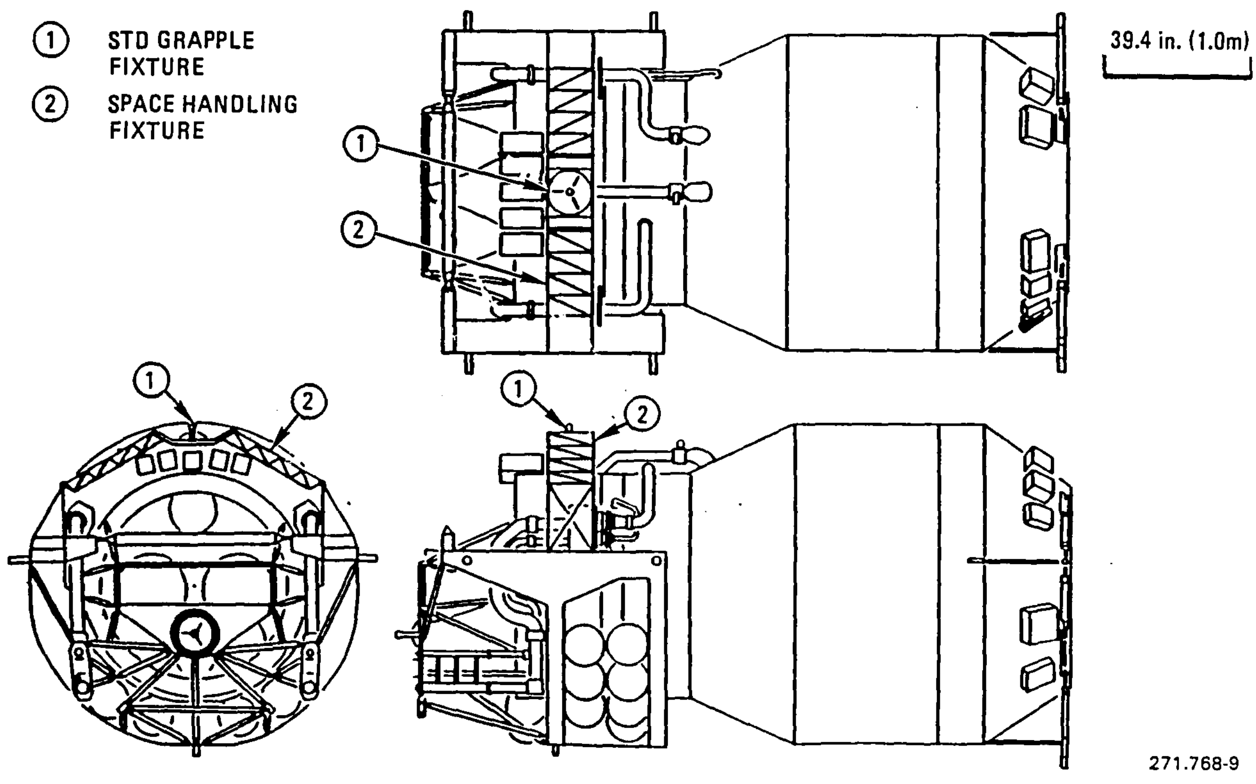


Figure 4-16. The Centaur Space Handling Fixture Is Attached to the Top of the CISS

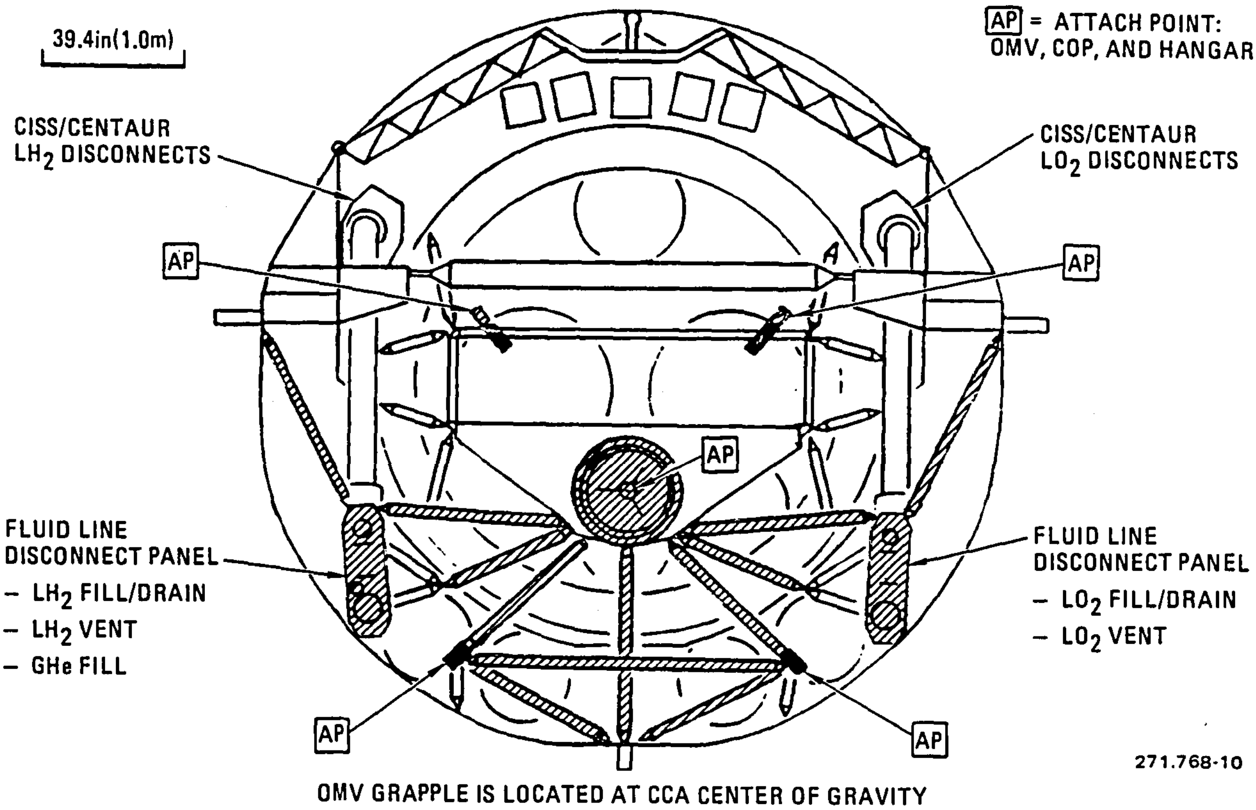


Figure 4-17. The Centaur Space Berthing Fixture Is Attached to the Rear of the CISS

4.3.5.4 Fluid Management. The major propellant management system modifications required to operate the G-prime vehicle in a zero-gravity environment are highlighted in Figure 4-18. Zero-gravity mass gauges, currently under development by NASA/JSC, and LADs are added to each tank. A LAD is a channel-type total liquid communication system required for zero-gravity fill and drain at the COP. LADs also provide efficient tank chilldown with minimum liquid loss. A thermodynamic vent system with mixer is added to the oxygen tank. This increases agitation during chilldown and no-vent fill and provides for liquid-free venting. A diffuser/dissipator is also added to the oxygen tank for zero-gravity draining.

Figure 4-19 shows the four-channel LAD in both the LO_2 and LH_2 propellant tanks. The channels gather liquid into a central manifold connected to the existing fill and drain outlet. Figure 4-20 shows details of LAD channel construction. The fully passive system is patterned after the CFMFE design. Its function is to separate the propellant liquid and vapor phases and channel only liquid to the outlet. As long as the screen remains wetted, surface tension forces will act to preferentially pass liquid into the channel. The perforated plate provides structural support for the screen.

Propellant transfer between Centaur and the COP is done through berthing disconnect panels. The two panels are located at the aft end of the CISS and are extensions from the present fill/drain and vent fluid lines (see Figure 4-21). There will be berthing panels at the Space Station hangar and the COP for Centaur panels to mate to.

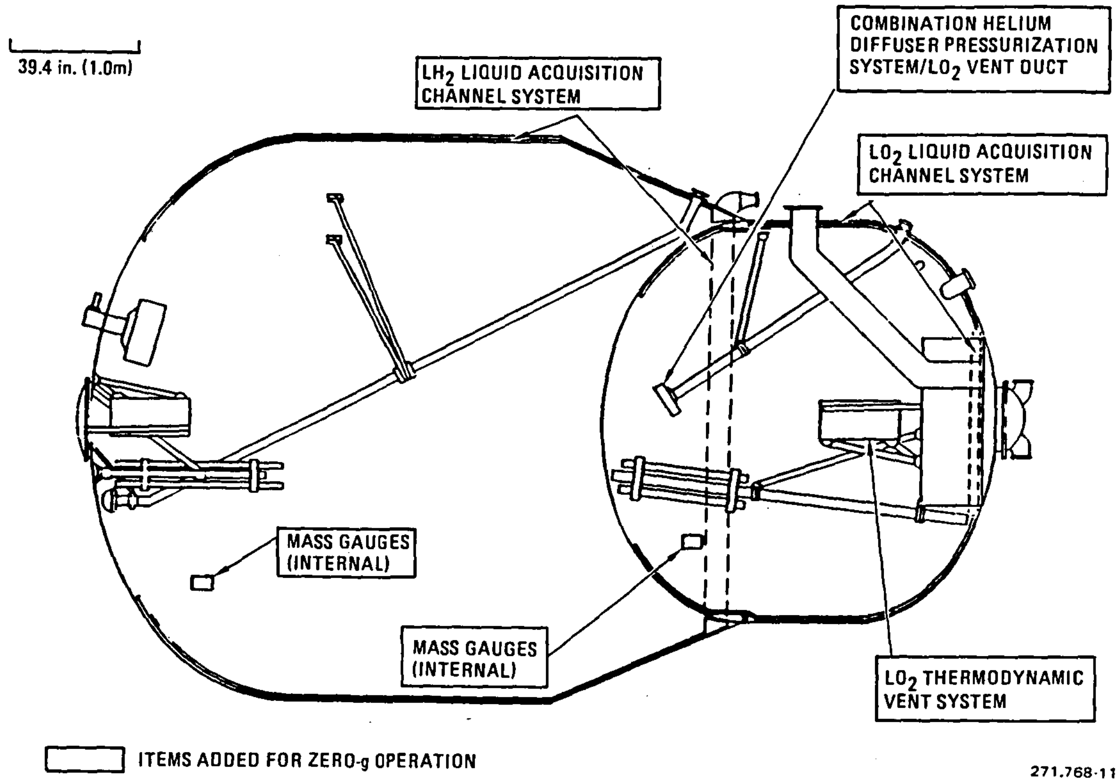


Figure 4-18. Several Internal Tank Modifications Allow Zero-Gravity Operation

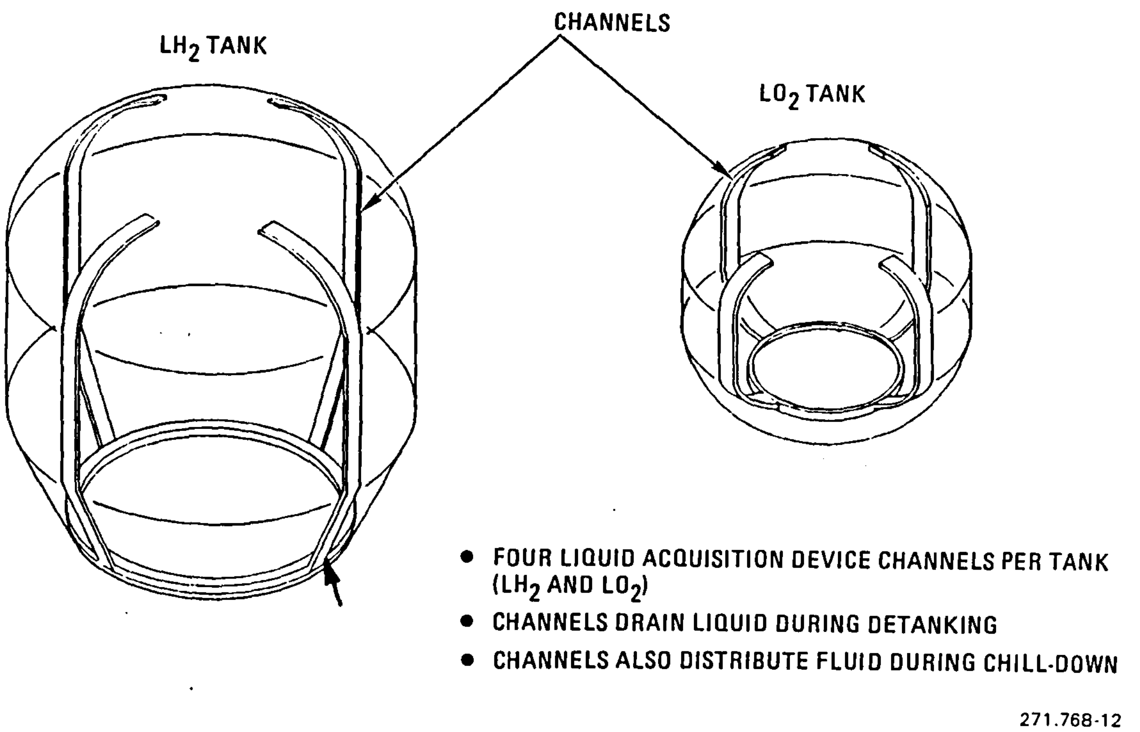
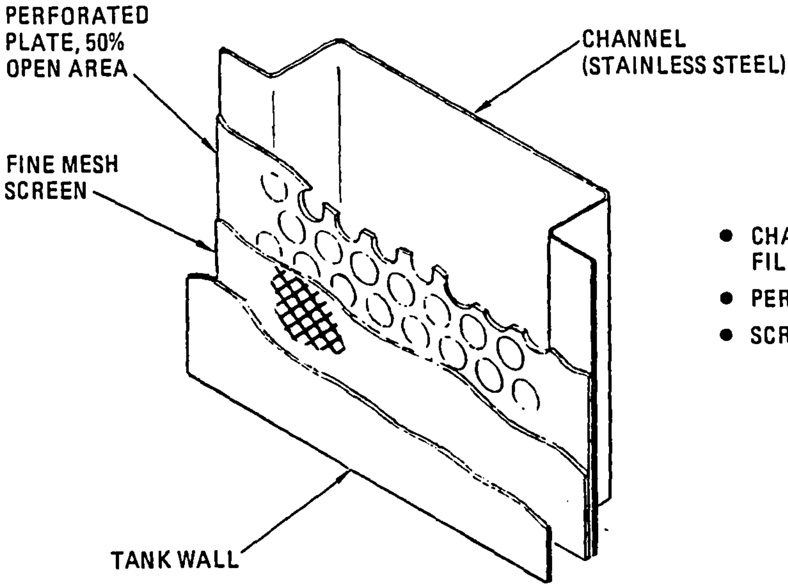


Figure 4-19. Each Propellant Tank Contains a Zero-Gravity Liquid Acquisition Device



- CHANNELS TRANSPORT LIQUID TO TANK FILL AND DRAIN OUTLET
- PERFORATED PLATE SUPPORTS SCREEN
- SCREEN PASSES ONLY LIQUID INTO CHANNELS

CROSS SECTION VIEW OF CHANNEL

271.768-13

Figure 4-20. Liquid Acquisition Device (LAD) Channels Have Fine Mesh for Vapor and Liquid Separation

The panel on the port side supports LO_2 fill/drain, GO_2 vent, electrical, and GHe. The panel on the starboard side supports LH_2 fill/drain and GH_2 vent lines. Each Centaur disconnect panel incorporates docking locating pins, berthing pins, and self-aligning fluid line disconnects. The berthing disconnect panels at the Space Station hangar have berthing latches that grip the berthing pins and pull the panels together connecting the self-aligning fluid lines and electrical connections.

Propellant line disconnects used for the fluid disconnect panels will be similar to the type presently used for Atlas/Centaur and Titan/Centaur (see Figure 4-22).

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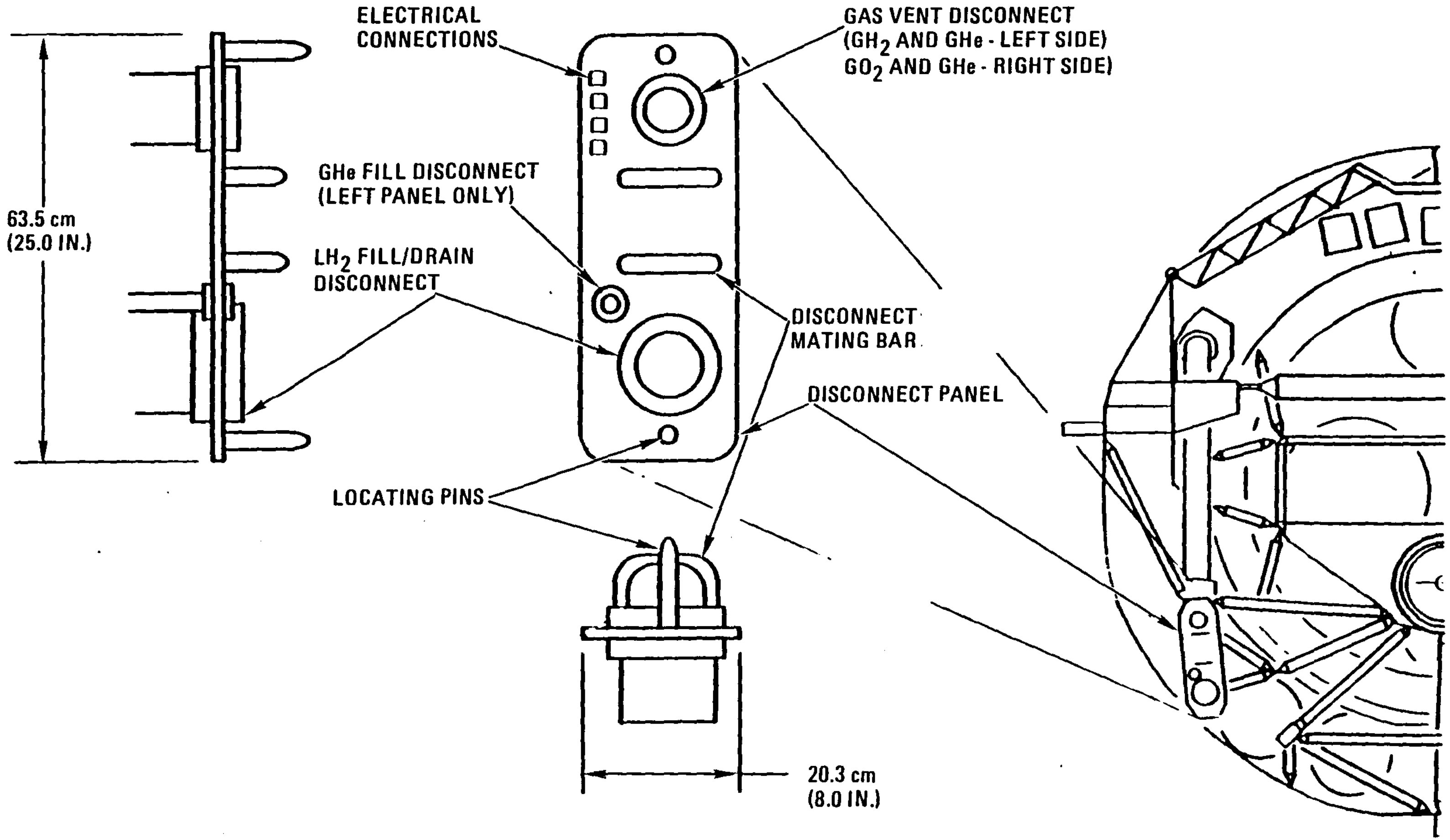

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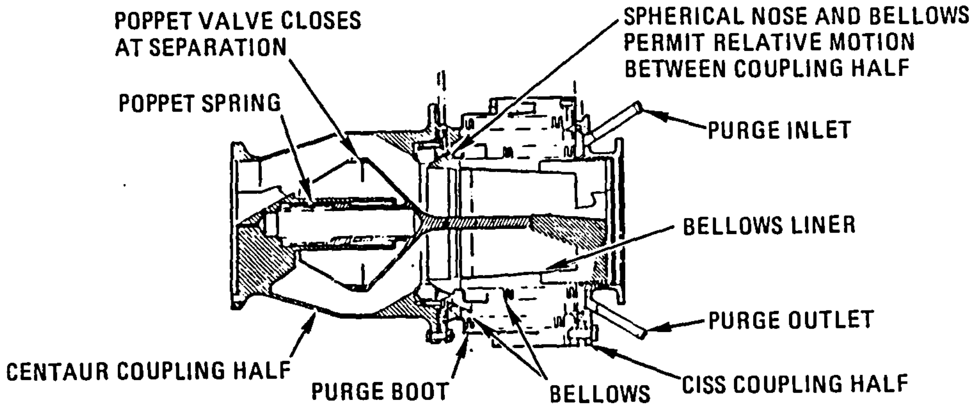
Figure 4-21. Centaur Disconnect Panels Supply Fluids and Power to Centaur



CRYOGENIC DISCONNECT DEVELOPED FOR SHUTTEL CENTAUR AND TITAN/CENTAUR.		
• WEIGHT		
SHUTTLE/CENTAUR	18.2 kg	(40 LB)
TITAN/CENTAUR	4.5 kg	(9.9 LB)
• MATING LOAD	181.8 kg	(400 LB)
• DIAMETER (LH_2 AND LO_2)	14 cm	(5.5 IN.)

271.768-15

Figure 4-22. Cryogenic Propellant Disconnects Are Similar to Current Centaur Designs

4.3.5.5 Electrical. CISS-to-Orbiter electrical connections will be modified to accommodate the removal of the CISS and Centaur from the Orbiter bay at the Space Station. Electrical disconnect mechanisms similar to those used on the present Orbiter spacecraft flight support system are proposed.

Male electrical connectors are mounted to the forward end of the CISS (see Figure 4-23) with a wiring harness routed back to the existing CISS-to-Orbiter electrical panel. Electrical disconnect actuator mechanisms (see Figure 4-24) are mounted on the Orbiter bay wall in front of the male electrical connectors. The electrical disconnect actuator mechanisms remain connected until the CCA is to be lifted out of the Orbiter bay. They then disconnect and allow clearance for the CCA to be removed.

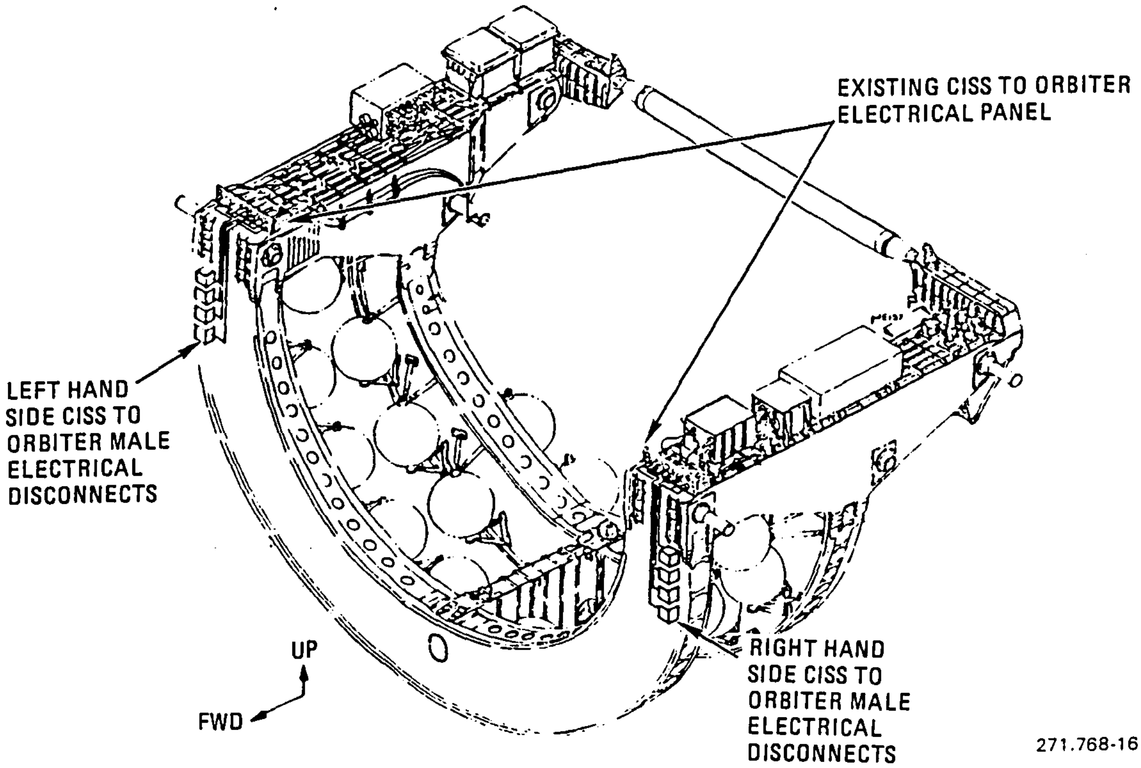


Figure 4-23. Modified CISS-to-Orbiter Electrical Connections Will Facilitate CCA Removal at Space Station

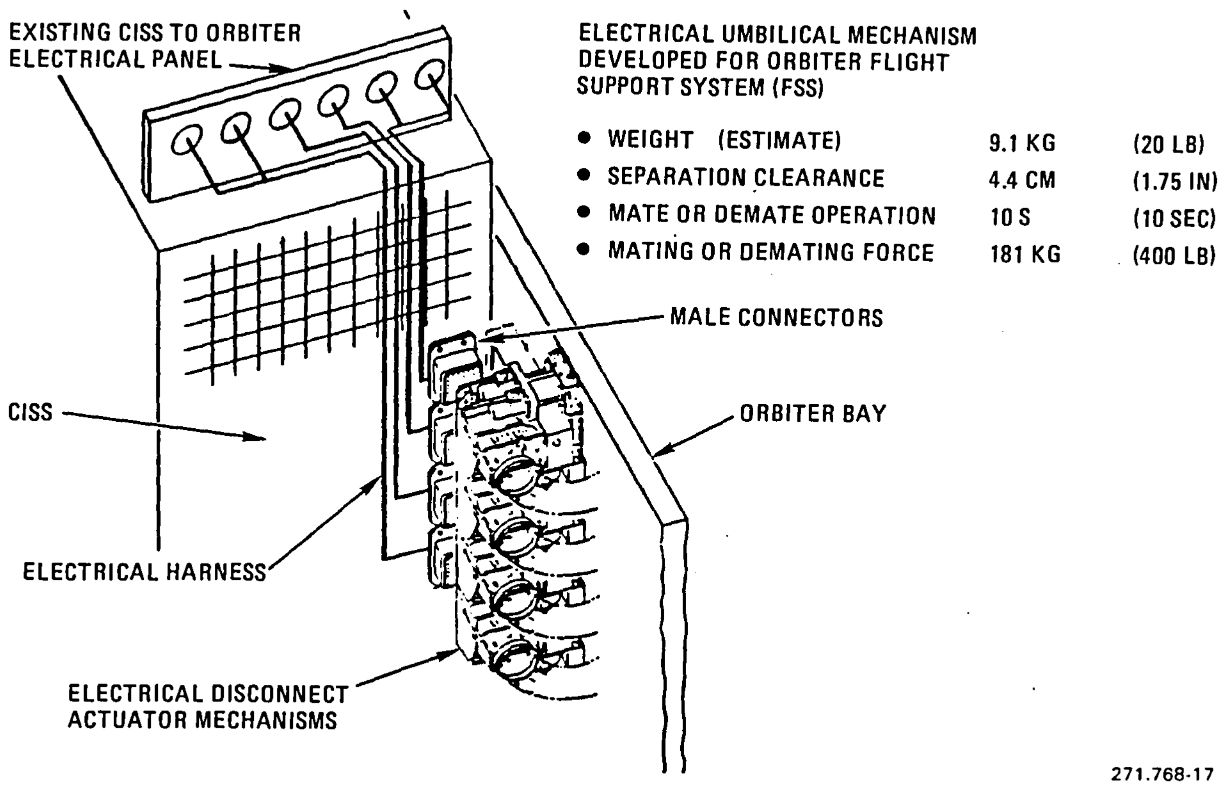


Figure 4-24. Electrical Umbilical Disconnects Are Mounted to Shuttle Bay Wall

4.3.5.6 Weight Summary. After modifications, Centaur weight increased 355 kg (780 lb) and the CISS increased 214 kg (470 lb) from the G-prime Galileo configuration (see Table 4-17 for weight summary). Additional mission-peculiar payload hardware weight will be added to Centaur. These components are also part of Table 4-17.

4.3.6 OPERATIONAL PLAN. Centaur will be delivered to Space Station inside the Orbiter with no propellants. The LO_2 and LH_2 tanks will be pressurized with helium to 2-3 lb and 4-5 lb, respectively, to ensure structural integrity during liftoff and handling at the Space Station.

The Centaur and CISS remain mated and are delivered from the Orbiter bay to the Space Station hangar by the MRMS. The CCA is berthed at the hangar and is dormant until used for TDMs. The hangar will supply the CCA with helium and electrical power. The Space Station will also monitor Centaur helium pressure.

4.4 CENTAUR-UNIQUE ACCOMMODATIONS REQUIRED

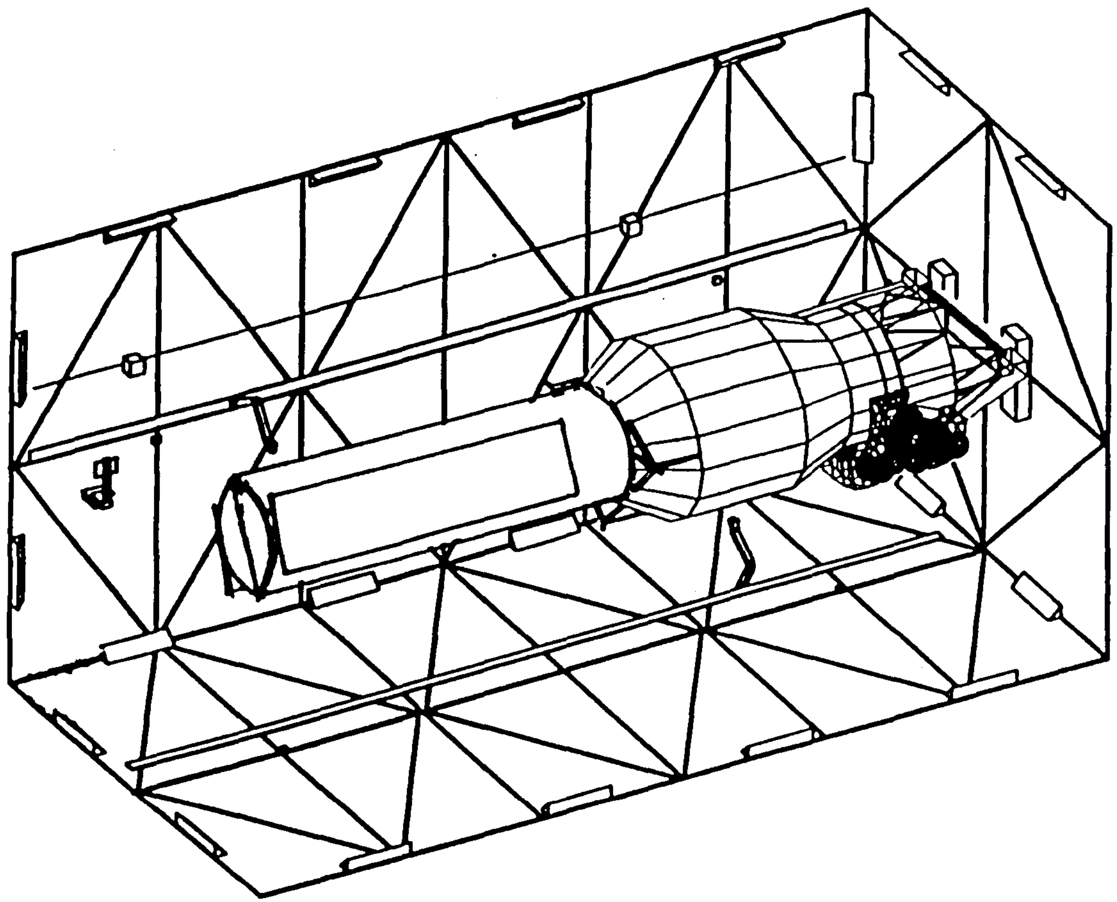
4.4.1 SUMMARY. A Centaur berthing hangar is the only unique accommodation required. It must be constructed before Centaur arrives at the Space Station.

4.4.2 RATIONALE AND OBJECTIVES. Space Station basing was the goal of Centaur modifications. A hangar for Centaur is a unique need not provided by the Space Station, but required for Centaur space basing. The hangar objectives are to accommodate storage, maintenance and servicing, and minimal environmental protection for Centaur.

4.4.3 ARCHITECTURE. The hangar and its Space Station interfaces are the major elements of unique accommodations. They are illustrated and detailed in Section 5.1 (Berthing, Checkout, and Maintenance).

Table 4-17. Centaur/CISS Weight Increased 569 kg (1250 lb) After Space Basing Modifications

Item	Reference Weight (G-Prime Galileo)	Weight	Change
Centaur Dry Weight	2731 kg (6008 lb)	3085 kg (6788 lb)	+355 kg (780 lb)
Avionics			200 kg (440 lb)
Propellant Management System			100 kg (220 lb)
Battery Module			55 kg (120 lb)
CISS	3168 kg (6969 lb)	3381 kg (7439 lb)	+214 kg (470 lb)
Handling Fixture and Interfaces			127 kg (280 lb)
Electrical Disconnects			73 kg (160 lb)
Fluid Line Disconnect Panels			14 kg (30 lb)
Totals	5899 kg (12,977 lb)	6,466 kg (14,227 lb)	+569 kg (1,250 lb)
Payload Adapters (Not included above. Attached in TBD combination for a mission.)	114 kg (250 lb)	434 kg (955 lb)	+434 kg (955 lb)
MPA			330 kg (725 lb)
UPA			41 kg (90 lb)
Centaur Transition Section			64 kg (140 lb)



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SECTION 5

TASK 2 - OTV ACCOMMODATIONS TDM CONCEPTS

5.1 ACCOMMODATIONS TDM

5.1.1 BERTHING, CHECKOUT, AND MAINTENANCE

5.1.1.1 Summary. Three Space Station Accommodations (TDMs) elements will be performed: 1) Berthing, 2) Vehicle Checkout and Maintenance, and 3) Payload Integration. The first two are so closely related that they will be covered together in this section.

The Berthing, Checkout, and Maintenance element TDM was designed to build an experience base in activities that the orbital transfer vehicle (OTV) would require for Space Station operations. To that end, a Centaur hangar will be constructed to emulate OTV hangar functions and construction experience. The Centaur will be monitored during storage. Maintenance will be performed as required, and for experience.

5.1.1.2 Space-Test Rationale and Specific Objectives. The goal of this element of TDMs is OTV emulation in a real environment, so they must be done in space. The TDM objective is to build an experience base in the following: diagnostic processes, maintenance operations using both teleoperator and extra-vehicular activity (EVA) techniques, dispatch, servicing, deservicing, payload mating and checkout, OMV handling, and payload launch with associated tracking and communication functions for the OTV using a Centaur vehicle as a trailblazer. This "live" precursor experience for the OTV will help absorb the learning curve and expose problems only evident in the real space environment.

5.1.1.3 TDM Schedule. The Berthing, Checkout, and Maintenance TDM Element will utilize the Shuttle, Space Station, dedicated Centaur hangar and tracking and data relay satellite (TDRS) as shown in Figure 5-1. The Centaur will be removed from the Shuttle upon arrival and transported to the Centaur hangar for storage, checkout, and planned and contingency maintenance. Figure 5-2 shows the schedule for the activities of this TDM.

5.1.1.4 Communications and Control Overview. The Centaur will be constantly monitored during its stay at the Space Station to ensure tank integrity and to flag any thermal anomalies which could damage hardware and affect later activities. Communication and control of the Centaur/CISS assembly (CCA) will be accomplished using umbilicals connected to the fluid and electrical interface panels. A computer-controlled launch set (CCLS)-type system on the Space Station will provide all prelaunch control to including initializing and powering up of the Centaur, uplinking digital computer unit (DCU) software tenants, avionics and fluids checks, and monitoring and displaying Centaur/CISS downlink data. In addition, updating of the Centaur state vector will be required. A functional diagram of the communication and control requirements is shown in Figure 5-3.

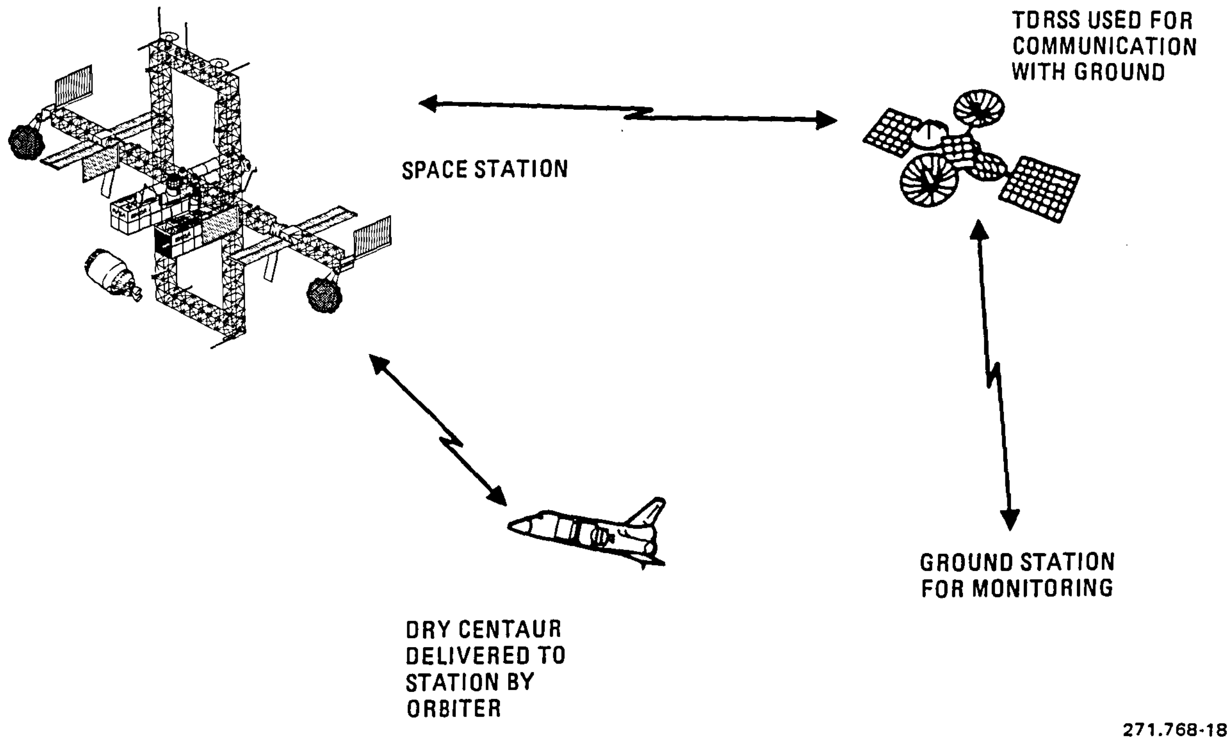


Figure 5-1. TDM Will Require Space Station, Orbiter, Hangar, and TDRS Resources

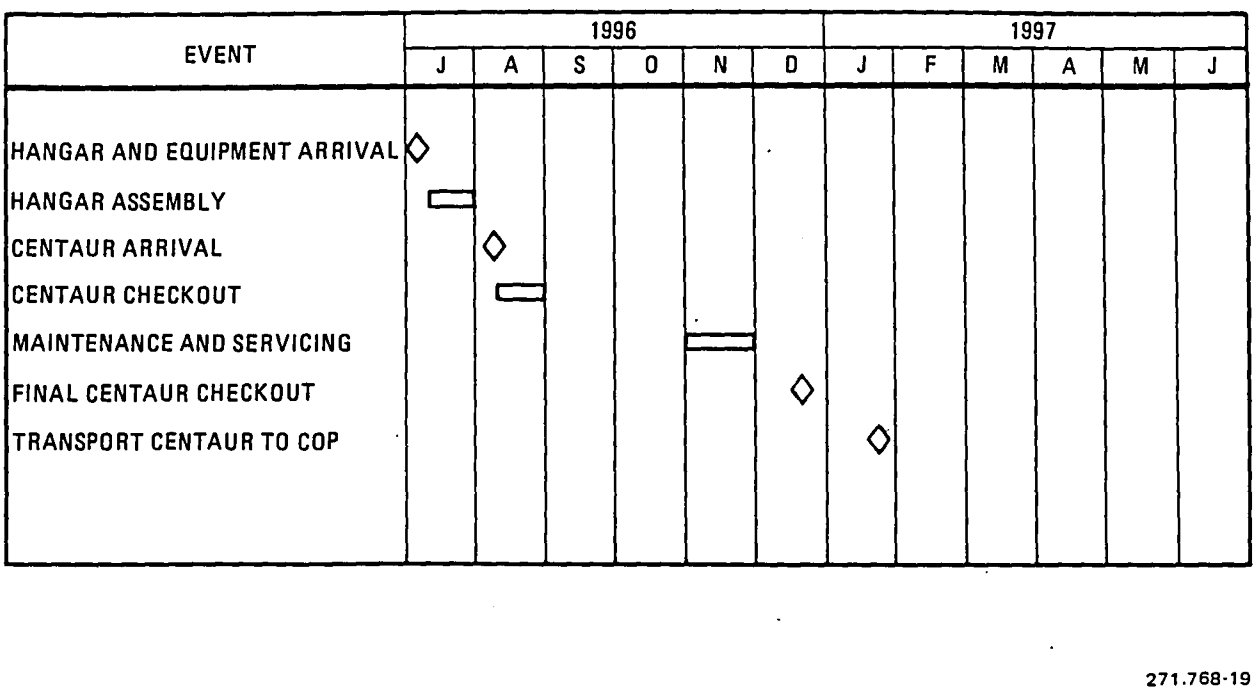


Figure 5-2. The Berthing, Checkout, and Maintenance TDM Will Span 6 Months

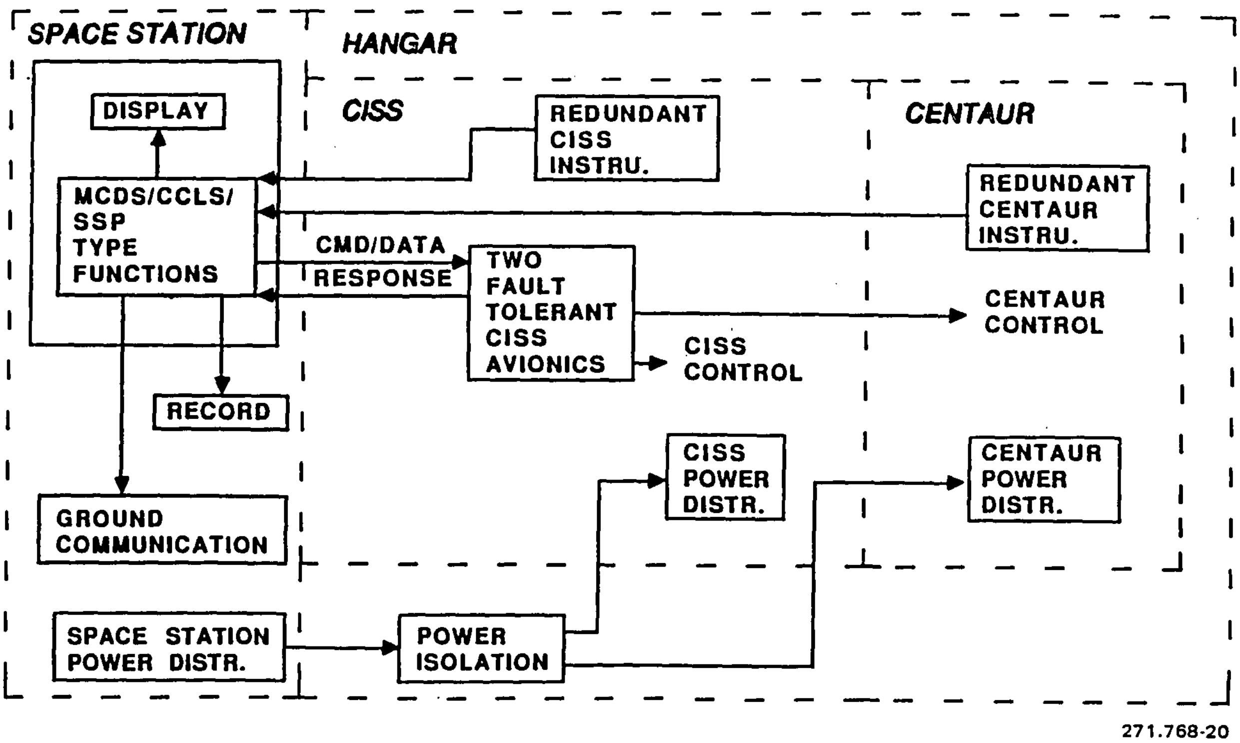


Figure 5-3. Continuous Communication Between the Space Station, Hangar, Centaur, and CISS Will Be Provided

5.1.1.5 Systems and Subsystems. To accommodate berthing Centaur at the Space Station, a hangar will be needed to protect the Centaur and to allow an area for support equipment and checkout activities. The Centaur G-prime maximum dimensions are approximately 4.25m (14 ft) dia. x 8.85m (29 ft) long. A berthing facility which could hold the Centaur with the CISS, allow attachment of payload(s) and allow circumferential access space for EVA and/or teleoperator maintenance operations should provide 1.2 to 1.8m (4 to 6 ft) access clearance around the vehicle and payload. This then dictates a hangar size of 8 by 20m (26 by 66 ft) minimum dimensions, assuming an 8m (26 ft) long nominal payload during mating and checkout. For reference, this is about the size of the spacecraft processing facility (SPF) (10 x 20m) now planned by NASA for the Space Station. The location for SPF, as shown in Figure 5-4, was selected for minimum decrement to Space Station viewing operations and to improve the Station drag force symmetry. We therefore propose a Centaur hangar identical in size, and mirrored in placement to the SPF, but equipped with Centaur-required interfaces (Figure 5-5). This duplication should reduce hangar development costs and provide additional Space Station accommodations when the Centaur mission is completed.

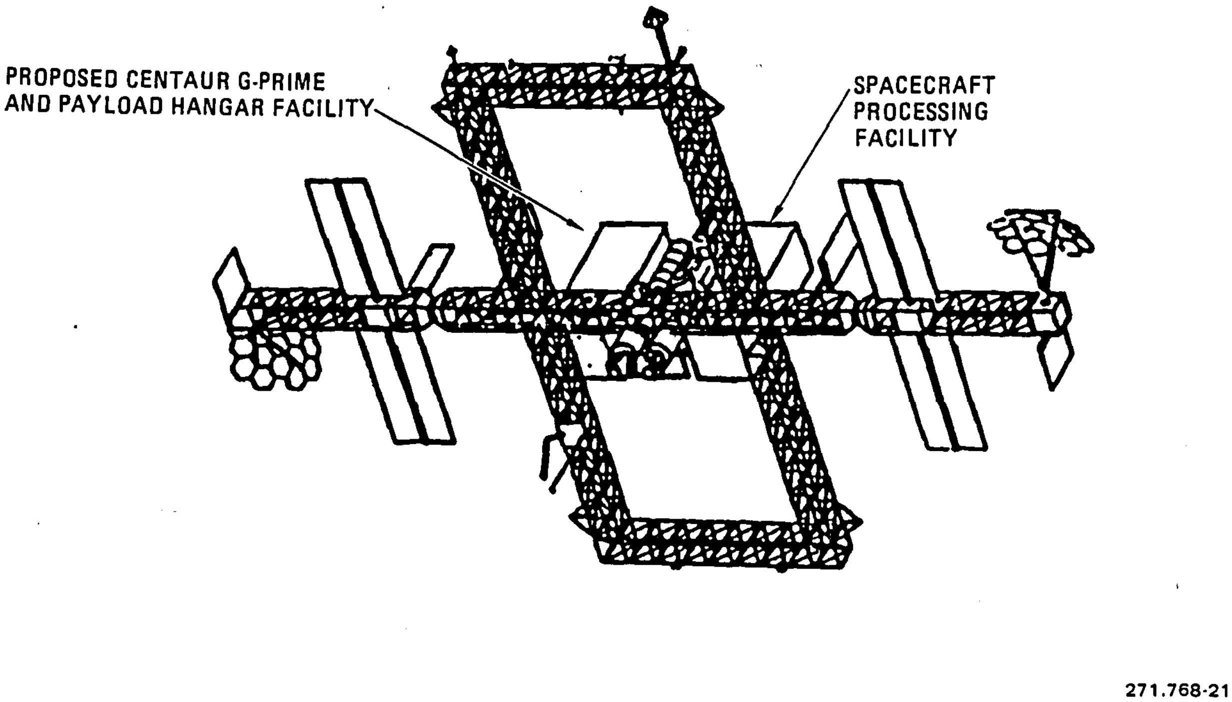


Figure 5-4. Hangar Facility Augments Future Station Capabilities

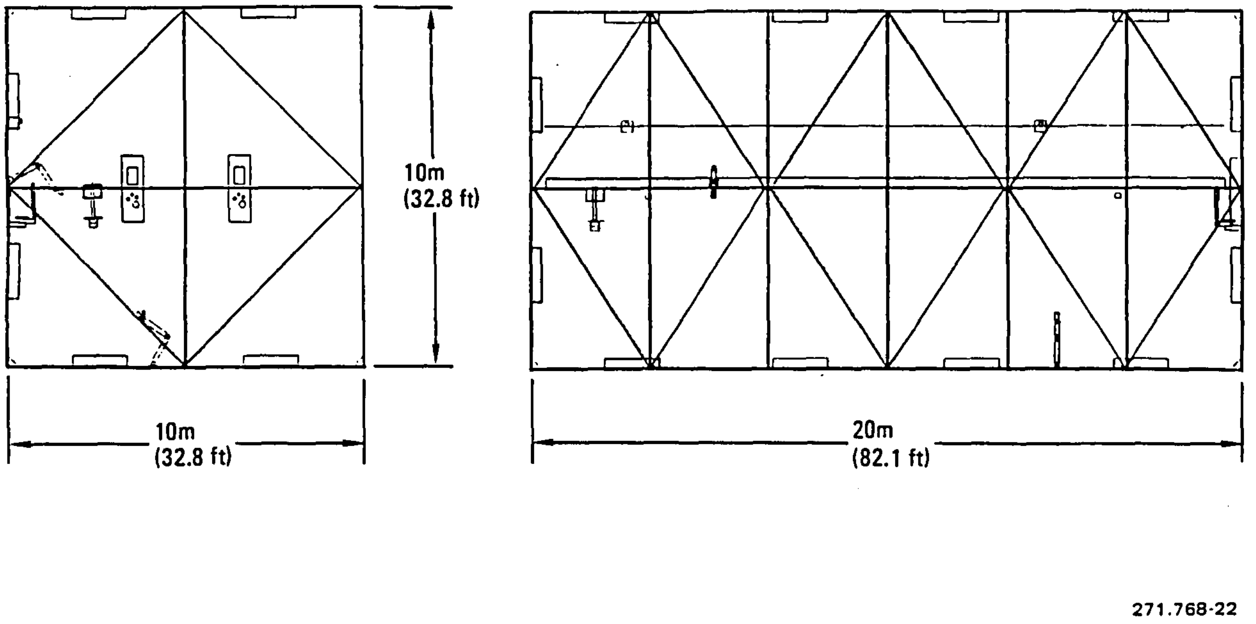


Figure 5-5. Hangar Dimensions Mirror the Spacecraft Processing Facility

The Centaur hangar will provide a work environment conducive for either EVA or inter-vehicular activity (IVA) maintenance and servicing. Selectable lighting, accessible utility outlets and umbilical connectors, and telerobotic arms will facilitate the activities required to conduct the TDM. Figure 5-6 shows many of the features of the hangar. The Centaur hangar will have minimum scarring impact on the Space Station. The Space Station truss node fitting will be the attach points for the hangar. Interface panels will be mounted on the Space Station truss structure and the rear side hangar wall. Test outlets at each panel provide a way to ensure interface panel operation by EVA. These features are illustrated in Figure 5-7.

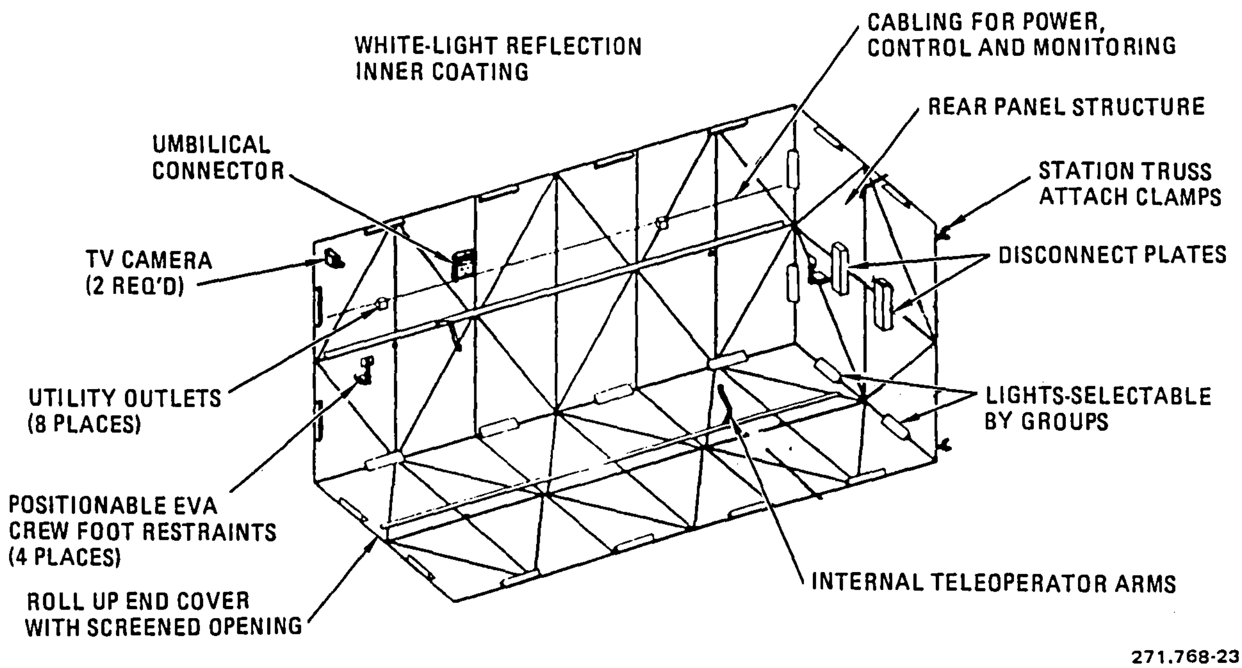


Figure 5-6. Hangar Provides Storage, Protection, and Servicing Provisions

An interface panel outside the rear hangar wall connects the hangar to Space Station electrical power, data communications, and gaseous helium (GHe). It is shown in Figure 5-8. As shown, buttons are provided to deadface and activate the panel during EVA maintenance, connection, and disconnection. Figure 5-9 shows the latching arrangement which will attach the hangar to the Space Station trusses at node locations.

The CCA is berthed at the rear of the hangar. The structural attach points are one hangar end effector and four berthing latches clasping the grapple fixture and attach points added to the rear of the CISS. Figure 5-10 shows a top view of Centaur berthed and secured to the rear hangar wall. Figure 5-11 shows a front view of the rear wall berthing facilities only. Figures 5-12 and 5-13 illustrate the details of the latch concept.

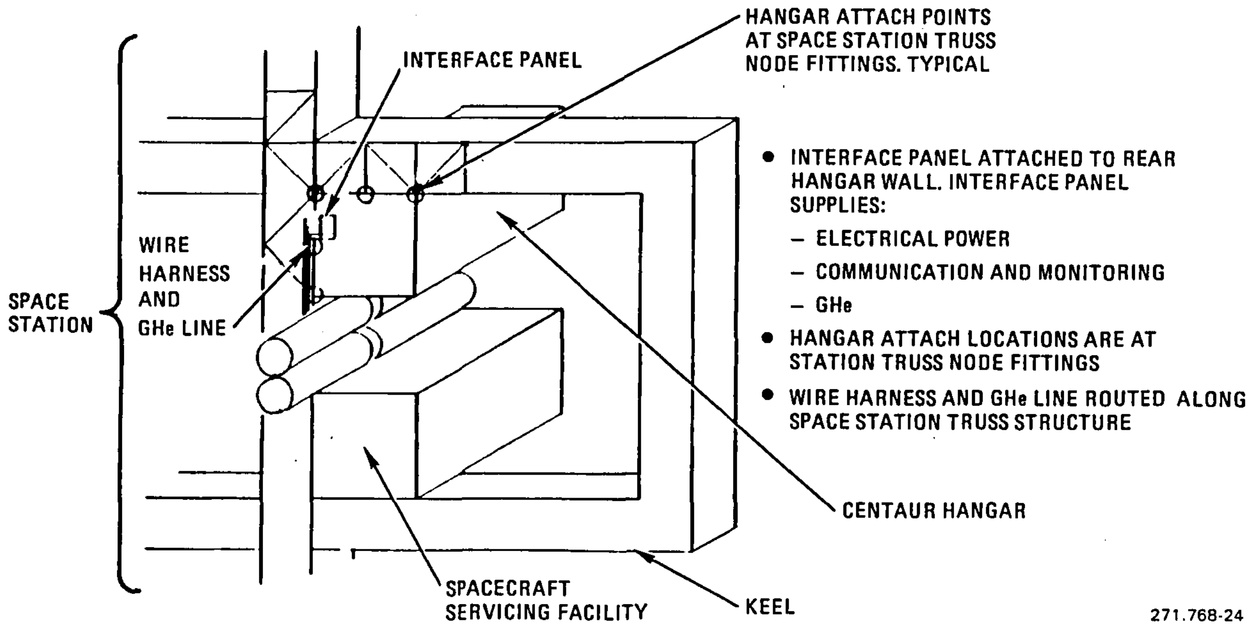


Figure 5-7. Hangar Scarring Requires Attach Points, Interface Panel, Wire Harness, and Gaseous Helium Line

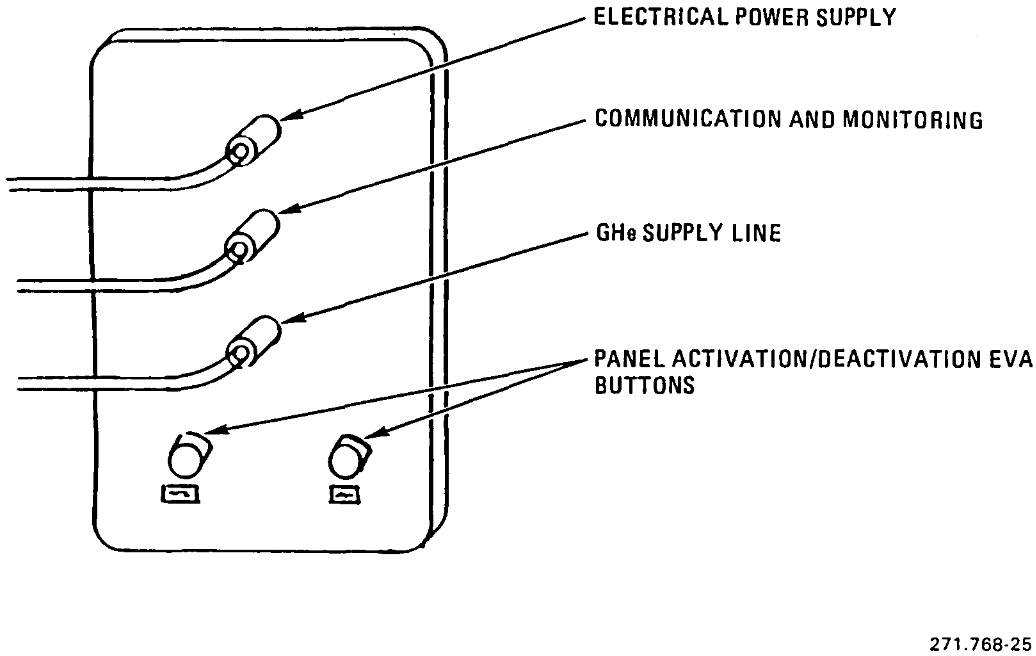


Figure 5-8. Space Station Supplies Hangar Services Through Interface Panel on Outside of Rear Hangar Wall

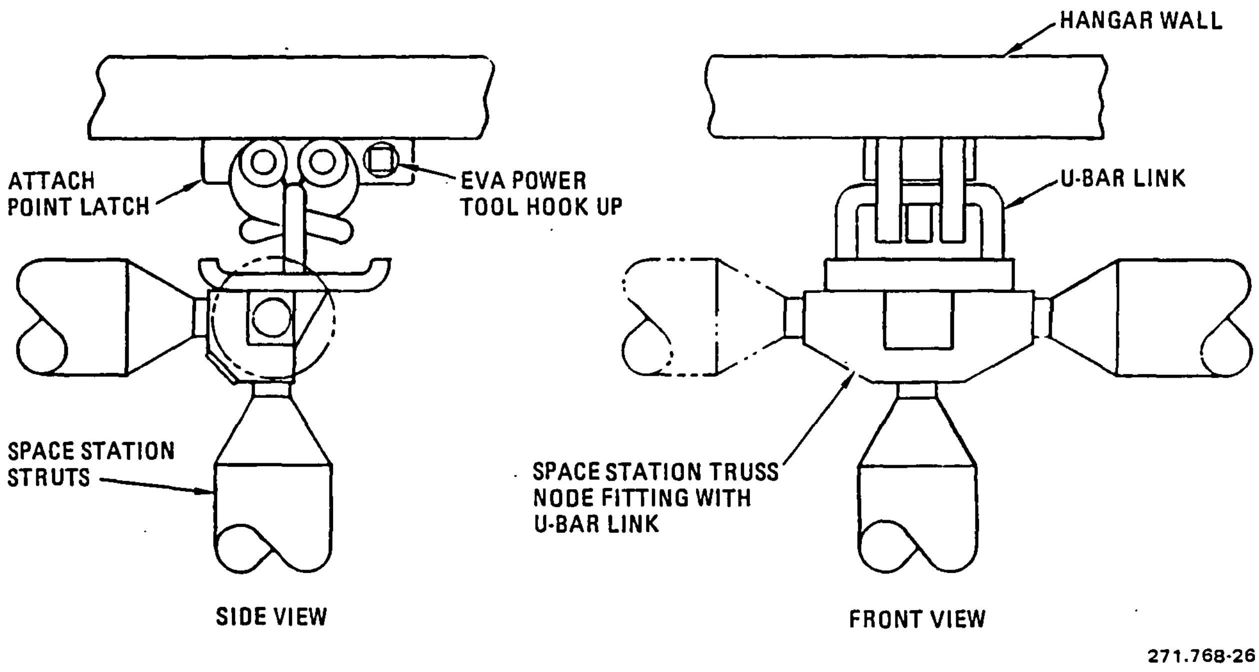


Figure 5-9. EVA Power-Tool-Activated Point Latch Secures Hangar to Space Station

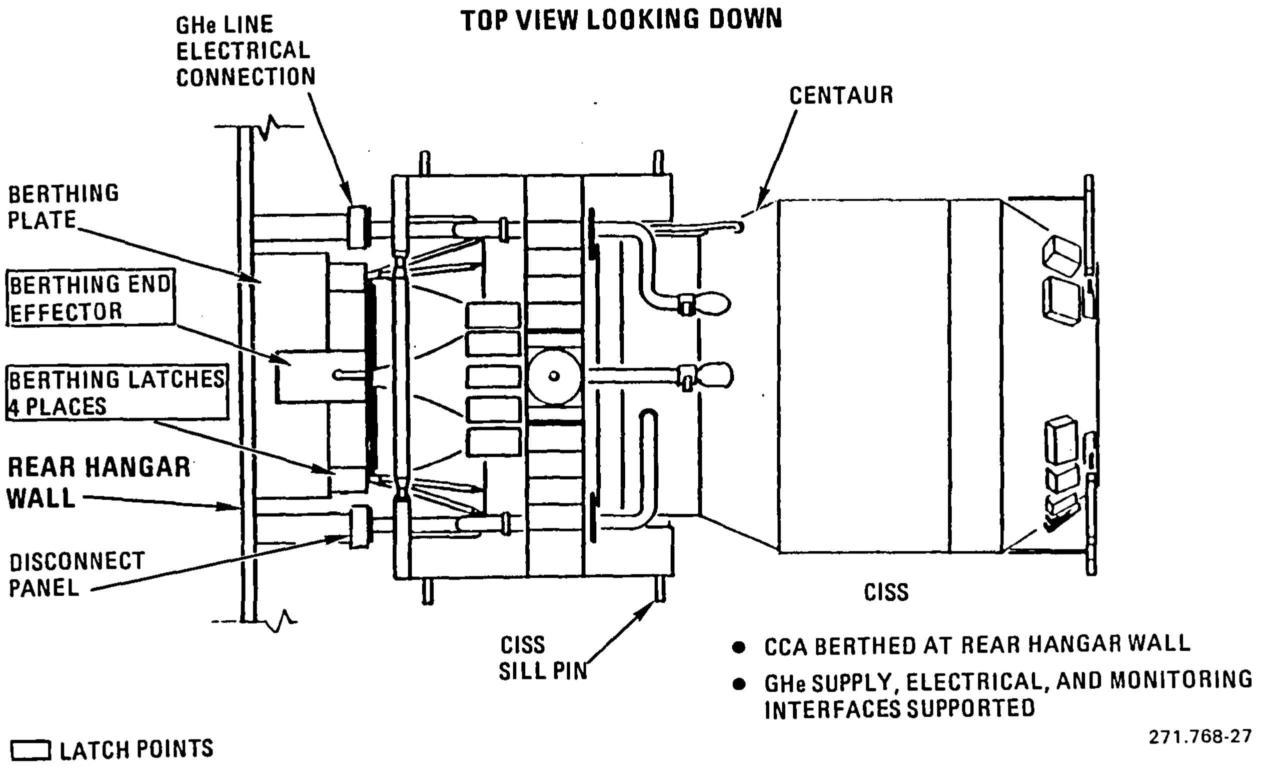


Figure 5-10. Top View Shows CCA Is Berthed by Five Latch Points on Hangar Rear Wall

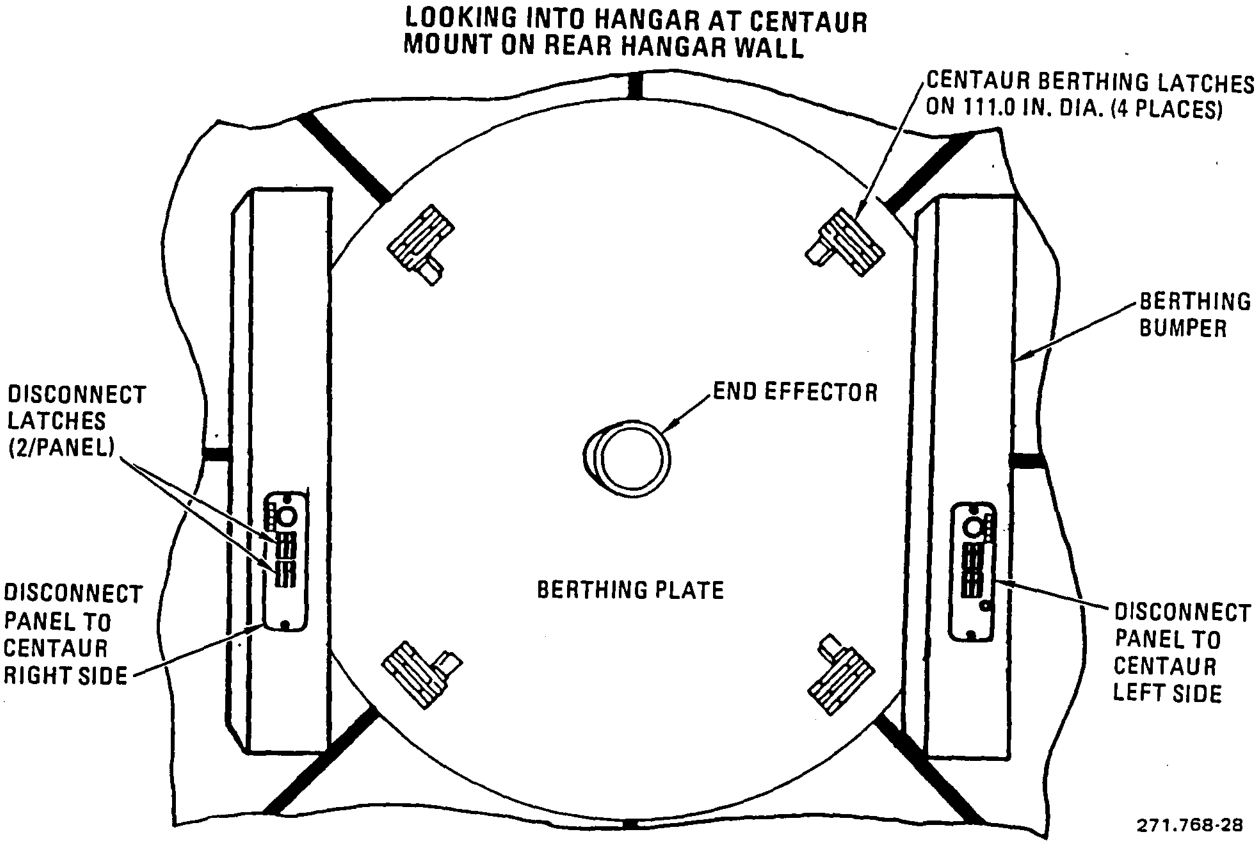


Figure 5-11. Rear Hangar Wall Details Show Berthing and Service Connections

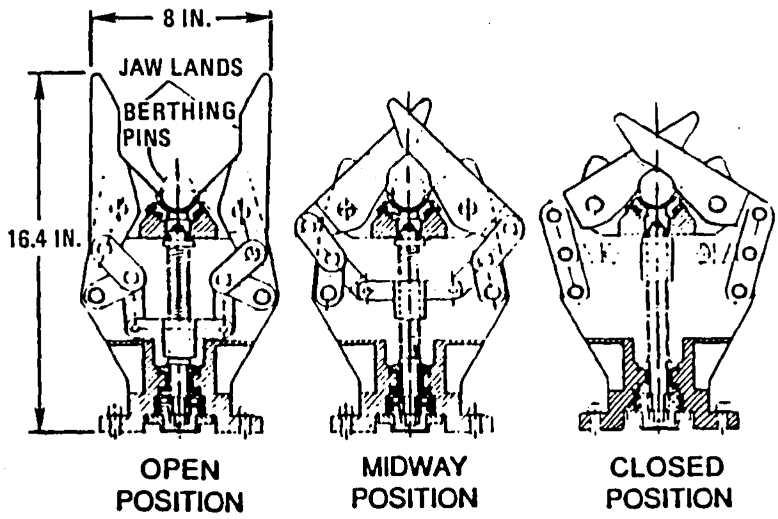
Fluid disconnect panels will support only GHe and electrical interfaces while Centaur is in the hangar. The panels will be securely mated by another set of latches, identical to the berthing latches, but much smaller.

The berthing sequence for the hangar and co-orbiting platform (COP) is:

- End effector attaches to grapple fixture
- Hangar berthing latches lock down on four attach points (AP)
- Hangar disconnect latches attach to Centaur/CISS disconnect panels
- Fluid, pneumatic, and electrical lines connected as latches pull panels together

The berthing sequence is the same for orbital maneuvering vehicle (OMV) except there are no fluid disconnect panels.

The hangar will be covered with a blanket of layered mylar as shown in Figure 5-14. The Ortho cloth outer cover is identical to that used for EVA suits. It provides additional micrometeoroid protection for Centaur and the payloads attached near the end of the TDM period. The blanket also reduces environmental temperature extremes, and facilitates contingency EVA activities.



• WEIGHT (ESTIMATE)	18.1 kg (EACH)	(40.0 LB) (EACH)
• LOADS DESIGN LIMIT LOAD (IN ALL RADIAL DIRECTIONS)	409 kg	(9,0000 LB)
DESIGN YIELD LOAD	18,000 kg	(18,000 LB)
DOCKING IMPACT LOAD LIMIT	1,4000 kg	(1,4000 LB)

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Figure 5-12. Berthing Latches Developed for Orbiter Flight Support System Used on Centaur Hangar

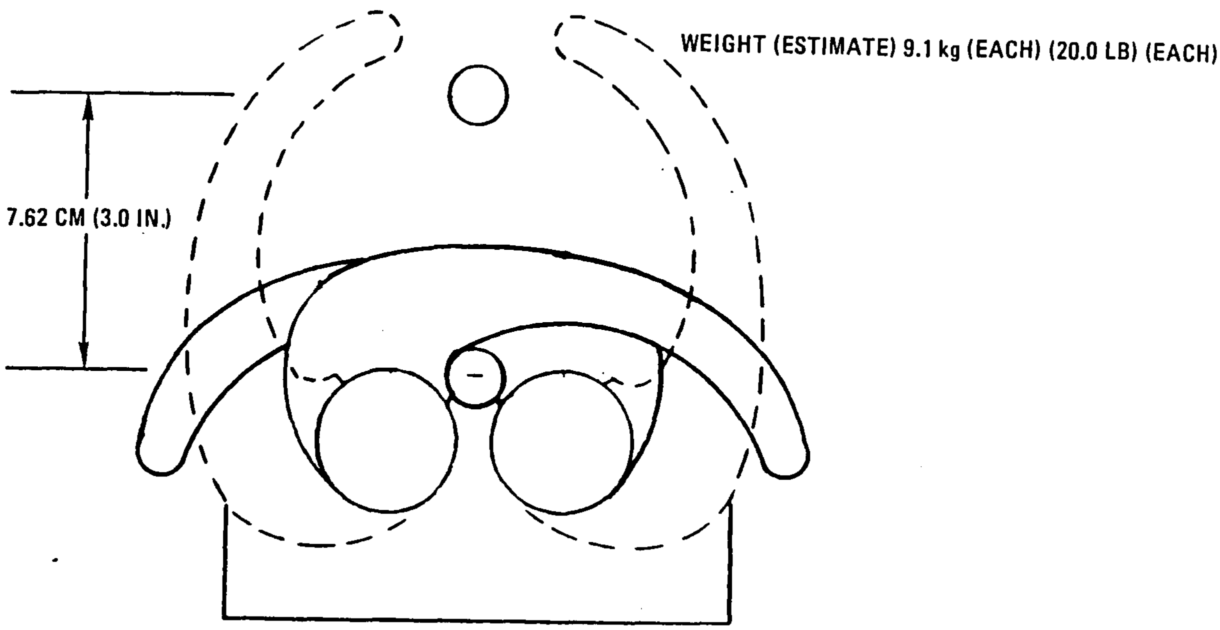

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Figure 5-13. Disconnect Latch Pulls Centaur Mating Bar to Hangar Disconnect Plates for Engagement

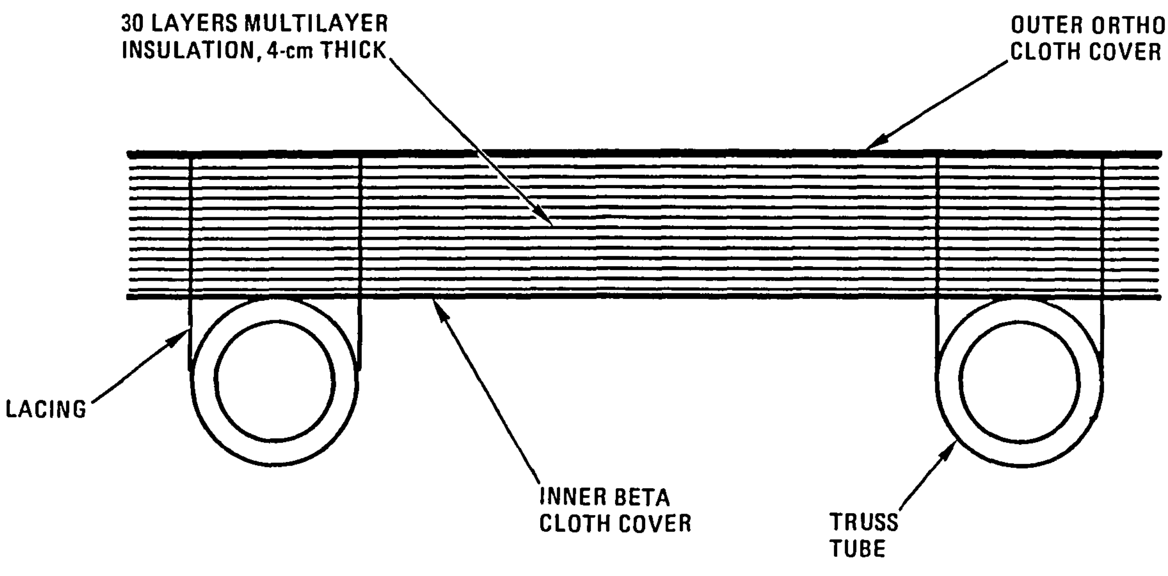

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Figure 5-14. Flexible Hangar Covering Will Fold and Compress for Compact Transportation

The hangar weight and power requirements are summarized in Tables 5-1 and 5-2. To facilitate operations within the hangar, two telerobotic arms (TRAs) will be present (see Figure 5-15). These arms allow an IVA person to perform a variety of tasks that normally would require EVA. The design is typical of those used extensively in the handling of dangerous or radioactive maintenance tasks.

Table 5-1. Hangar Will Be a Lightweight Structure for Easy Handling

Hangar Weight Summary	
Item	Weight
Truss Structure	1009 kg (2220 lb)
Truss Tubes	
Fittings	
Hangar Door	
Insulation	2191 kg (4820 lb)
MLI and Binding	
Cloth and Binding	
Operational Equipment	1205 kg (2650 lb)
Lighting Fixtures	
Foot Restraints	
TRA Arm	
Cabling	
EVA Tool Kit	
Auxiliary Power	
CISS Berthing Fixture	
TV Units	
Avionics	
Total	4405 kg (9690 lb)

Table 5-2. Standby Power Requirements for Centaur and Hangar Will Be Minimal

Hangar Power Requirements	Power (W)
Hangar	
Test Equipment	150
Telerobotic Arms (2)	1000
Lighting (All On)	600
Communications	40
Avionics Monitoring Equipment	200
Total	1990 Maximum (240 Nominal)
Centaur CISS Assembly	
Centaur	1000
CISS	
Standby Power	1200
Intermittent Heaters	200
Operational Peak	2200
Total	3400 Maximum (1200 Nominal)

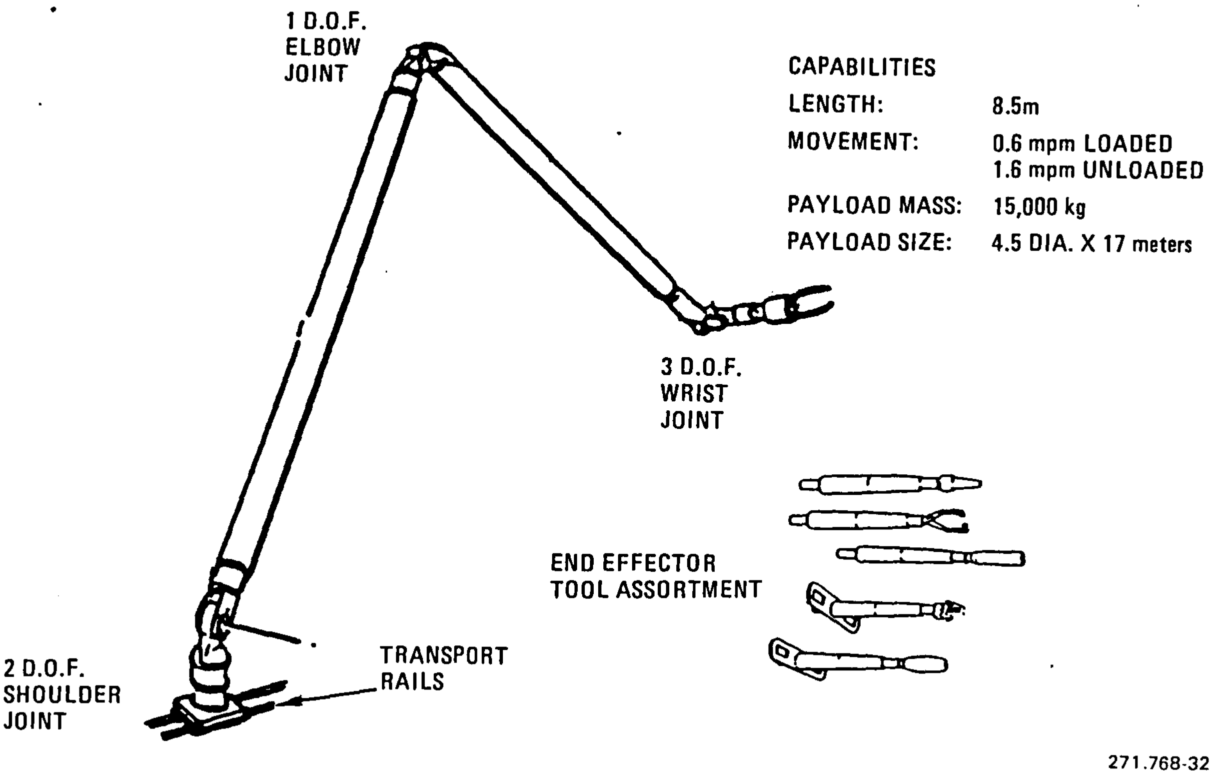


Figure 5-15. TRA End Effectors Will Accommodate Many Needs in the Hangar

5.1.1.6 Operations Plan. The Berthing, Checkout, and Maintenance TDM will occur throughout the course of the TDM program. Berthing will be one of the first functions upon arrival of the Centaur at the Space Station, and the checkout of the avionics one of the last before flight of the mission.

The sequence of major operations activities is shown in Figure 5-16. Below, all accommodations components are listed as one Shuttle flight. However, they may be sequenced and integrated with other Shuttle payloads depending on weight limitations and priorities. A desired sequence would be as follows:

- Hangar (spacecraft processing facility) structure
- Internal equipment (lighting, plumbing, cabling, etc.)
- Centaur interfaces equipment and connectors
- Teleoperator arms, tools, and TV
- Centaur with CISS
- Propellant supplies and consumables
- Contingency parts supplies and consumables

This ensures that the hangar, along with necessary equipment and Space Station interfaces, is in place before Centaur arrival.

Contingency maintenance can be accomplished when these stores are available. Teleoperator use for maintenance is preferred over EVA, however either method may be utilized as required.

Once the hangar components are delivered, assembly of the hangar will proceed as shown in Figure 5-17.

After completion of the hangar, the orbiter will deliver the dry CCA and berthing operations will begin. When the CCA is secured in the hangar, the Centaur systems will be powered up and checked out. During the course of the TDM program, periodic planned and contingency maintenance will be performed. Tables 5-3 and 5-4 show battery replacement timelines for both EVA and TRA automated scenarios. Figure 5-18 shows the helium and hydrazine bottle locations on the Centaur and the maintenance considerations for each.

5.1.1.7 Emergency Operations. There are no emergency operations which have been identified for the berthing, checkout, and maintenance activities of this TDM.

5.1.1.8 Resource and Equipment Requirements. The berthing, checkout, and maintenance TDM will require a variety of equipment as shown in Table 5-5. In addition, this TDM will require crew participation, TRAs for berthing operations, and ground communications for technical support.

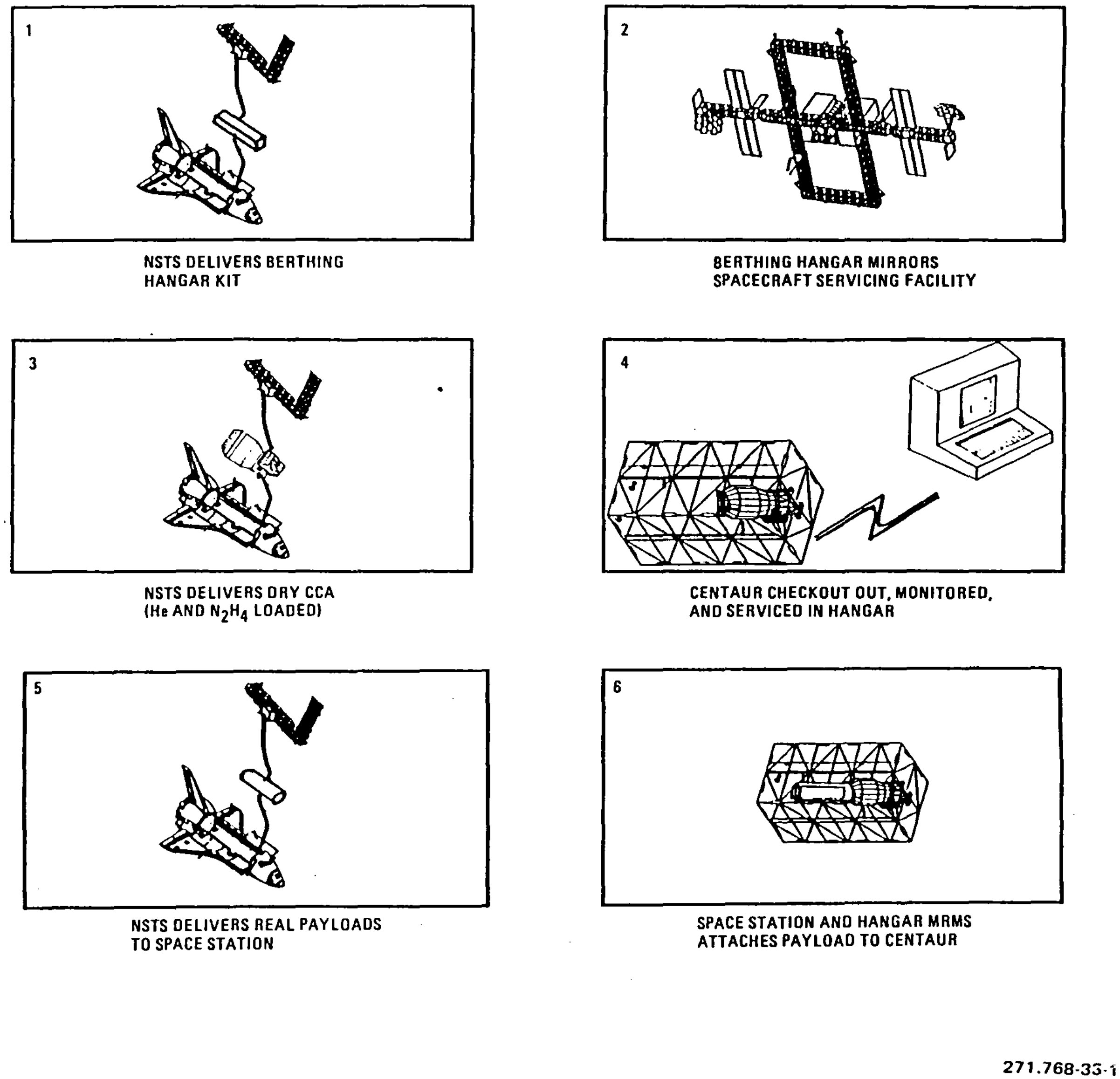


Figure 5-16. Hangar Will Be Delivered and Assembled Before Centaur Arrival

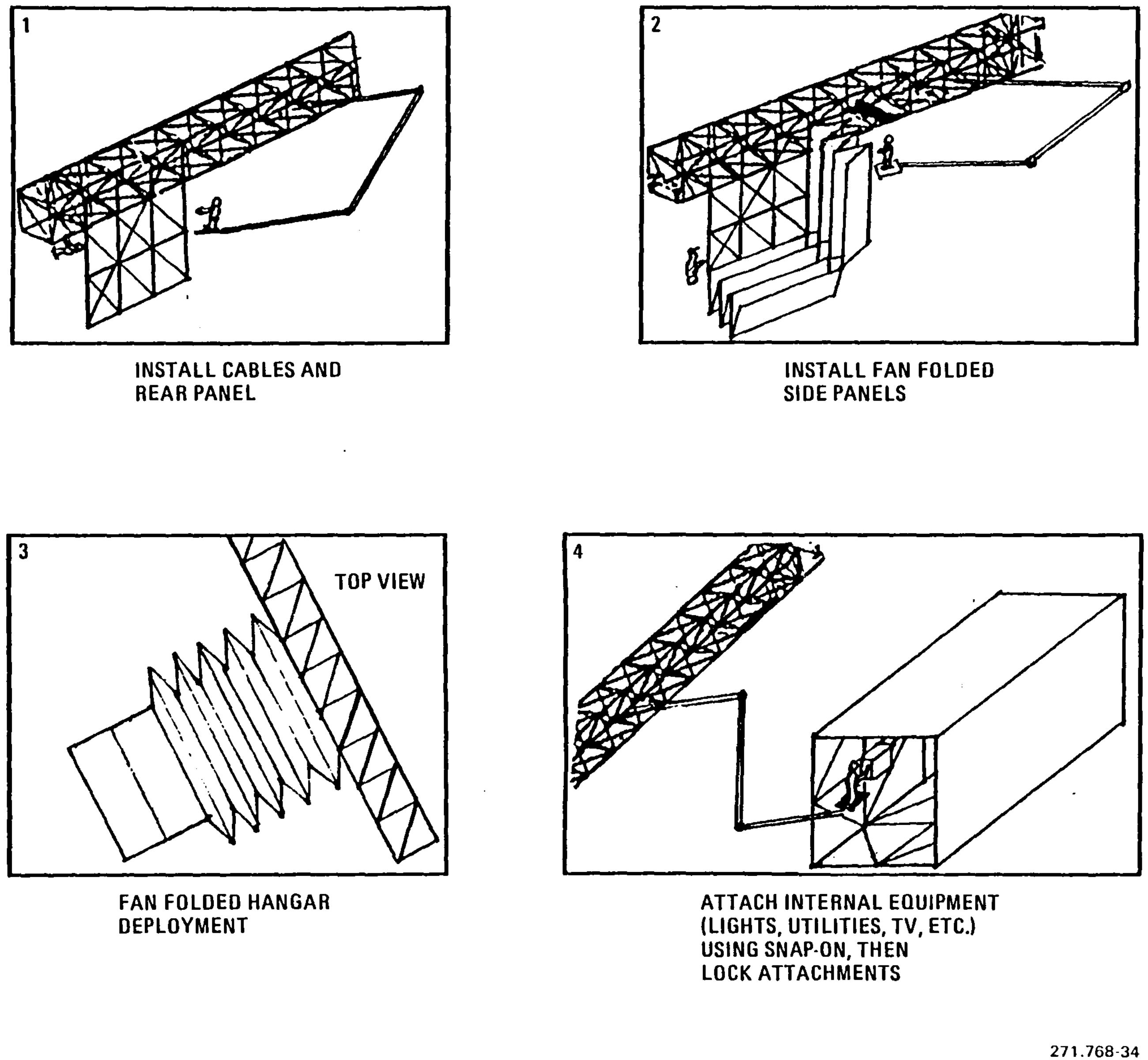


Figure 5-17. Hangar Assembly Designed as an Easy, Minimum Time EVA Task

Table 5-3. Alternate Battery Replacement Using EVA Is Labor Intensive

Maintenance Timeline Event Description	Start	Duration	Finish
Donn and check out EVA suit	0:00:00	0:30:00	0:30:00
Depressurize and exit airlock	0:30:00	0:10:00	0:40:00
Translate on MSC to storage	0:40:00	0:05:00	0:45:00
Move batteries to hangar	0:45:00	0:10:00	0:55:00
Stow batteries on wall	0:55:00	0:10:00	1:05:00
Position foot restraints for each crewman	1:05:00	0:20:00	1:25:00
Two-man relay to exchange batteries (3*)	1:25:00	0:30:00	1:55:00
Move old batteries to storage	1:55:00	0:15:00	2:10:00
Translate to airlock	2:10:00	0:05:00	2:15:00
Enter airlock and repressurize	2:15:00	0:05:00	2:20:00
Doff EVA suit and stow	2:20:00	0:10:00	2:30:00

Total man-hours = 2:30 x 3 = 7:30:00

*EVA requires three people - two EVA plus one inside Space Station for monitoring and control.

Table 5-4. Telerobotics Battery Replacement Uses One-Tenth the Total Manhours Required for the Same Task Using EVA

Maintenance Timeline Event Description	Start	Duration	Finish
Unstow from storage spare batteries (IVA)	0:00:00	0:05:00	0:05:00
Translate to hangar, attach to hangar wall	0:05:00	0:05:00	0:10:00
TRA remove old battery from Centaur and stow	0:10:00	0:05:00	0:15:00
Detach new battery, attach to Centaur	0:15:00	0:05:00	0:20:00
Replace two other batteries in same manner	0:20:00	0:20:00	0:40:00
Verify battery functioning	0:40:00	0:01:00	0:41:00
Transfer old batteries to storage	0:41:00	0:05:00	0:46:00

Advantage = 7:30:00 0:46:00 = approximately 10

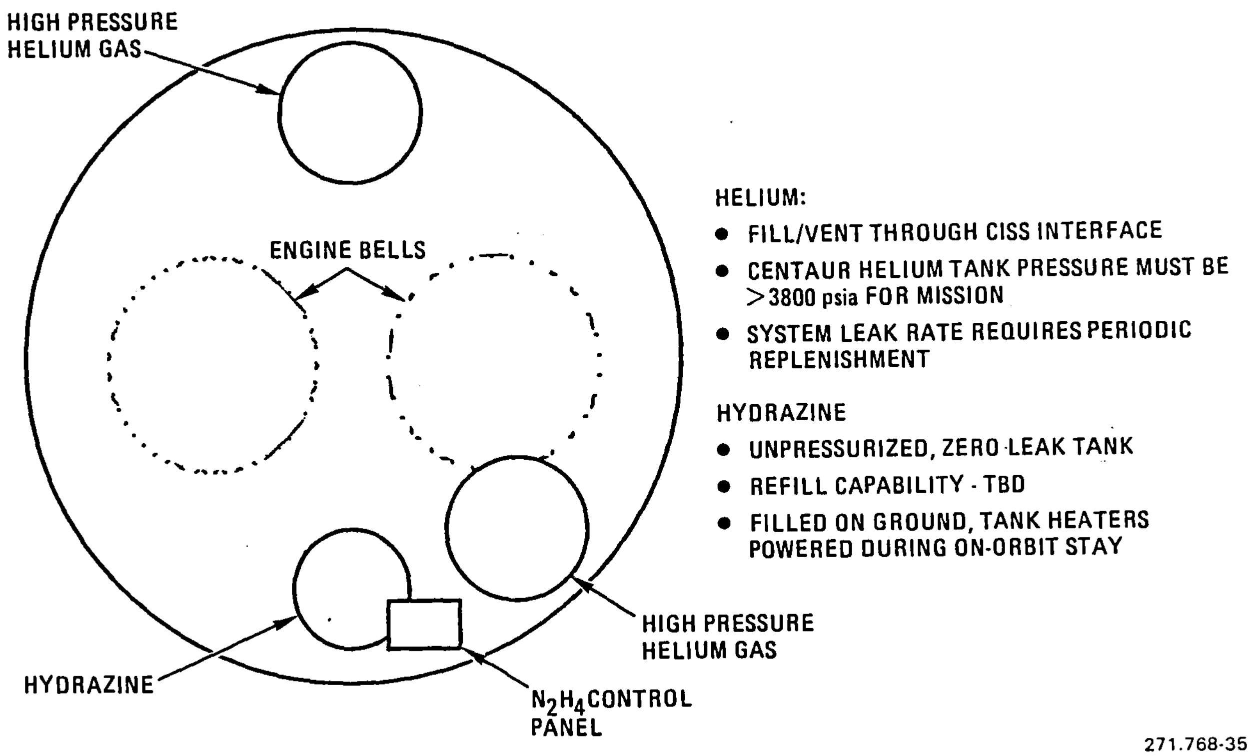


Figure 5-18. Helium Replenishment Will Occur During the Program

Table 5-5. Berthing and Checkout Will Require a Variety of Equipment

Equipment Required for TDM	Weight (lb)
Existing at Space Station	
Cabling and connectors: power, signal, and data interfaces, etc.	
Tie-in points to Space Station monitoring, control, and caution and warning systems	
Space Station external lighting systems	
EVA suits and equipment	
To Be Delivered by NSTS	
Centaur umbilical connectors and cables	60
Centaur and hangar servicing tool kit	100
Internal and portable lighting, TV units, etc.	300
Centaur replaceables: orbital replaceable units (ORUs), batteries, helium, etc.	600
Payload simulators (single large, four small)	3000

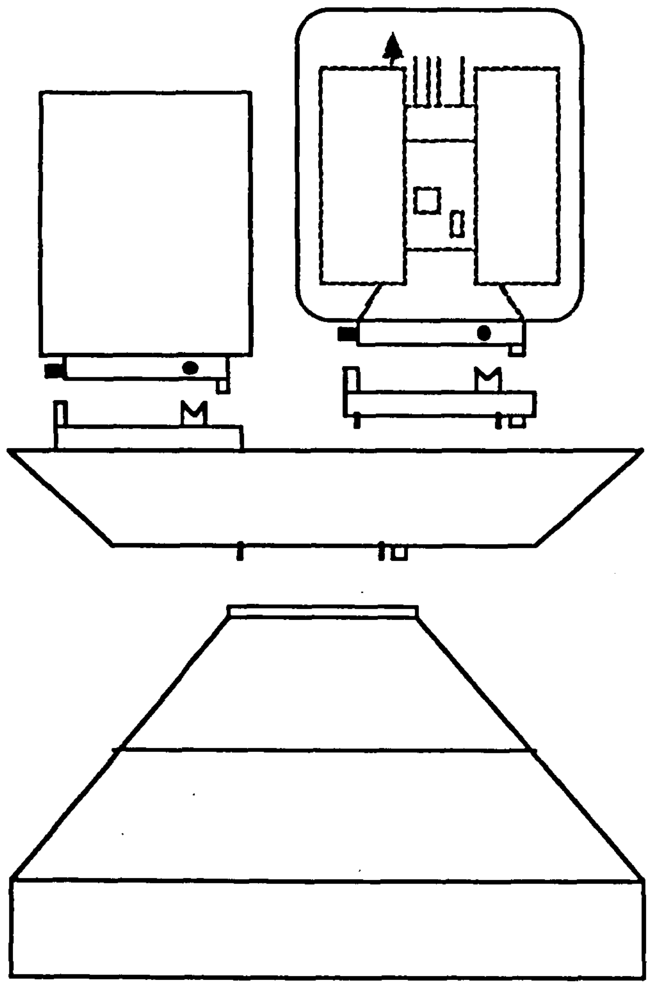
5.1.1.9 Assembly and Teardown. The major element of this TDM will be the hangar constructed for the Centaur storage. Figure 5-17 illustrates the procedure for hangar assembly, and Table 5-6 shows the timeline of events required and the durations of these activities. The hangar will remain for future Space Station use and storage after the TDM program; therefore, no teardown will be required.

Table 5-6. Hangar Assembly Timeline Is Minimal

Event Description	Start	Duration	Finish
Donn and check out EVA suit	0:00:00	0:30:00	0:30:00
Depressurize and exit airlock	0:30:00	0:10:00	0:40:00
Translate MSC to hangar assembly area	0:40:00	0:30:00	1:10:00
Unstow rear hangar panel from storage	1:10:00	0:20:00	1:30:00
Attach panel to Space Station structure	1:30:00	1:00:00	2:30:00
Add fasteners to rear panel	2:30:00	0:30:00	3:00:00
Inflate gas-filled struts to deploy panels	3:00:00	0:10:00	3:10:00
Unstow side panels and attach to rear	3:10:00	2:00:00	5:10:00
Attach side panel joints to each other	5:10:00	2:00:00	7:10:00
Inflate deploy struts	7:10:00	0:10:00	7:20:00
Unstow electrical cables and install in hangar	7:20:00	1:00:00	8:20:00
Unstow and install CCTV, lights, robotic arms	8:20:00	4:00:00	12:20:00
Attach hangar door power, close door	12:20:00	0:30:00	12:50:00
Enter airlock, repress, doff EVA suit	12:50:00	0:30:00	13:20:00
IVA installation of power outlets, foot restraints, tool kits, etc.	13:20:00	2:00:00	15:20:00

5.1.1.10 Safety and Other Issues. Safety of the Centaur at the Space Station will be not be a major concern as the Centaur will not contain propellant in the Space Station proximity. The only fluids onboard will be the helium and the hydrazine system. The hydrazine will remain unpressurized until after deployment from the COP and is a leak proof system. The helium is a leak-before-burst system, and all other Centaur electrical and mechanical equipment meets Space Station requirements for redundancy and safety.

5.1.1.11 Scarring Summary. The Space Station scarring as a result of this TDM will be minimal. The addition of CCLS hardware and cables will require modification to the OMV control room, but as many existing systems and cables as possible will be used to reduce the effects. The Centaur hangar will attach to the Space Station truss structure at the nodes for minimum structural scarring. Cabling will also be required from the Space Station to the hangar for electrical power, data, and communication as well as a line to supply helium.



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5.1.2 PAYLOAD INTEGRATION

5.1.2.1 Summary. Payload integration is the third element of Accommodations TDM. To standardize integration for a variety of potential missions, a 50-in. universal payload adapter (UPA) was developed for the OTV adapter. This will be evaluated by using the Centaur standard forward adapter with a transition section to reduce the diameter to 50 in. The UPA will then mate to the payload and will allow either direct mating to the Centaur for a dedicated mission or mating to an multiple payload adapter (MPA) for multiple payload missions.

5.1.2.2 Space-Test Rationale and Specific Objectives. This TDM element will develop the technology and operational requirements for a common adapter for payload integration to the OTV. Actual interface design, development, and fit checking will occur on the ground. The benefit of space-based operations would be actual verification of the hardware and the development of procedures to handle spacecraft at the Station. Attaching multiple dummy payloads in a confined environment in zero-gravity will allow risk-free experience while exposing unforeseen difficulties.

5.1.2.3 Architecture and Schedule. The payload integration TDM element will occur during the middle of the TDM program. This will allow development of a series of procedures and ground rules which will standardize and expedite payload mating. Payload integration will utilize the Space Station Mobile Servicing Center (MSC), Spacecraft Processing Facility (SPF) hangar, Centaur hangar and the OMV control room as shown in Figure 5-19. The payload will be mated to the UPA in the SPF hangar and then translated by remote control using the MSC to the Centaur hangar. Handling characteristics and maneuverability will be evaluated as well as actual mating verification of the payload to the Centaur. Figure 5-20 shows the schedule for the activities of payload integration.

5.1.2.4 Communications and Control Overview. Communication and control during the Payload Integration TDM element will involve mainly Space Station internal communication with Ground observation and assistance possible, but not necessary. To take advantage of the training benefit from the payload integration TDM element, it would be desirable during most of the activities to have full Ground participation in a simulation using the real data generated. Payload movement will be carried out by the MSC and controlled remotely by the crew within the Space Station. Once the payload is translated to the Centaur hangar, TRAs within the hangar will be used for internal translation and attachment to the interfaces.

During the integration of the actual mission payload(s) prior to the flight, active communication must be available between the Space Station, Centaur payload operations control center (POCC), spacecraft POCC, and mission control center Houston (MCCH). Spacecraft status and health will monitored throughout the integration activity by the spacecraft POCC which will provide GO/NO-GO calls should any anomaly occur. The Centaur POCC will be responsible for Centaur health and status and will give a GO prior to actual payload mating. Once spacecraft/Centaur mating is complete, a series of electrical and system checks will be carried out to verify a successful mate, and a joint Centaur/spacecraft mission GO will be given prior of the CCA and spacecraft movement to the COP.

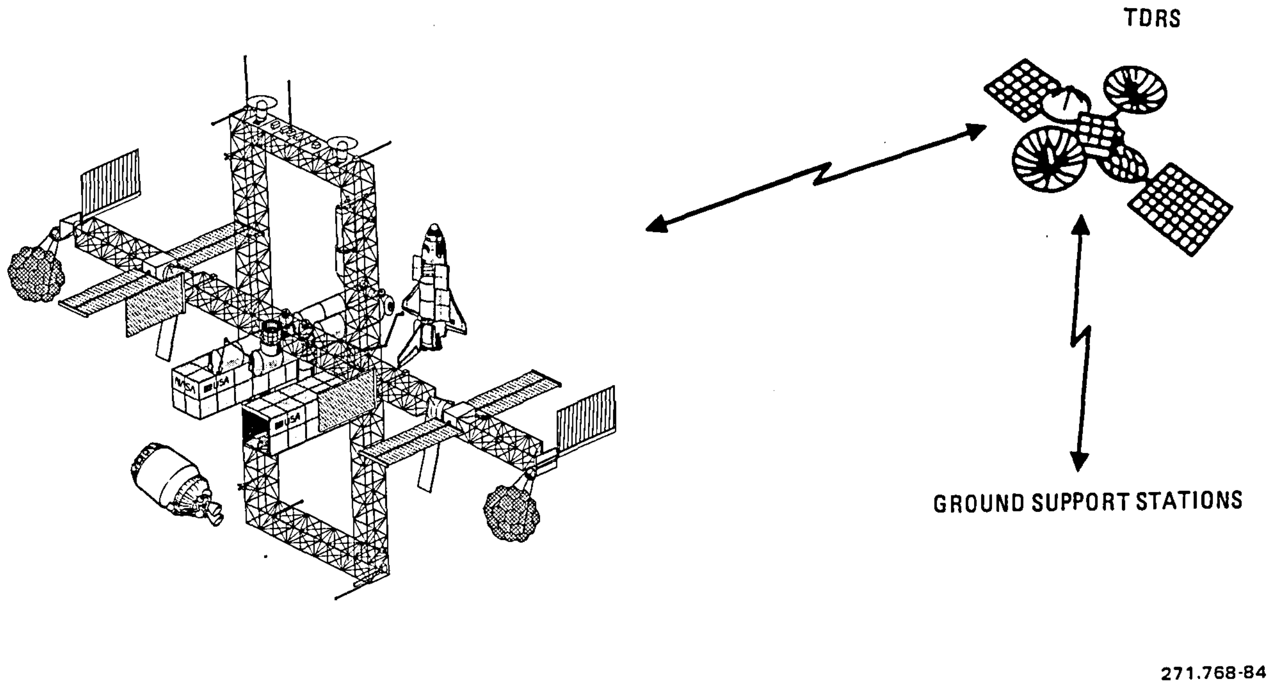


Figure 5-19. Payload Integration Will Utilize the MSF, SPF, Centaur Hangar, and OMV Control Room

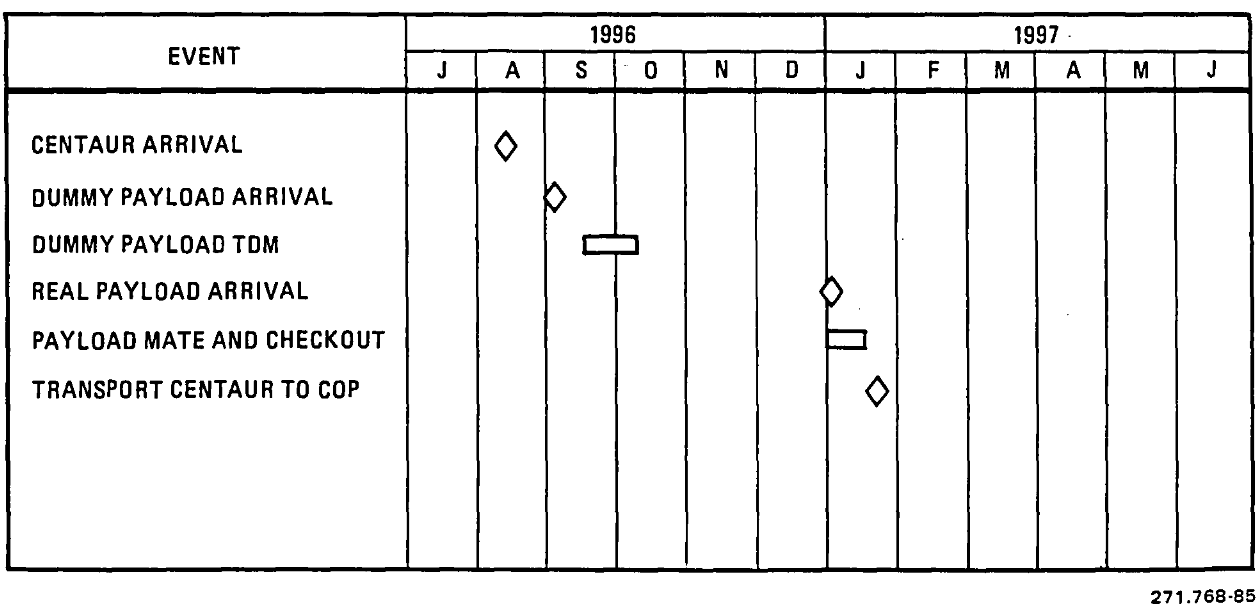


Figure 5-20. Payload Integration Will Culminate in a Real Spacecraft Integration

5.1.2.5 Systems and Subsystems. The Centaur will use an OTV-prototype UPA to allow evaluation of payload integration activities. The MPA will allow several payloads to be carried simultaneously with each payload using a UPAs as the interfaces to each payload. This commonality and modularization will allow quick changeout and replacement of payloads for optimum flexibility. Figure 5-21 illustrates the payload adapter concepts for the universal and multiple adapters and the physical characteristics of each. Also refer to Section 4.3.5.2.

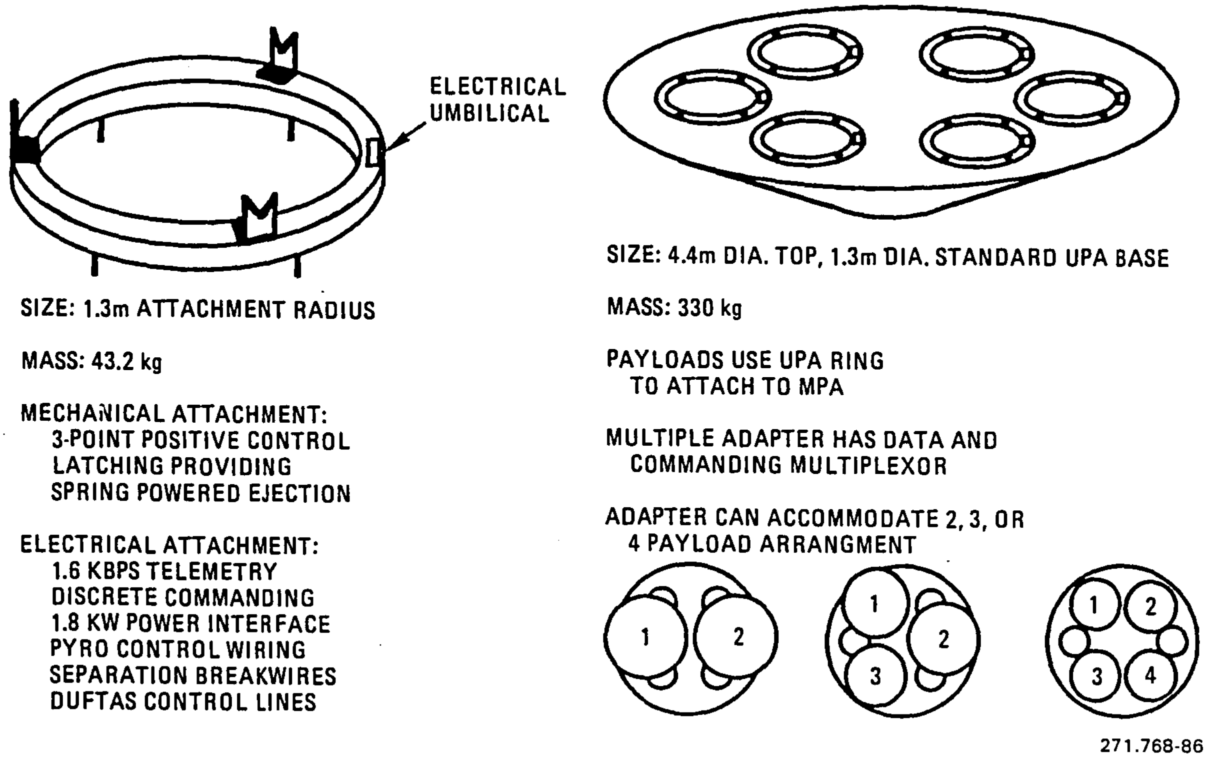


Figure 5-21. The UPA Can Be Used Alone or as One of Several on the MPA

A dummy payload Figure 5-22 will be carried up with a physical envelope of the TDRS-size class. This will allow operational verification of handling techniques for single large payload integration. The UPA will be attached to the dummy payload and then mated to the Centaur. A checkout of the interface will then be carried out through the dummy payload's avionics signal emulator which will emulate telemetry, commanding responses, power usage, and control line status.

Dummy payloads of the global positioning system (GPS)-size class (Figure 5-23) will be carried up to gain experience in the integration of multiple payloads and the associated geometry constraints and considerations. At least one of the dummy payloads will have avionics to allow interface verification and spacecraft signal emulation. The MPA will have multiplexed commanding and data busses to allow each payload redundant isolation.

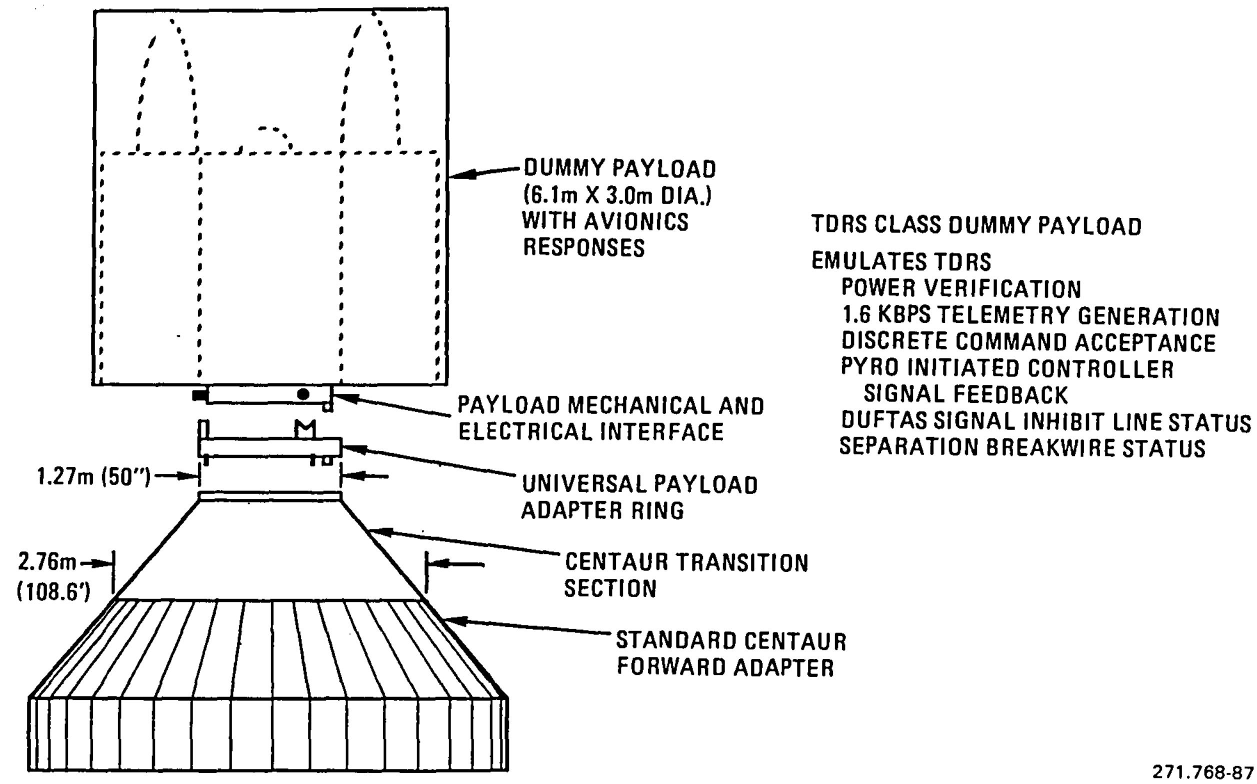


Figure 5-22. A Dummy Payload Will Check Out the Single Payload Configuration

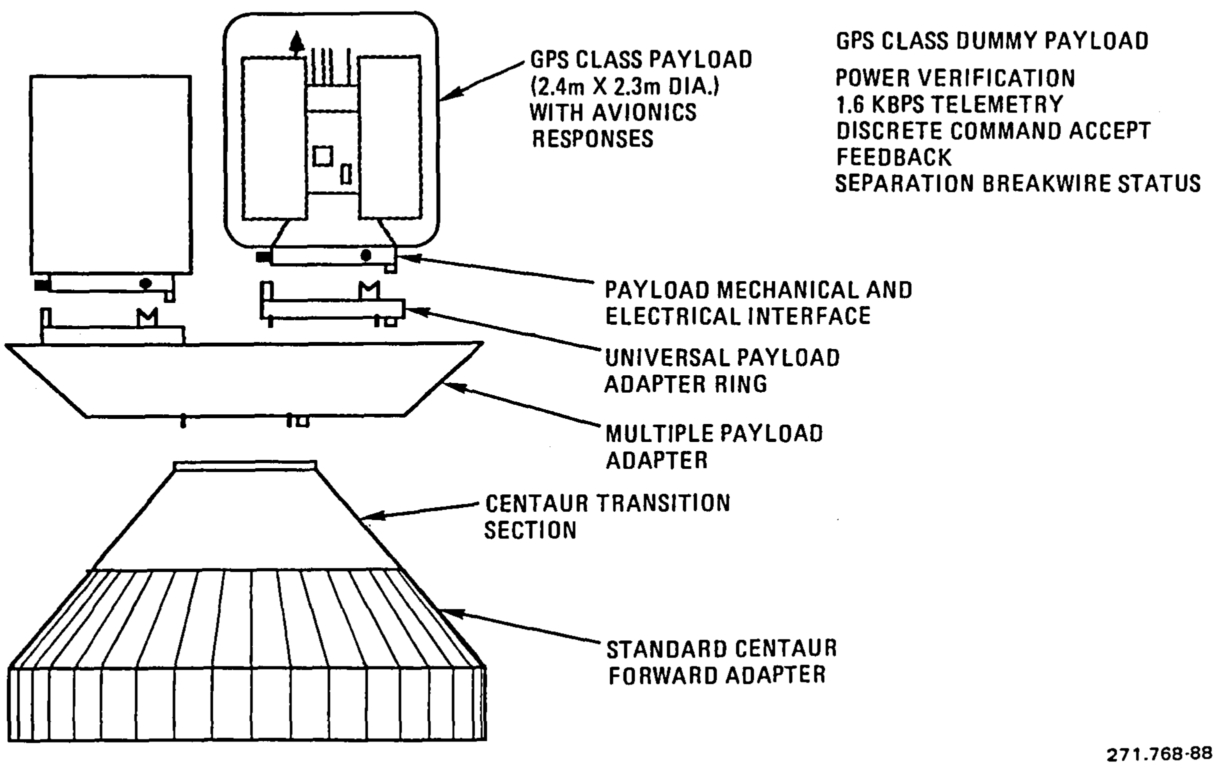


Figure 5-23. Multiple Dummy Payloads Will Check Out the Multiple Payload Configuration

Table 5-7 is a detailed timeline of the integration activities and durations of the single and multiple payload matings.

Table 5-7. Payload Integration TDM Timeline Shows 3 Hours Are Required for Multiple Payload Mating

Event Description	Start	Duration	Finish
Grapple payload using payload servicing Facility TRA	0:00:00	0:10:00	0:10:00
Mate payload to the UPA	0:10:00	0:20:00	0:30:00
Move payload and UPA to Centaur hangar	0:30:00	0:25:00	0:55:00
Mate payload and UPA to Centaur forward adapter	0:55:00	0:15:00	1:10:00
Secure latches at UPA Centaur interface, verify	1:10:00	0:05:00	1:15:00
Verify power, telemetry, and commanding interface	1:15:00	0:30:00	1:45:00
Retract TRA from payload	1:45:00	0:05:00	1:50:00
Grapple payload with TRA	1:45:00	0:05:00	1:55:00
Deadface electrical interface	1:55:00	0:01:00	1:56:00
Disconnect mechanical latches, verify	1:56:00	0:05:00	2:01:00
Move payload and UPA back to payload servicing facility	2:01:00	0:20:00	2:21:00
Attach MPA to Centaur	2:21:00	0:20:00	2:41:00
Move payload and UPA combination to Centaur hangar	2:41:00	0:25:00	3:06:00
Repeat mating and checkout procedures for each payload			

The baseline sequence for demonstration and evaluation will consist of translating the MSC to the SPF hangar and picking up the TDRS-class dummy payload. The payload will be attached to a UPA in the SPF and then moved to the Centaur hangar. Within the Centaur hangar, the MSC will hand off the spacecraft to the TRAs for attachment to the Centaur transition section. A series of maneuvers with the payload using the TRAs will be carried out to gather data and experience on the handling of a large payload in a closed environment. The actual mating of the payload to the Centaur will be monitored by both closed-circuit TV as well as telemetry through the TRA connectors and Centaur data bus. After mating, a series of avionics, mechanical, and electrical interface checks will be carried out to verify the systems. After system verification, the payload and UPA will be detached from the Centaur and returned to the SPF hangar for storage.

The second phase of the payload integration will be the testing of a GPS-class dummy payload in a multiple payload configuration. The MPA will be stored in the SPF hangar along with the dummy payloads. The MSC will be used to move the payload to the UPA for mating and then to the MPA for mating. After mating three dummy payloads to the MPA, the entire arrangement will be translated to the Centaur hangar using the MSC. The TRAs will grapple the MPA with the dummy payloads and carry out a series of maneuvers similar to those for the TDRS-class payload to gather additional information on payload handling techniques. The arms will then mate the MPA to the Centaur and proceed with the interface checks. The checkout will be more comprehensive as all three payload-to-MPA interfaces as well as MPA-to-Centaur interfaces will be verified. The MPA and payloads will be removed from the Centaur, returned to the SPF hangar, demated, and stowed after the checkout is complete.

The summation of this TDM program will be the attachment of the final real mission payload to the Centaur using the procedures and techniques developed during the dummy payload integration tests. The final payload integration will occur 1 day before the Centaur, CISS, and payload are moved to the COP for final fueling. This sequence is shown in Table 5-8.

Table 5-8. Payload Integration Timeline Shows 45 Minutes Are Required to Single Payload Mating

Event Description	Start	Duration	Finish
Transfer payload from STS to hangar	0:00:00	0:20:00	0:20:00
Pass payload from MSC to TRA in hangar	0:20:00	0:10:00	0:30:00
Move payload to Centaur adapter, latch	0:30:00	0:10:00	0:40:00
Verify latching via TV and retract arm	0:40:00	0:05:00	0:45:00
Repeat for each payload (45-min duration each)			
Verify payload interfaces and health		Payload peculiar	
Launch decision based on payload checkout		Payload peculiar	
Move Centaur and payload(s) out of hangar if go		0:20:00	
Attach OMV and start to translate to COP		0:15:00	

To prepare for this activity, a series of simulations with special training will be required. These simulations will address the procedures peculiar to the mating of the payloads to their adapters, movement around the Space Station and exercising the command centers required. This training will take place over a period of time starting in early 1996 and will thoroughly test out the timelines before the hardware is at the Space Station. The major justification for the training schedule is to ensure that the mating of the actual mission payload to the Centaur can be carried out in a smooth, expeditious manner.

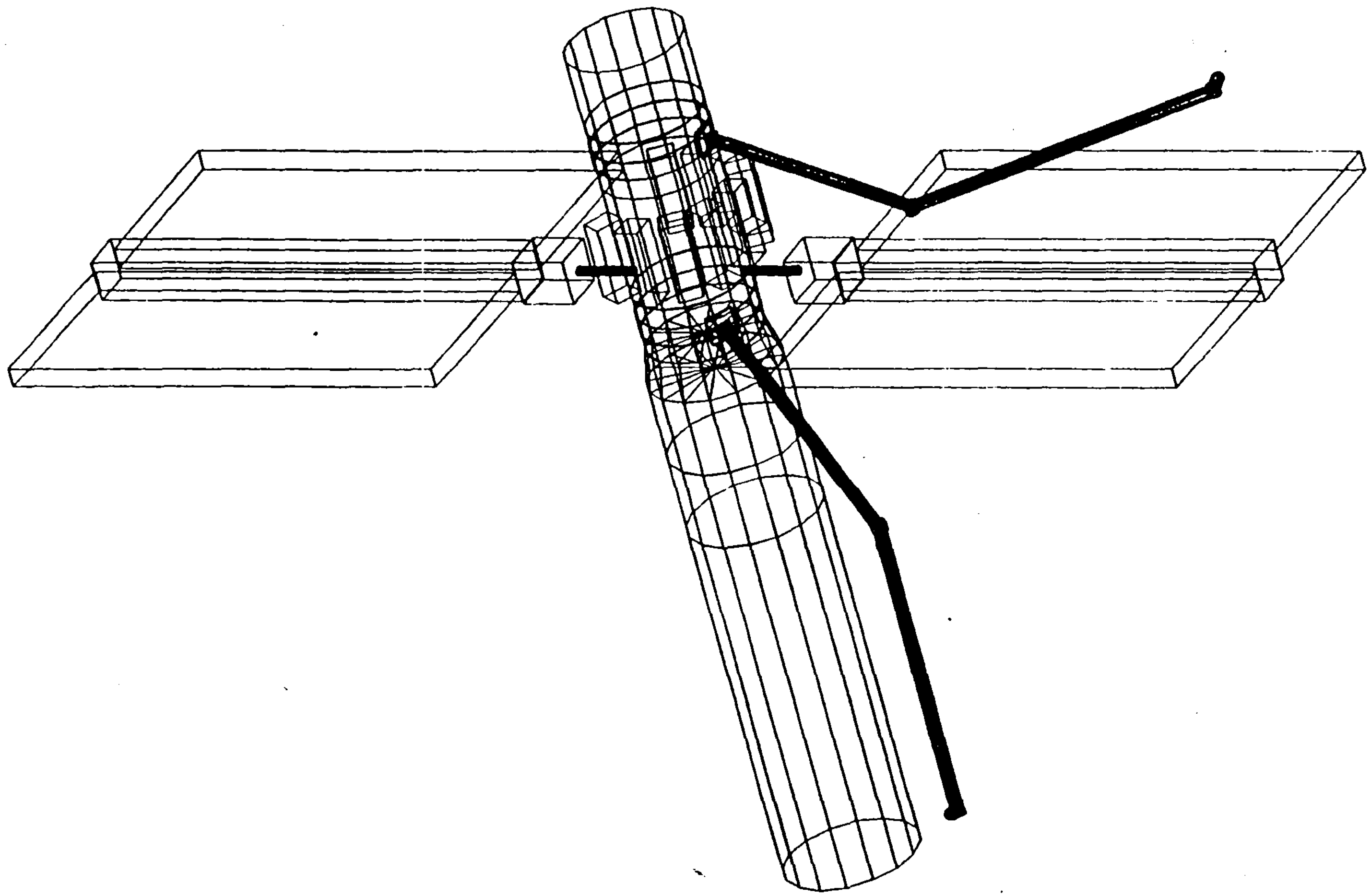
5.1.2.6 Emergency Operations. There are no emergency operations associated with payload integration which have been identified at this time.

5.1.2.7 Resource and Equipment Requirements. A variety of Space Station resources will be utilized during payload integration. The spacecraft dummy models will be stored in the SPF until needed for the operation. When needed, the crew will maneuver the MSC into a position to remove the spacecraft from the hangar and move them to the Centaur hangar. There they will be handed off to the TRAs in the hangar for final attachment to the adapters. The equipment and resources required include the MSC, OMV Control Room, SPF hangar, Centaur hangar, crew, and potential EVA and TDRS communication links.

5.1.2.8 Assembly and Teardown. There is no assembly or teardown of elements other than the actual mating of the spacecraft and adapters, which is covered in other sections.

5.1.2.9 Safety and Other Issues. The Centaur and spacecraft will have multiple redundancy inhibits to preclude reaction control system activity in the vicinity of the Space Station. All pyro initiators will be verified safe and the interface deadfaced prior to mating of the payload to the Centaur.

5.1.2.10 Scarring Summary. No Space Station scarring is foreseen as a result of payload integration but station manpower schedule will be impacted.



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5.2 OPERATIONS TDM

5.2.1 CRYOGENIC PROPELLANT TRANSFER

5.2.1.1 Summary. Cryogenic Propellant Transfer and Payload Deployment are the two elements of the Operations. This section covers the former. Specifically, this TDM is proposed to demonstrate cryogenic propellant storage and transfer in space using a full-scale upper stage vehicle and a prototypical propellant storage depot. An unmanned co-orbiting platform (COP) will be developed to serve as the refueling depot, and the propellant transfer experiments will be performed at that platform remotely from the main Space Station. Both tanking and detanking of the vehicle in the zero-gravity environment of space will be demonstrated.

5.2.1.2 Space-Test Rationale and Specific Objectives. The purpose of this element is to demonstrate propellant resupply systems and operations typical of a space-based OTV. The primary operations to be demonstrated include tank chilldown, no-vent fill, and draining of the vehicle tank back into the propellant depot. The zero-gravity environment of space and the requirement to minimize the loss of liquid propellants due to venting require the incorporation of specially tailored propellant management systems and operations. While such systems and procedures are presently used for storable propellants in space, cryogenic propellants present an additional set of requirements which must be met. The CFMFE is designed to answer many of the basic questions concerning cryogenic propellant management in space, but that experiment alone will not be sufficient to demonstrate tanking and detanking on the scale required for the OTV application.

5.2.1.3 Architecture and Schedule. It appears possible that the OTV will ultimately be based away from the main Space Station. For this study, it has been assumed that propellant transfer will be moved off the Space Station and onto a COP. The principal TDM elements and how they interrelate are shown in Figure 5-24. The Centaur G-prime upper stage vehicle will be used for this TDM to simulate the systems and operations which will be used for fueling and draining the OTV. The COP design selected is an extension of the U.S. Reference Configuration as shown in Section 3 of JSC 30000 with the addition of a propellant depot, two mobile remote manipulating system (MRMSs), and associated adapters. COP functions are automated. It is unmanned, but man-tended by the Shuttle in off-nominal situations. The COP elements will be designed to be adaptable to the final OTV servicing facility, whether at the main Space Station or at a co-orbiting station. Since all of the TDM operations are performed remotely from the Space Station, there is no direct safety impact on it.

The schedule for the propellant transfer element in relation to the total program is shown in Figure 5-25. Due to the relative level of risk to the Centaur vehicle associated with this experiment, it is scheduled to occur near the end of the program.

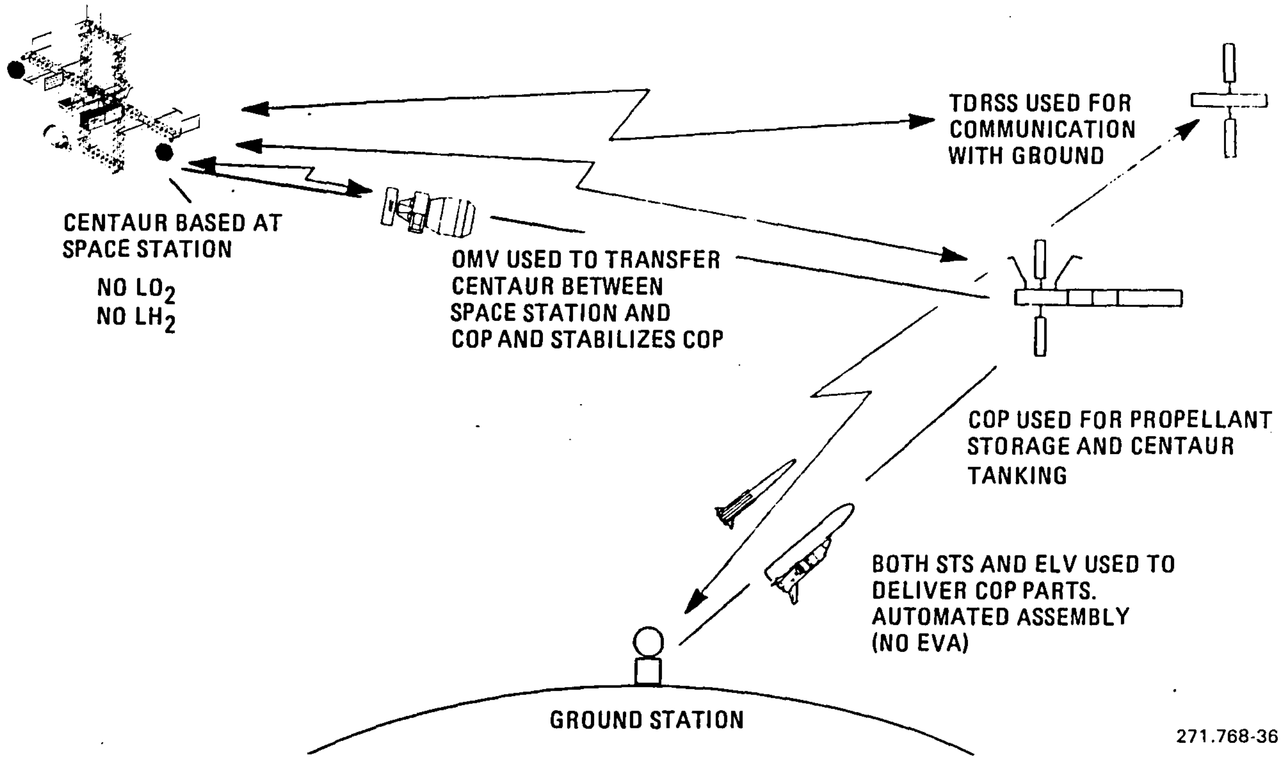


Figure 5-24. A Variety of Space Assets Are Used for Propellant Transfer

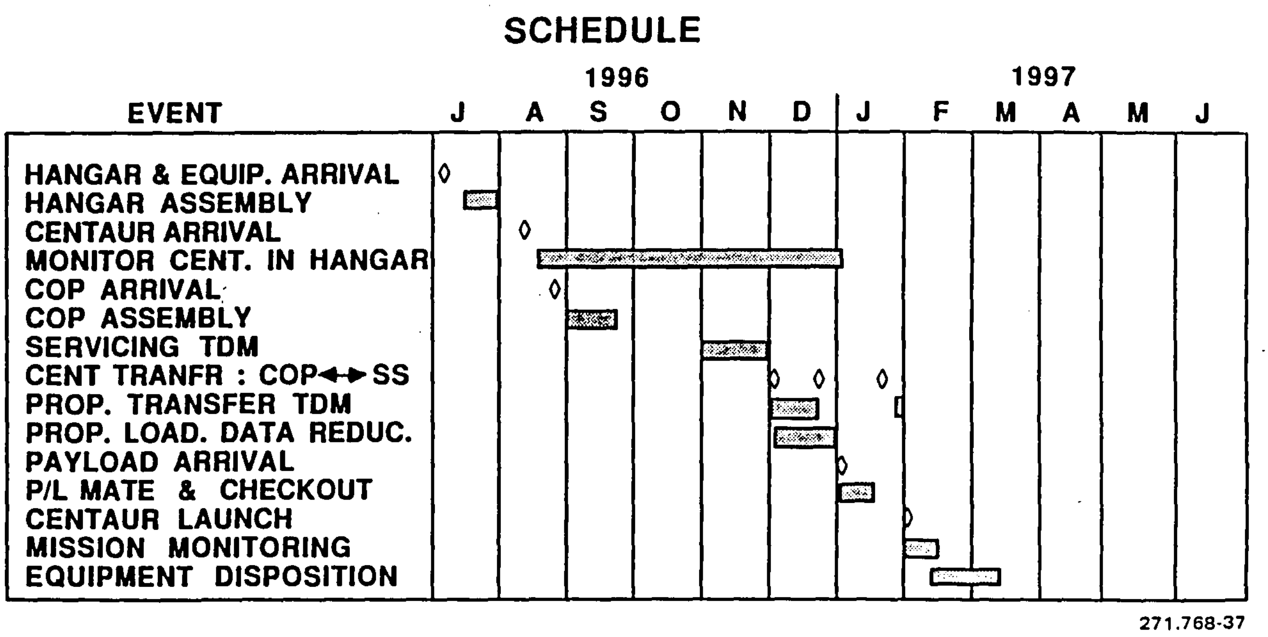


Figure 5-25. Propellant Resupply Will Occur Near the End of the Program

5.2.1.4 Communications and Control Overview. The COP will supply power, TV support, adapters, and connectors for Centaur accommodation. Control and data links with the COP are shown in Figure 5-26. The TDM itself will be controlled by a CCLS installed on the COP, with manual override capability from the ground. Key links shown in this diagram include the following:

- The Ground-to-TDRS-to-COP control link. The Ground must be able to configure the computer onboard the COP that will control the tanking operation. This will allow the timeline and event sequencing to be modified for subsequent resupply cycles. The Ground computer must also be able to override the COP computer.

- The Space Station-to-COP link. The Space Station will control the OMV/CCA-to-COP docking and berthing operation. The Space Station will be observing video of the operation while controlling COP equipment (as well as OMV/CISS/Centaur) as Centaur arrives and departs from the platform.

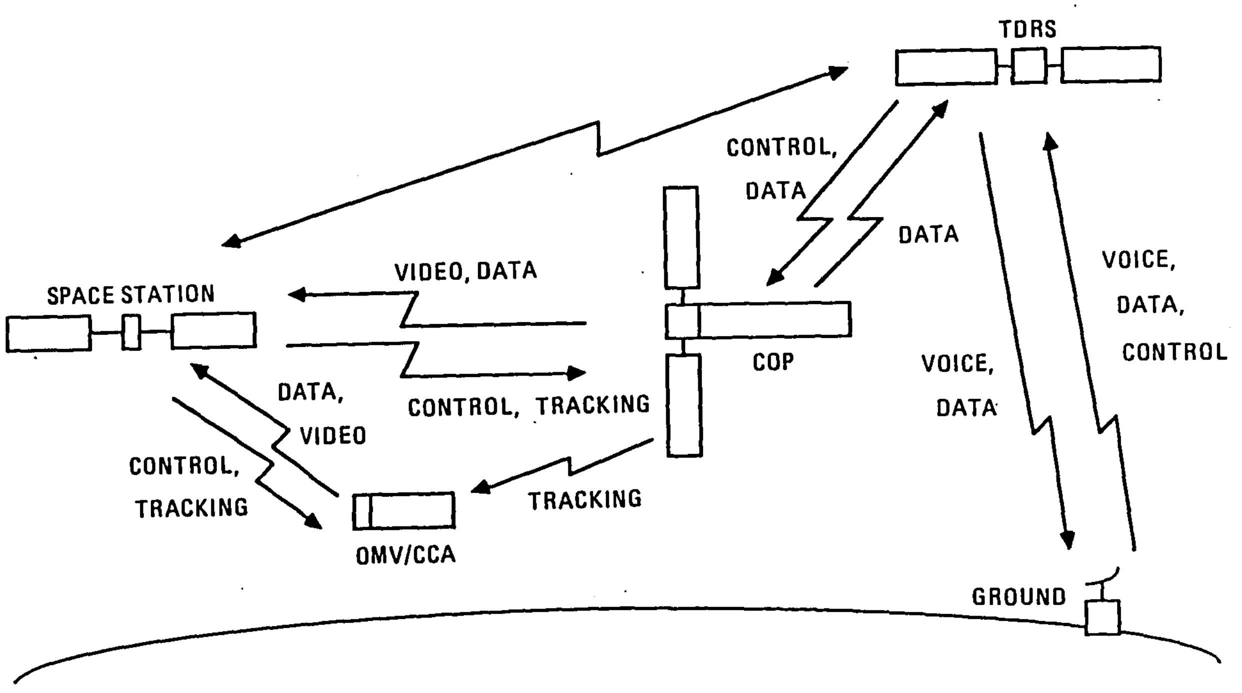


Figure 5-26. The TDM Is Controlled By a CCLS on the COP

5.2.1.5 Systems and Subsystems. Figure 5-27 shows the COP after the propellant depot modules have been added and the CCA has been transferred from the Space Station and handed off to the MRMS. The core platform is derived from the U.S. Reference Configuration with the addition of MRMS modules and adapters for the depot and CCA. It contains a CCLS equivalent and other avionics required for performing the TDM and for coordinating with the Space Station and the Ground. It also contains a boiloff recombination system, probably in the form of a fuel cell. The water produced could be transported to and used on the Space Station. The platform will have an attitude control system, but the OMV will be used to provide orbital reboost. Platform peak power requirement is estimated to be on the order of 8 kW. The CCA adapter will contain helium for propellant transfer and for resupply of the CISS and Centaur bottles. The same adapter will also house the vehicle emergency jettison system.

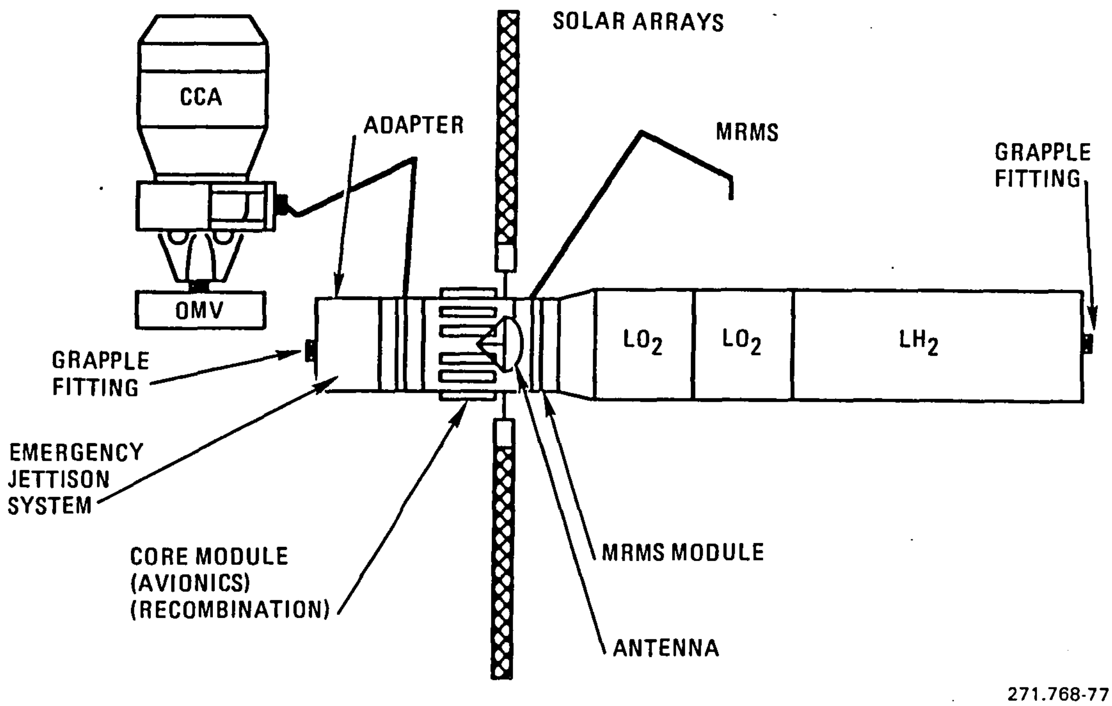
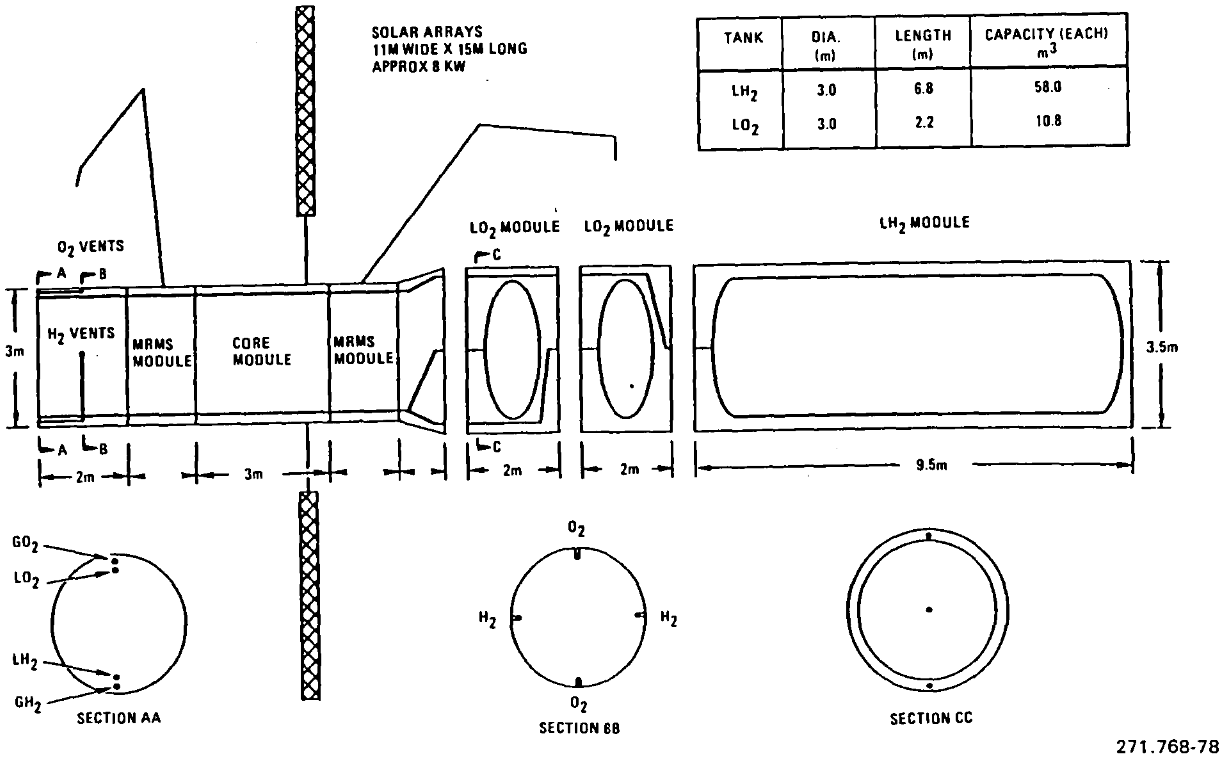


Figure 5-27. CCA Berthing to COP Uses Same Sequence and Mechanisms as CCA Berthing to Hangar

The COP propellant depot was sized to contain 27,000 kg (60,000 lb) of liquid oxygen and liquid hydrogen at a 6-to-1 mass ratio. The G-prime propellant capacity is similar to that being proposed for the single-tank-set OTV, approximately 20,000 kg. The extra is to provide excess for boiloff, experimental vending, etc. As shown in Figure 5-28, the 23,400 kg of oxygen are contained in two identical modules to accommodate existing launch capabilities to the 407 km (220 n.mi.) platform orbit. For this study, it was assumed that the Shuttle will deliver the LO_2 modules while the Titan 4 expendable launch vehicle (ELV) will be used to transport the LH_2 module. Each propellant module will have MRMS grapples and the hydrogen module will also have an OMV grapple fitting at the end. Each module will contain the necessary propellant management systems for delivery to orbit, for long-term storage, and for fluid transfer. These modules will be capable of being adapted to the OTV servicing facility, whether it be at the main station or on a separate COP. The platform will provide contingency Centaur vent and dump capability in the event that the thermodynamic vent system venting or liquid acquisition device draining fails.



TANK	DIA. (m)	LENGTH (m)	CAPACITY (EACH) m^3
LH_2	3.0	6.8	58.0
LO_2	3.0	2.2	10.8

Figure 5-28. COP Propellant Tanks Are Modular to Fit Weight Limits of Supply Launch Vehicles

The weights of the various elements of the COP and propellant depot are summarized in Table 5-9. The consumables make up two-thirds of the total mass of the COP system.

The Centaur G-prime vehicle was not designed to provide for orbital changeout of subsystems and components. It is not anticipated that any vehicle subsystem changeouts will be attempted at the COP. Provisions will be made to resupply helium from the COP, and it is possible that the system could be modified so that hydrazine could be resupplied on-orbit if necessary. The latter operation would require additional study.

On the other hand, the COP itself will be specifically designed for on-orbit servicing. Modular construction of the various elements makes it possible to remove and replace a major component if the need arises. Subsystems will be packaged as orbital replacement units which can be delivered by the shuttle or OMV and changed out by the MRMS from the Shuttle.

Table 5-9. Consumables Account for Two-Thirds of the Total COP Weight

Element	Weight (kg)	Weight (lb)
Structure	14,211	31,264
Platform	7705	
Core	2341	
MRMS(2)	2409	
Adapters(2)	2955	
LO_2 Modules	2625	
LH_2 Module		3881
Propellants	27,273	60,000
Total	41,484	91,264

5.2.1.6 Operations Plan. Propellant transfer occurs after the completion of the servicing TDM element at the Space Station. The goal is to demonstrate the cryogenic propellant management systems required for storage and transfer of liquids in the micro-gravity environment of space.

The operations plan is illustrated in Figure 5-29. Propellant Transfer element begins with the construction of the COP. The core COP is delivered to orbit followed by the propellant storage depot elements. These operations will be presented in more detail in Section 5.2.1.9. After the Space Station accommodation TDM has been completed, the CCA is transported from the station to the COP by the OMV. The COP MRMS grapples the CCA/OMV system, the OMV disengages, and the CCA is rotated into position and latched to the platform. The OMV then returns to the station while the TDM is being performed. Three propellant transfer cycles are planned, two involving warm receiver (Centaur) tanks and one while the tanks are still chilled. Both the transfer timeline and the sequencing of events will be reviewed and varied between transfers. All operations will be performed automatically with monitoring and override capability provided by the Ground Station. The capability to jettison the Centaur vehicle will be provided to protect the COP in the event of an uncontrollable emergency on the vehicle. The existing spring systems would probably not provide sufficient separation acceleration, but any higher level would require a detailed structural analysis. We recommend that this issue be examined in more depth. At the completion of the three transfers, the OMV will return to the COP, the CCA will be unlatched and rotated by the MRMS, the OMV will grapple the CCA, and the system will be returned to the Space Station for mating of the mission payload. Finally, the CCA is returned to the COP for final tanking for the mission. This completes the propellant resupply TDM, element.

5.2.1.7 Emergency Operations. During the performance of the TDM, there are a number of off-nominal situations which could occur. These range from situations which can be handled by the CCLS to situations which require that an attempt be made to jettison the vehicle. These situations are lumped into the following three broad categories:

- Those which could result in the inability to vent the propellant tanks through the TVSs
- Those which prevent normal draining of the tanks through the LADs
- Those which could result in the loss of the COP/CCA system

If a TVS does not function properly, pressure can be relieved through the ground vent system which will channel tank contents to the CCA/COP adapter and out opposed vents. Alternately, the fluid can be dumped through the LAD to the depot or overboard. If an emergency condition arises, such as an uncontrollable tank pressure rise, tank rupture due to micrometeoroid/debris penetration, or bulkhead reversal, there may be sufficient time to jettison the vehicle to protect the platform.

5.2.1.8 Resource and Equipment Requirements. Today, Centaur tanking is controlled by a manually operated CCLS located at the launch site. The CCLS controls the Ground side of the tanking procedure. The CCLS also configures the CISS Control Units (CUs) to control the Centaur side of the tanking procedure. CCLS operators monitor and react to CISS and Centaur telemetry displayed at the CCLS. For propellant transfer, the control, monitor, and react functions will be automated on the COP during this operation. The Ground will have the capability to override the COP fluids control equipment and control the operation manually.

The data station puts the Centaur/CISS telemetry into CCLS format and supplies Centaur/CISS pressures, temperatures, currents, and other data to the CCLS. The Ground will configure and initiate automated CCLS functions at the COP. A CCLS on the Ground will be able to manually override and control the tanking operation. Telemetry must be supplied to the CCLS functions at the COP and to the Ground and Space Station. Resource requirements are shown in Table 5-10.

For this study, "equipment" is defined to be hardware that is required for the TDM, but which will not subsequently be made part of the space station. Major equipment items required to support the Propellant Resupply TDM element are the modified CISS, the two MRMS modules, and the adapters. The remote manipulation system (RMS) arms themselves are part of the accommodations which will be used for the OTV servicing facility. It is intended that the COP will eventually be disassembled and the majority of the component parts used at the OTV servicing facility. An alternative would be to retain the core reference platform for later scientific studies.

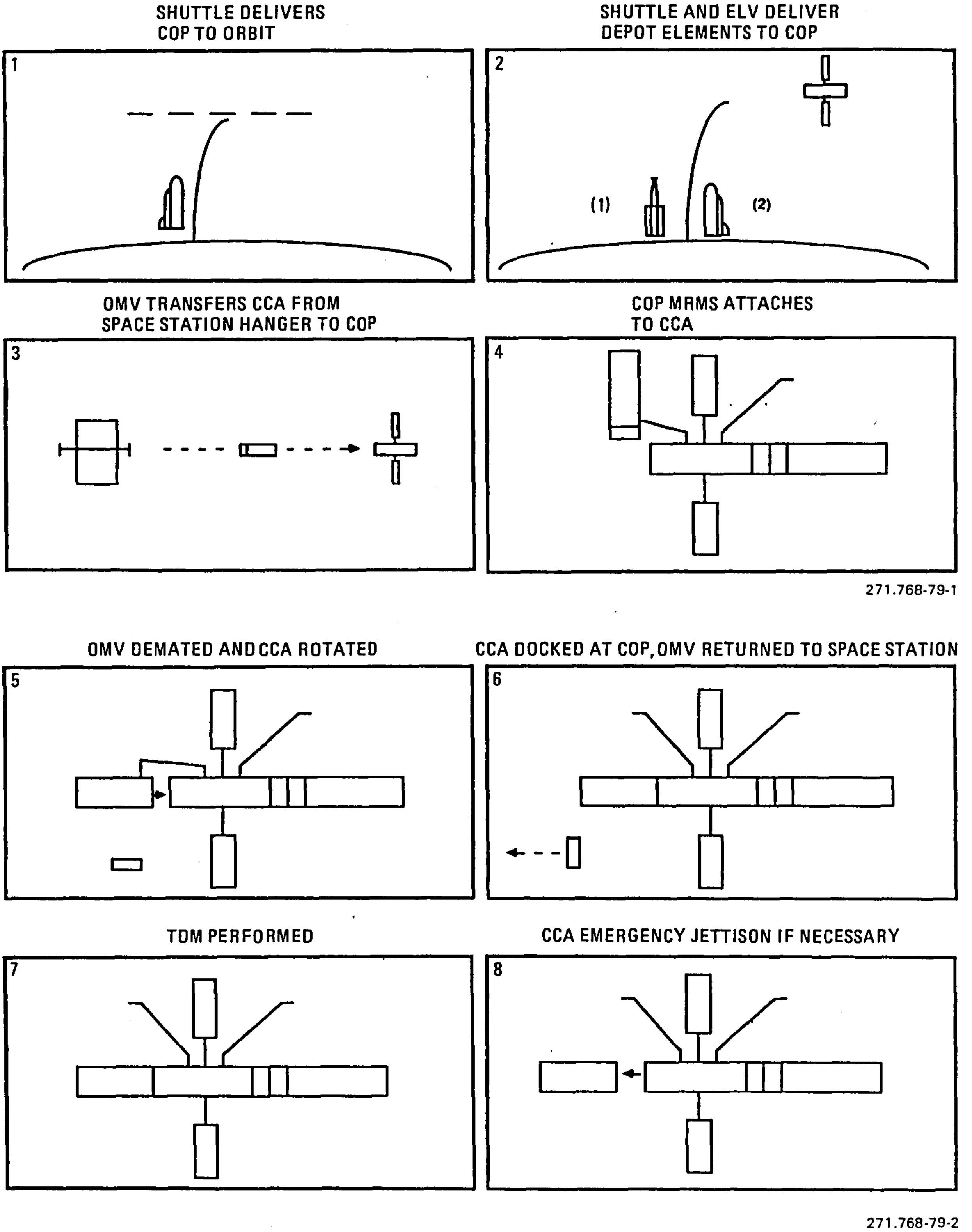


Figure 5-29. Propellant Transfer Operations Plan Begins With Construction of the COP

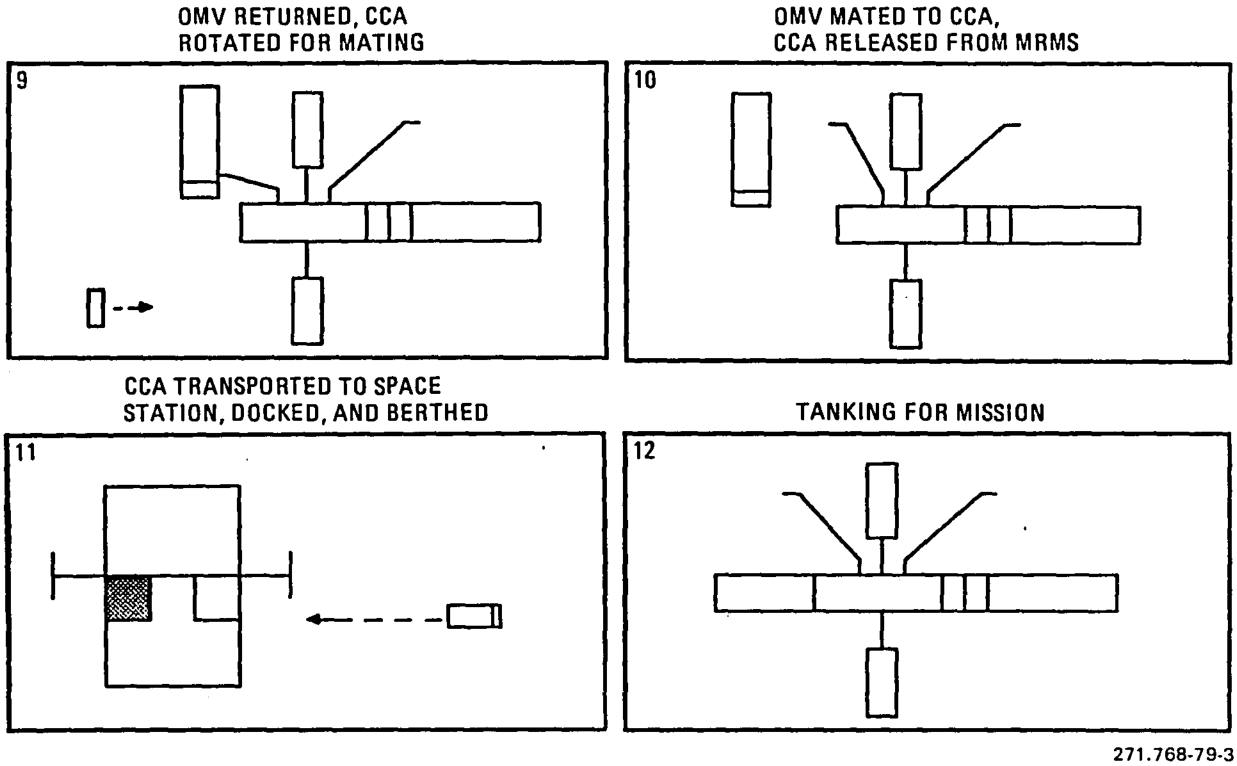


Figure 5-29. Propellant Transfer Operations Plan Begins With Construction of the COP, Contd

Table 5-10. Various Resources Are Required to Perform Propellant Transfer

Resource	Used in Weeks
CCLS functions	12, 18, 20
Automated COP fluids control	23-25
Reconfigurable and overrideable by Ground	30-31
Configure CISS for Centaur fluids control (load software)	
Monitor and react to telemetry	
Data station functions	12, 18, 20
Telemetry DECOM, supply to CCLS	23-25
	30-31
Communications	7, 12, 18, 20
Control	22-26
CCLS	30-31
COP	
Manual override of CCLS	
Data	
To CCLS (hardline)	
Telemetry to Ground (TDRS) and Space Station	

Delivery of the COP and the depot elements is flexible. Assembly must allow sufficient lead time so that the system can be fully activated and checked out prior to arrival of the CCA for the propellant resupply. Each Shuttle flight is estimated to require approximately 5 days, while hydrogen module launch by the ELV and delivery by the OMV is assumed to take somewhat longer. Two days are allowed to transport the CCA to the platform and prepare it for the TDM. The duration of the TDM itself will depend on the time required to reduce and analyze test data and modify the software for subsequent transfers. It is currently assumed that the total duration will be on the order of 3 weeks. After the vehicle is drained and safed, it will be transported to the Station for payload mating. Finally, it will be returned to the COP for mission fueling and launch. The overall TDM schedule is shown in Figure 5-30.

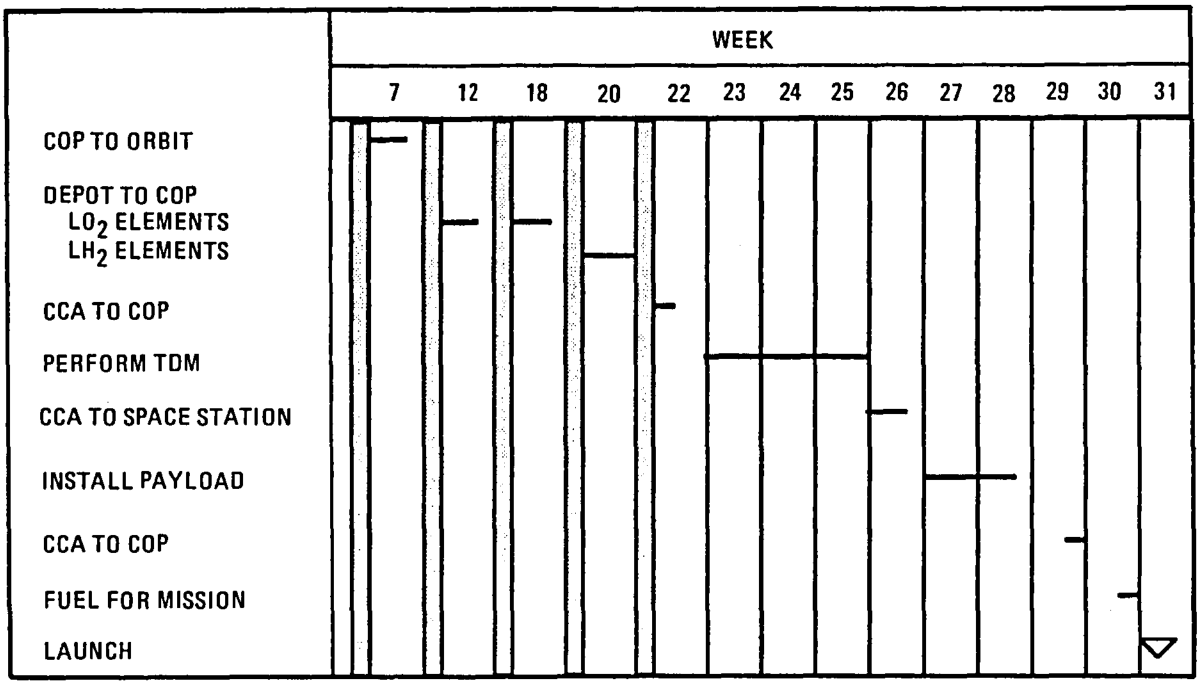


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Figure 5-30. Schedule of Propellant Transfer Events Shows Transfer Operations in Weeks 23 - 25

5.2.1.9 Assembly and Teardown. Assembly of the elements required to perform the TDM is illustrated in Figure 5-31. The core COP, consisting of the reference platform, the MRMS modules and the adapters, will be transported to the Space Station by the Shuttle. It will be docked to the Station and its various systems will be activated and checked out. It will then be transported to its permanent co-orbital location by the OMV. The first of the LO_2 modules will be delivered by the Shuttle. The Orbiter will dock with the COP and the module will be removed from the cargo bay and installed on the depot adapter. A second launch will deliver the remaining oxygen module. The hydrogen module will be delivered to orbit by an ELV. The OMV will transport the module to the platform where it will be grappled and installed by the MRMS. Once system checkout is completed, the platform is ready to initiate propellant resupply. After completion of the TDM operations, the COP will be dismantled and the various components used on the main station or on the OTV servicing facility. Teardown is discussed further in Section 5.2.3.9.

5.2.1.10 Safety and Other Issues. For the purposes of this program, it is assumed that the Shuttle will be capable, both physically and politically, of delivering the loaded liquid oxygen modules to the COP. It is also assumed that the Titan 4 ELV can be configured to launch the loaded liquid hydrogen module and deliver it to a rendezvous point where the OMV can pick it up and transfer it to the COP. Additional work is required to determine the best method of purging and safing the CCA prior to returning it to the Space Station. This program hinges on the successful completion of the CFMFE presently scheduled for the 1991-95 time frame. Centaur propellant resupply would be a higher risk element without the data which will be provided by CFMFE.

The Space Station is surrounded by control zones to maintain an orderly environment for the many users. The COP will be in Zone 5 at the time of TDM operations and Centaur mission deployment (Figure 5-32). This is the posigrade co-orbiting area greater than 187 km from the Station. The posigrade co-orbit zone was selected because it would most easily accommodate transfer between the Station and the platform. In addition, Centaur will be deployed in the posigrade direction thus allowing the separation from the Station to increase both due to the separation delta V and the greater ballistic coefficient of the Centaur.

5.2.1.11 Scarring Summary. Scarring for propellant transfer occurs in two areas: provisions for checkout of the COP and provisions for control of the transfer experiment. The COP will be launched in the Shuttle cargo bay to the Space Station. There, all systems will be activated and checked out prior to transporting the COP to its co-orbital position. Part of the CCLS will be installed in the COP core module, and part will be mounted on the Station. Although the Operations TDM is expected to be fully automated, the Space Station as well as the Ground Station will have monitoring and override capability.

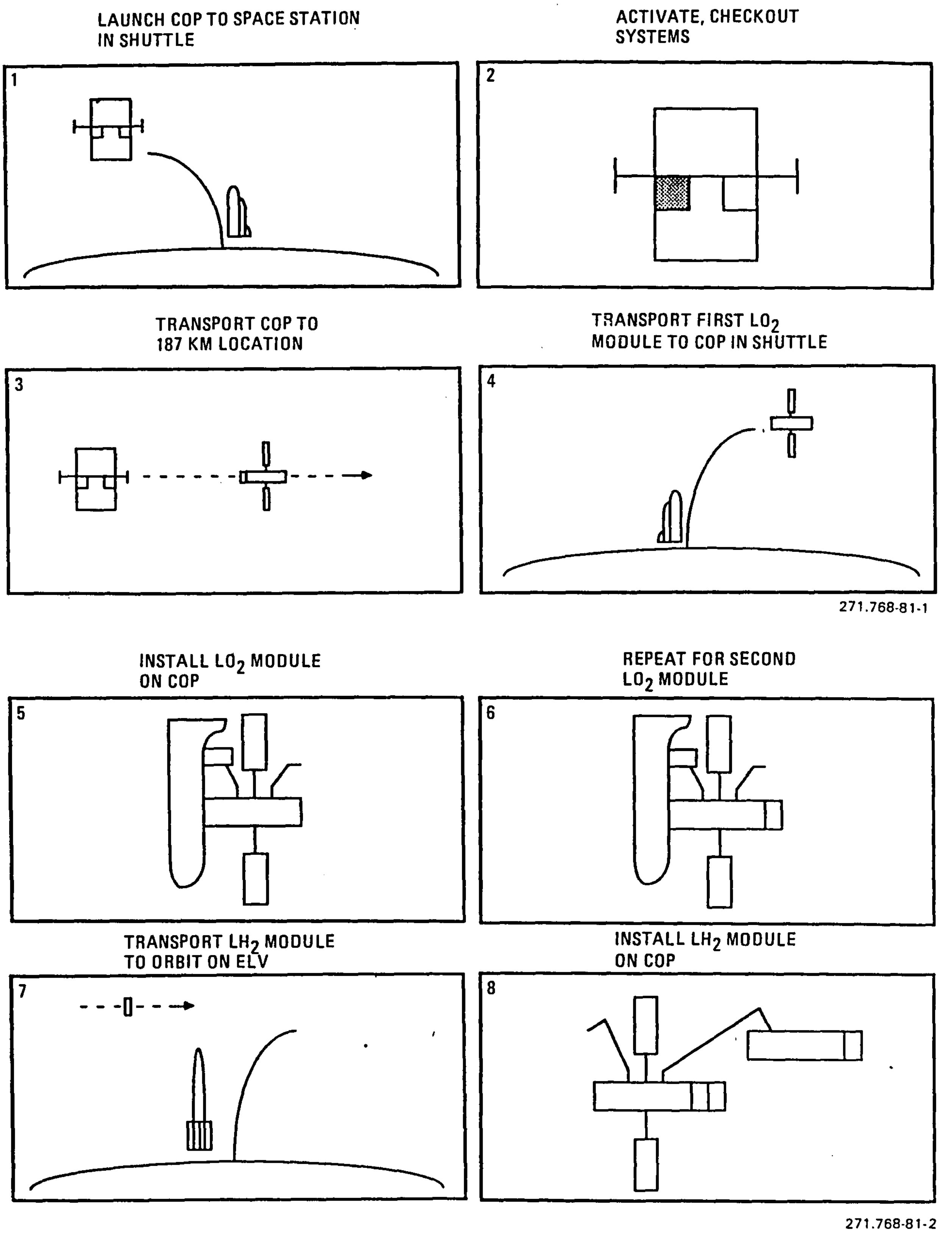


Figure 5-31. Shuttle and an Unmanned Launch Vehicle
Are Required in TDM Assembly Sequence

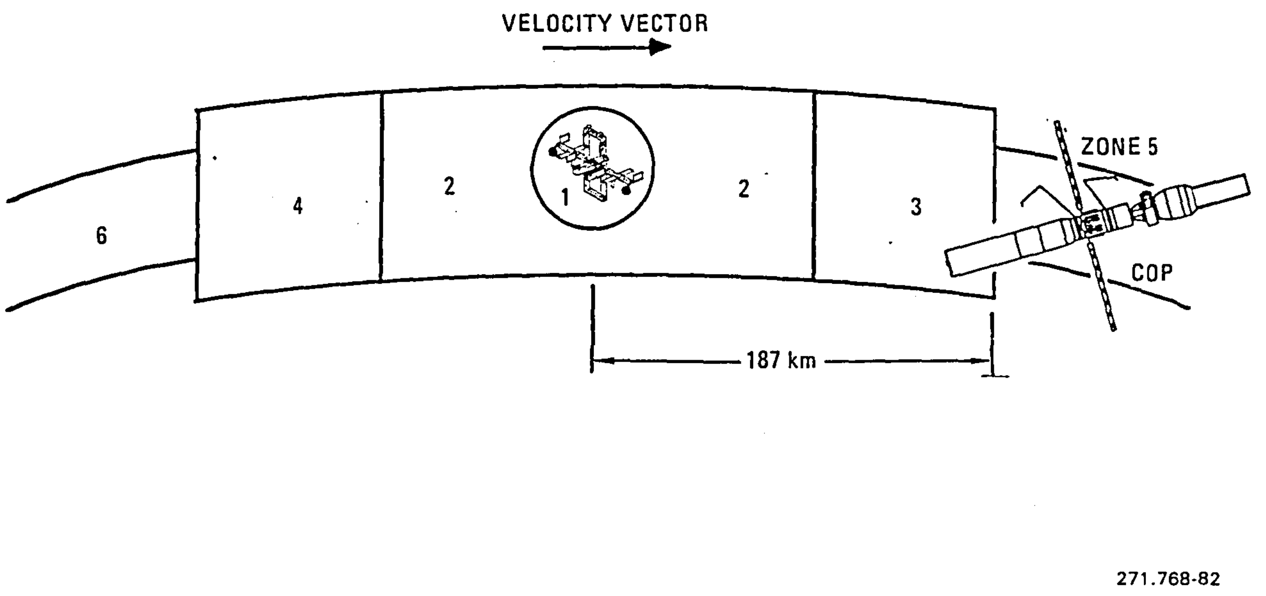
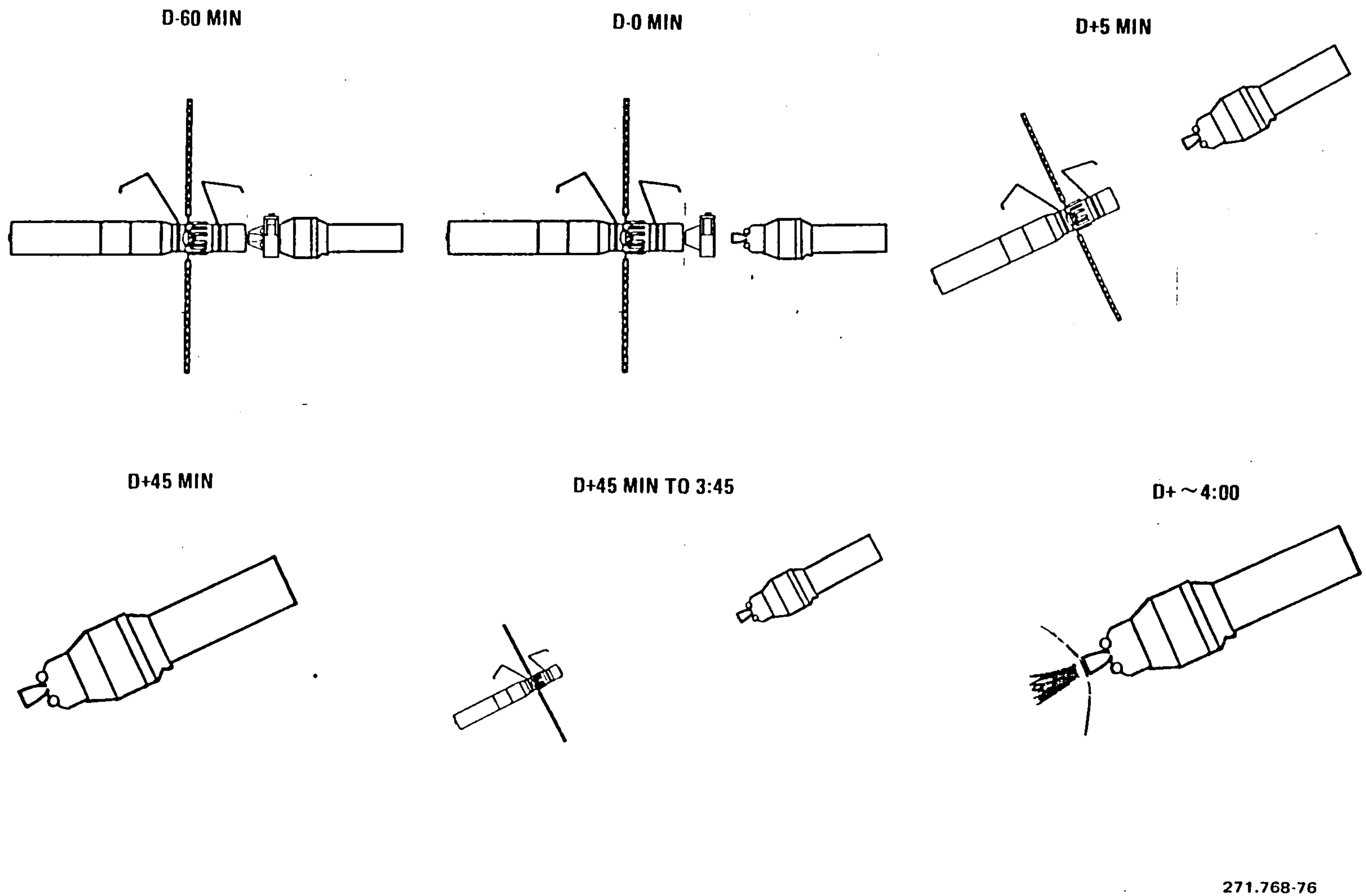


Figure 5-32. The COP Will Be Located in Space Station Zone 5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D-0 MIN
D+5 MIN
D+45 MIN
D+45 MIN TO 3:45
D+ ~4:00
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5.2.2 DEPLOYMENT

5.2.2.1 Summary. Cryogenic propellant transfer and payload deployment are the two Operations TDM elements. This section covers the latter. Specifically, the Centaur will deploy multiple, real, geosynchronous or planetary payloads at the conclusion of the TDM program. Deployment will occur from the fueling platform in Zone 5, the leading (posigrade), co-orbiting zone which is 187 km from the Space Station (see Figure 5-33). Centaur deployment will consist of avionics and fluid checks and interface deadfacing. The Super*Zip will separate the Centaur and CISS and separation springs will impart a 0.5-mps nominal separation velocity. The dual failure tolerant arm safe system (DUFTAS) will remove the reaction control system (RCS) inhibits 5 min after separation and the main engine start (MES) inhibits 45 min after separation. The flight control processor (onboard computer) will then initiate MES approximately 3 hr later, after Centaur has coasted 7.5 km from the COP. Centaur would have the capability to carry up to 9000 kg to geo-circular orbit and could use an MPA to carry several satellites at once.

ELEMENT ORIENTATION AT DEPLOYMENT

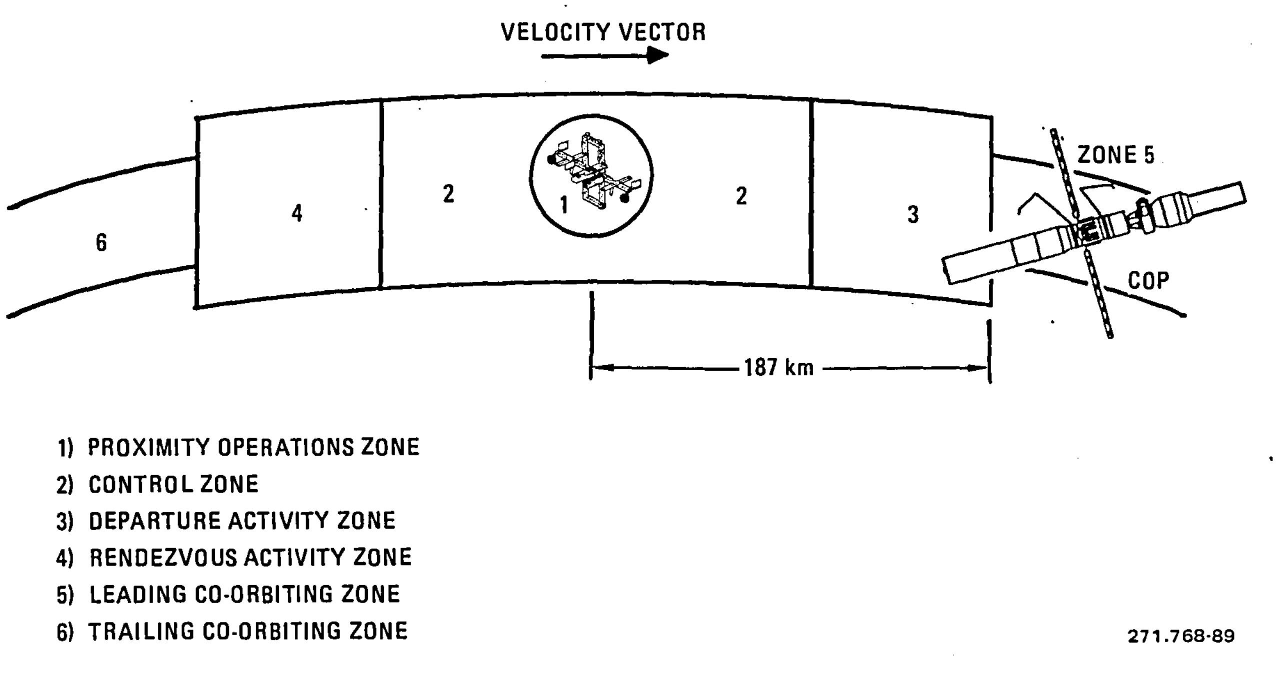

Figure 5-33. The COP Will Be in the Leading Co-Orbiting Control Zone (Zone 5) Around the Space Station

5.2.2.2 Space-Test Rationale and Specific Objectives. The flight of a mission after the TDM program will be a significant contribution to the technology base gained from the program. The experience gained from the flight of an expendable deployed from the Space Station environment will allow refinement of the operations and governing policies. The mission would also allow a final checkout of all the procedures developed in the TDMs as this would require the knowledge gained throughout the rest of the program to mate the spacecraft, checkout the avionics, load propellants, and then deploy the Centaur from the COP. The program will culminate by launching a Centaur G-prime vehicle with a geo-circularization payload capability of 9000 kg. The funds generated from the launch would greatly increase the cost effectiveness of the TDM program.

5.2.2.3 Architecture and Schedule. The deployment of the Centaur from the COP to fly a mission will utilize the Space Station and TDRS for communications as well as proper COP orientation as shown in Figure 5-34. The Centaur will be fueled and checked out prior to deployment so that the deployment phase of the program runs from 1 hr prior to separation to 5 hr after as shown in Figure 5-35.

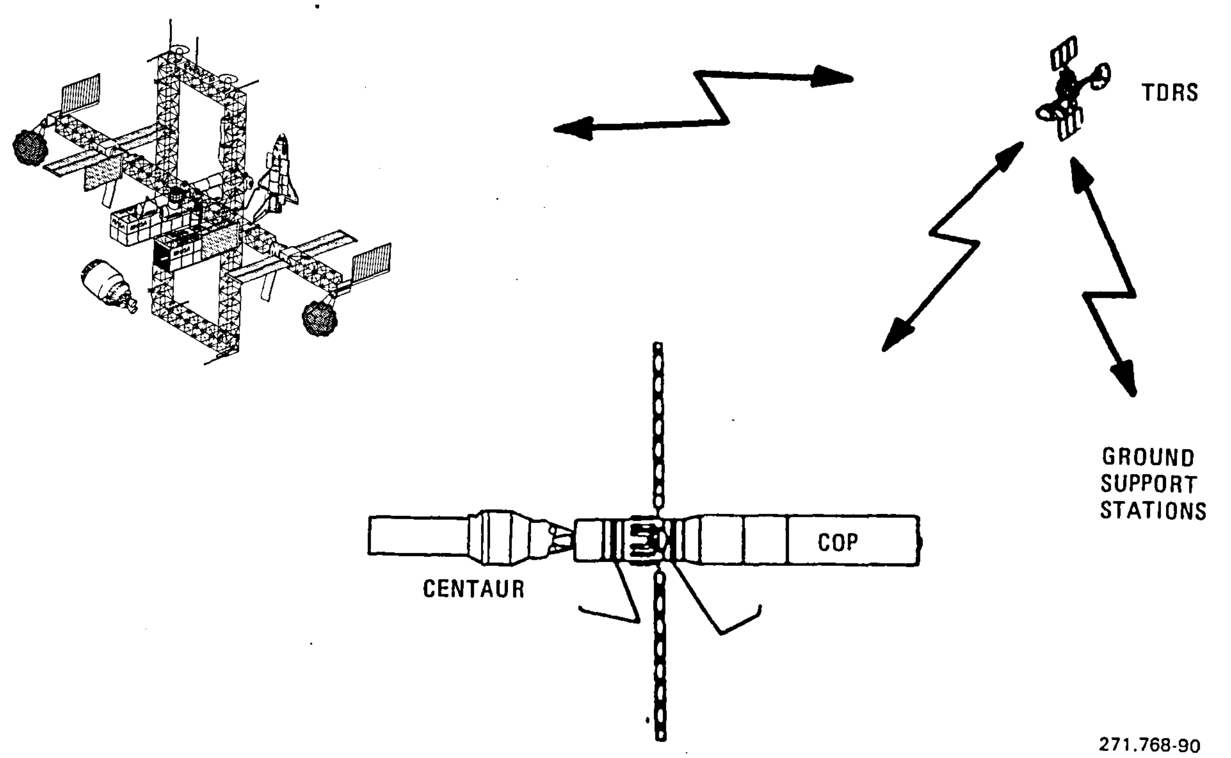

Figure 5-34. Deployment Operations Will Be Controlled From the Space Station With Ground Monitoring Through TDRS

5.2.2.4 Communications and Control Overview. Prior to deployment, the communication network will consist of Space Station, TDRS, COP, Spacecraft Payload Operations Control Center (S/C POCC), Centaur Payload Operations Control Center (CPOCC), MCCH, and White Sands Ground Station. The Mission Director at MCCH will be in control of operations flow and flight rule implementation. The director will be in contact with the S/C POCC and CPOCC

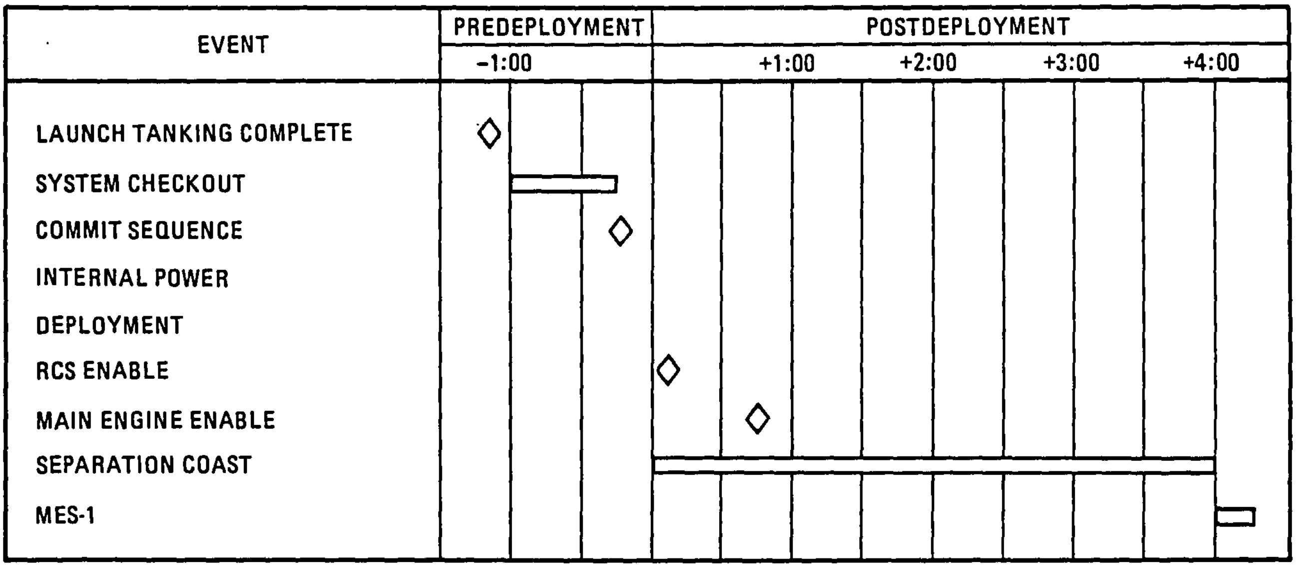

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Figure 5-35. The Deployment Events Will Occur After Centaur Is Tanked and Checked Out

should anything arise affecting the mission. The Space Station crew will be prime to carry out the deployment sequence and will monitor a reduced data set. CPOCC will be prime on Centaur systems monitoring and health assessment. Figure 5-36 illustrates the pre- and postdeployment communication arrangement.

After deployment, the only nominally active elements will be Centaur through TDRS to the Ground Stations. Centaur commanding through TDRS will be possible should a contingency arise requiring Main Engine Start inhibit, power down or some other safety-related action. The Space Station will continue to provide radar tracking data of the Centaur to the Ground Stations until out of range.

Control of the deployment operations will be carried out through remote telemetry link from the Space Station. The deployment sequence consists of a software function stack residing in the CISS CUs. A command issued from the OMV control room standard switch panel functional equivalent (see Figure 5-37) increments the stack and the CUs carry out the functions. The OMV control room will be modified to accommodate the deploy commanding, and a signal conditioner will format the command for broadcast to the platform. A receiver on the platform will relay the signal through the CISS signal processor to the CUs.

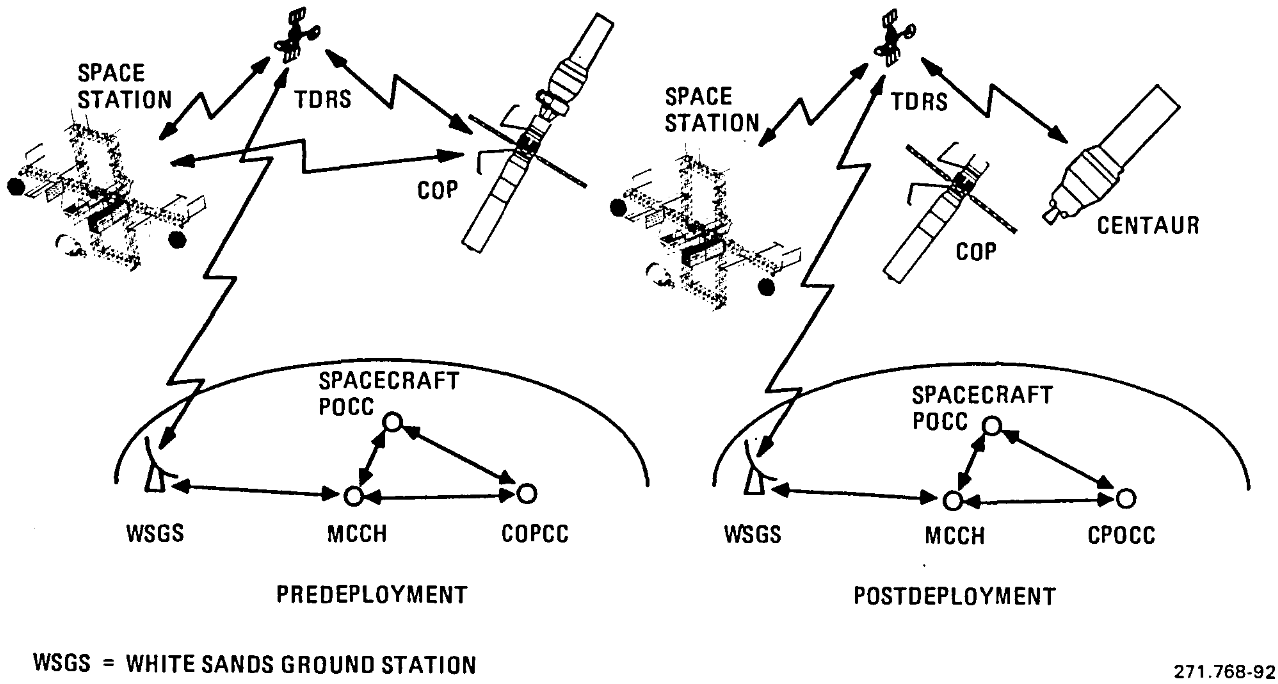

Figure 5-36. Continuous Monitoring of the Centaur Will Be Available to All Stations

5.2.2.5 Systems and Subsystems. The Centaur will use the standard Super*Zip separation system with springs for deployment, thus obviating the need for any additional equipment or modifications. The Space Station and COP will already have CCLS capabilities from the checkout and propellant transfer TDM element so that the only deployment-unique modification required is the provision for a deploy sequence commanding capability at the OMV Control Room.

5.2.2.6 Operations Plan. The final aspect of the TDM program will be the flight of a mission using the Centaur G-prime vehicle used during the TDM. The goal will be to verify the procedures and experience gained from the TDM program. At this point, the Centaur avionics have been verified at the Space Station, the payload has been mated to the Centaur and the interface checked out, and the payload and Centaur CISS have been transported to the COP and have been fully tanked with all systems GO.

The deployment sequence begins approximately 60 min before firing of the Super*Zip with final system checkout, AC power activation, and dummy rotation clutch engaged verification (see Figure 5-38). The rotation system will not be required for separation. The CU software will be modified to always indicate successful rotation even though no physical action will be taken. The fluid and avionics systems are then prepared for deployment through the commit sequence initiation. After final system checkout, the Centaur will be commanded to go to internal power and if successful, the Super*Zip will be fired, separating Centaur from the CISS at 0.5 mps nominal.

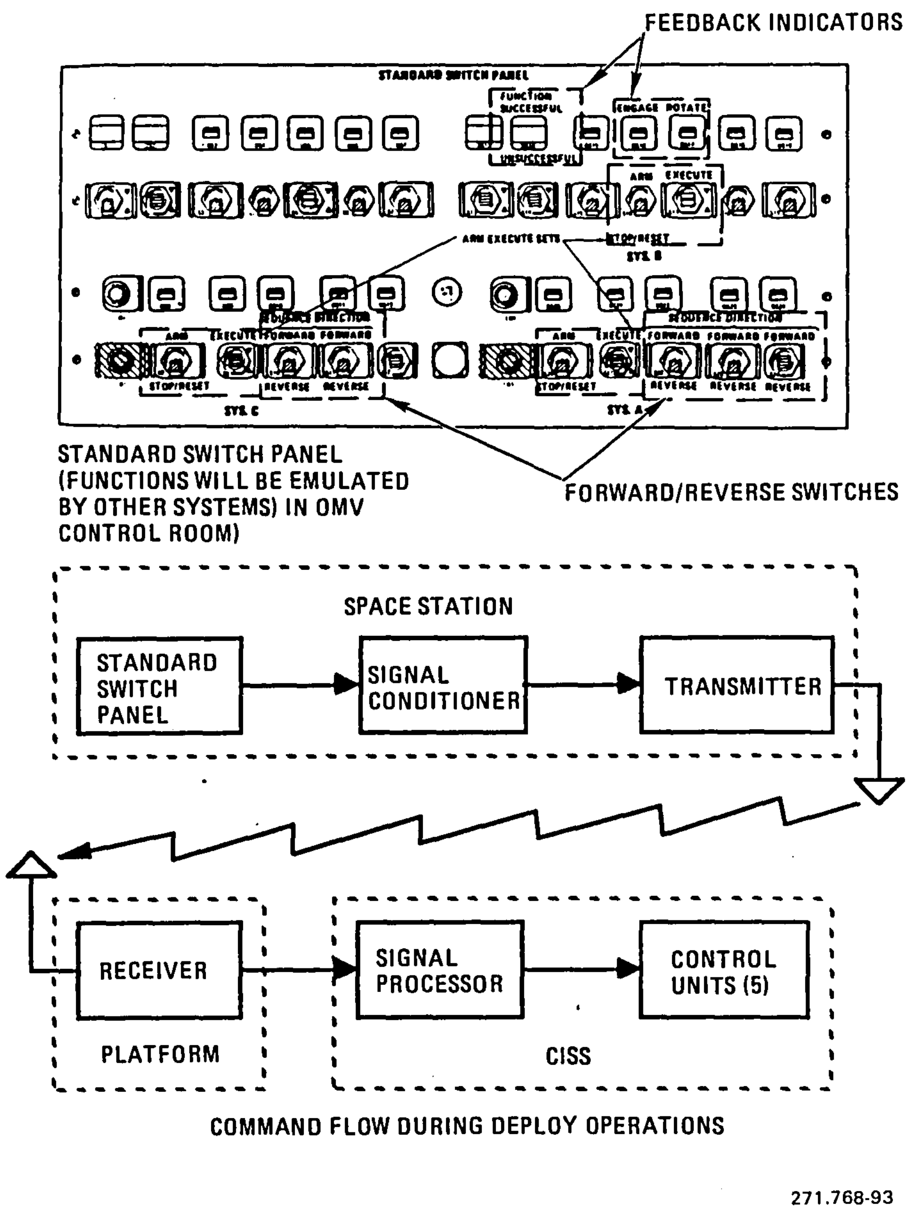

Figure 5-37. Centaur Commanding Will Be Carried Out Similar to the Shuttle and Centaur

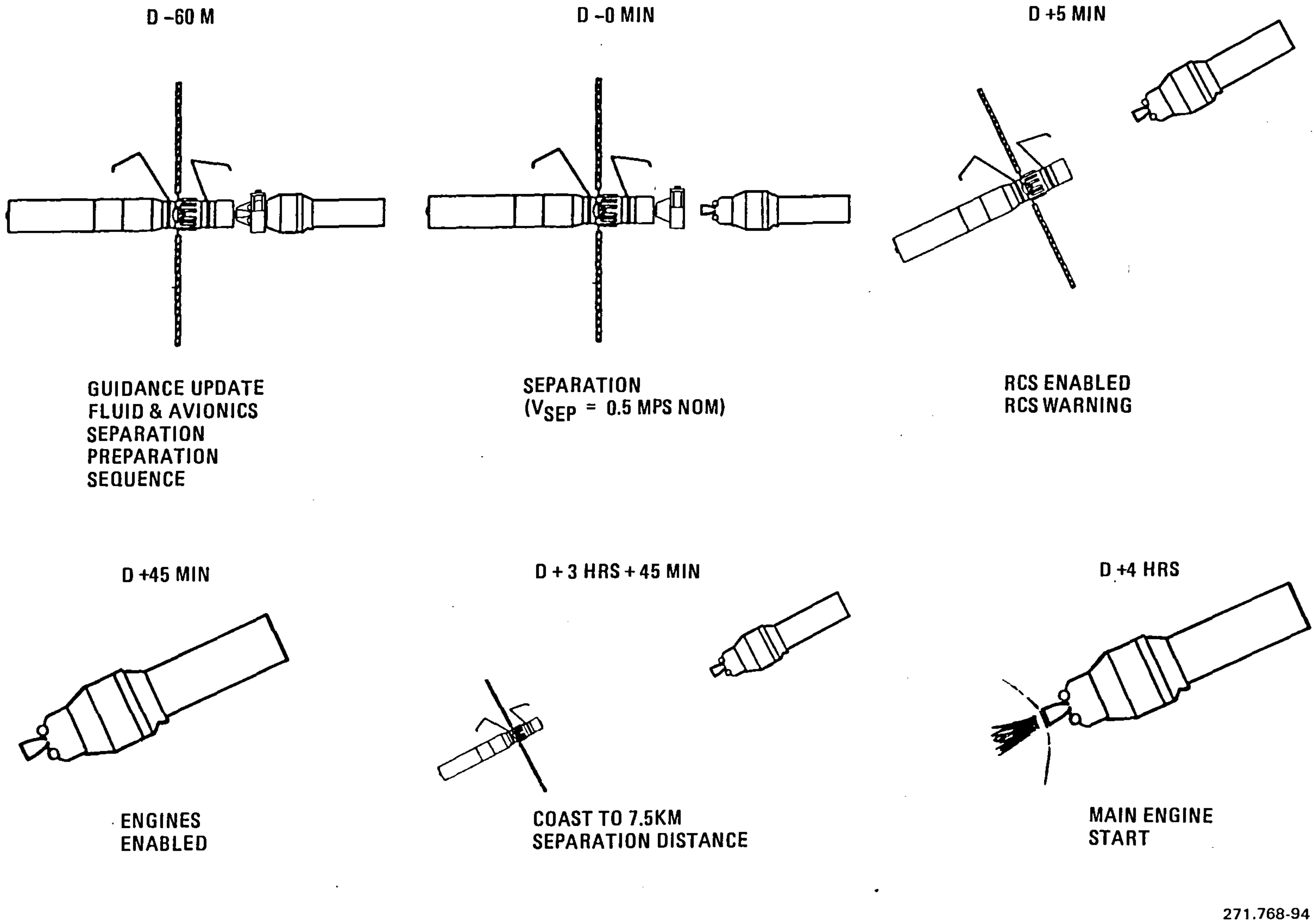

Figure 5-38. Centaur Deployment Sequence Will Provide a Safe Controlled Mission Start

Approximately 15s after deployment, the Centaur S-Band antennas deploy and 15s later begin transmitting to TDRS. After 5 min, the DUFTAS enables the RCS system. After a 2-min warm-up sequence, the Centaur will be fully capable of attitude control. After 45 min, the Centaur main engines will be enabled, although the burn will be inhibited by the flight control processor (FCP) for another 3 hr to ensure at least a 7.5-km separation distance from the COP. Centaur will coast to the correct inertial point in space before initiating the engine prechill and geo transfer burn. An overview of the flight sequence is shown in Figure 5-39.

The missions for 1997 are shown in Figure 5-40 and were obtained from the 1986 Battelle mission model. This includes only commercial payloads. The Global Positioning System flights are Department of Defense (DoD) and, along with the High-Frequency Direct Broadcast Platform mission, come from a Space Station Architecture Study mission model. As can be seen, a variety of mission pallet combinations may be flown with the MPA.

To prepare for this mission, a series of simulations with special training will be required. These simulations will prepare the Ground and crew for the nominal and contingency procedures that may be required for deployment. Data analysis and anomaly recognition will be emphasized as well as intercenter communication for quick resolution of problems. The training for deployment activities will begin in early 1996, which will allow evaluation and refinement of the procedures and timelines prior to the TDM program.

5.2.2.7 Emergency Operations. Centaur contingencies have been thoroughly evaluated through the Shuttle/Centaur Program. Several of the more significant contingencies follow.

If the Super*Zip should fail to fire, there would be no immediate hazard since the signal could be removed from the interface. There is no way to change out the Super*Zip so the only action would be to back out of internal power and commit, evaluate the possible reasons for Super*Zip failure, then proceed through the software stack and attempt separation again.

If the Centaur, through a navigation failure, were to head into Space Station proximity, a command would be issued to safe or inhibit it. Inhibit Main Engine Start (MES) will prevent the main engines from firing although the RCS system would still be active to maintain vehicle stability. Commanding after deployment requires the addition of a transponder.

If the DUFTAS timers should fail on prior to deployment (premature or false breakwire indication), the RCS and main engines will be enabled while still attached to the platform. The FCP must still command RCS firing or engine firing before they would occur, but the system would be zero fault tolerant. The first objective would be to deploy as soon as possible to try for mission success. If this should be impractical, the objective would be to inhibit MES and power down the Centaur to prevent the RCS from fighting the platform attitude control system.

Centaur must be in communication with the Space Station and Ground for deployment. A communications failure would require a delay until communication was re-established with all the elements.

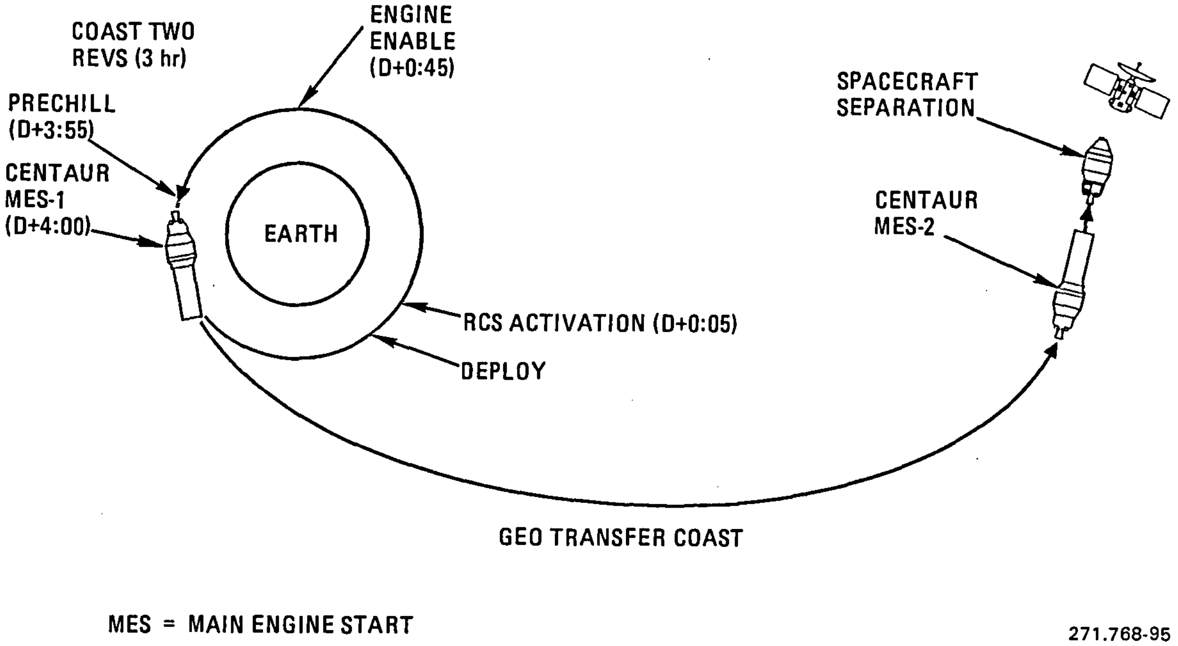

Figure 5-39. The Centaur Two-Burn Capability Can Deliver Large Payloads to Geosynchronous Earth Orbit

CENTAUR MISSION MODEL FOR 1997 FLIGHT			
SATELLITE NAME	WEIGHT (kg)	LENGTH (m)	DIAMETER (m)
WESTAR 12	660	2.4	2.3
GOES - L	1060	2.4	2.3
GALAXY KA-2	1320	4.5	2.3
GSTAR	1340	4.5	2.3
INTELSAT VII	1360	6.8	2.1
SBS/IBM	1360	6.1	2.1
GLOBAL POSITIONING SYSTEM (4 FLTS)	1410	3.0	2.3
FLTSATCOM	2040	4.2	3.0
HF DIRECT BRDCST PLTFRM	6360	9.1	4.6

SAMPLE MISSION MANIFESTING OPTIONS

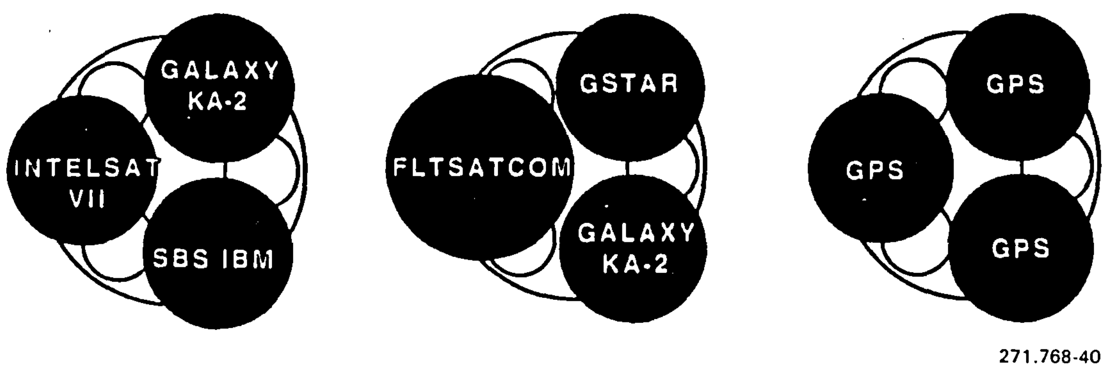

Figure 5-40. Many Manifesting Options Are Available With the Multiple Payload Capability

5.2.2.8 <u>Resource and Equipment Requirements</u>. To carry out the deployment of the Centaur from the platform will require several Space Station systems and accommodations. The OMV control room will be modified to allow monitoring and control of Centaur systems and provide the crew with Caution and Warning indications. The Space Station TDRS link will be required to relay data to the Ground as well as a direct RF link to the COP. At least two crew members will be required to assist in data monitoring and commanding during the predeployment sequence. The Space Station will need to provide radar ranging from deployment until the Centaur is out of range to ensure Space Station safety should a malfunction occur. Figure 5-41 shows the equipment and resources required for deployment and Figure 5-42 shows the scheduling.

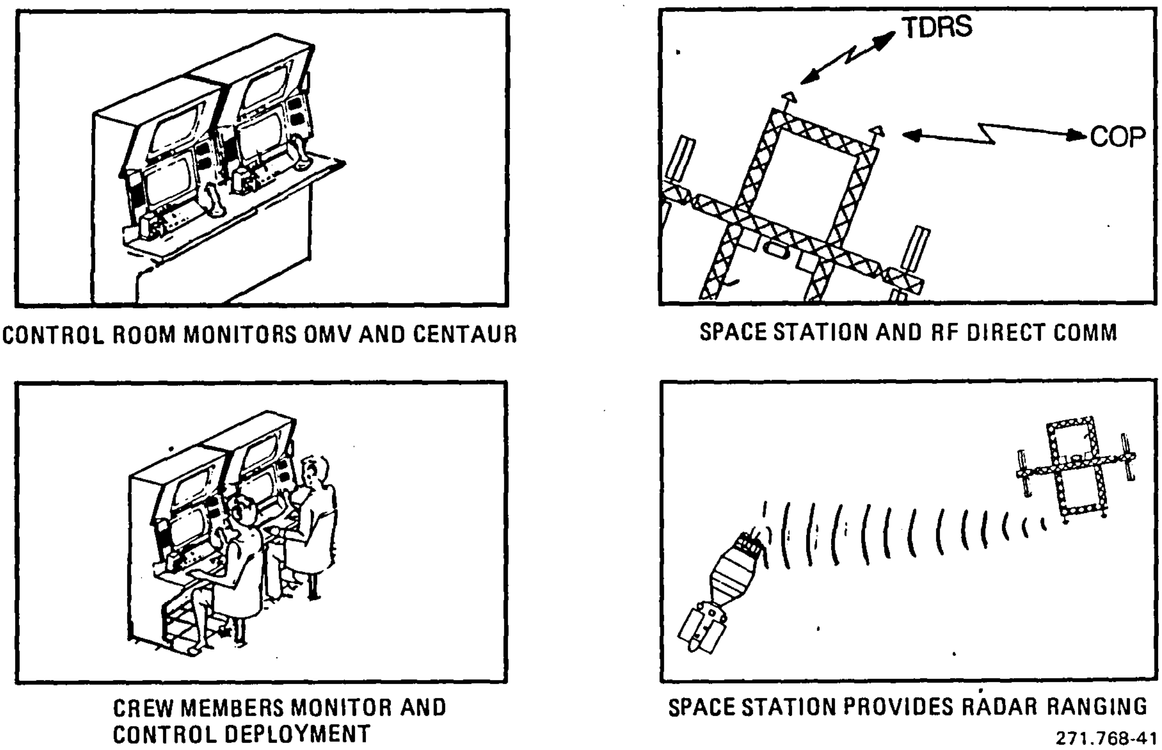

Figure 5-41. Existing Space Station Accommodations and Equipment Are Employed for Centaur Deployment

5.2.2.9 <u>Assembly and Teardown</u>. After the Centaur has been deployed from the COP and a decision to teardown the COP has been made, the OMV will rendezvous with the platform and return it to the Space Station. Once secured to the station, the CISS will be removed for return to Earth. The COP will be disassembled (at least all elements different from the U.S. Reference configuration) and reused in constructing the Orbital Transfer Servicing Facility as shown in Figure 5-43. The propellant tanks, grapple fixtures, manipulator arms, and solar arrays will all be reusable, thus improving the cost effectiveness of the TDM program.

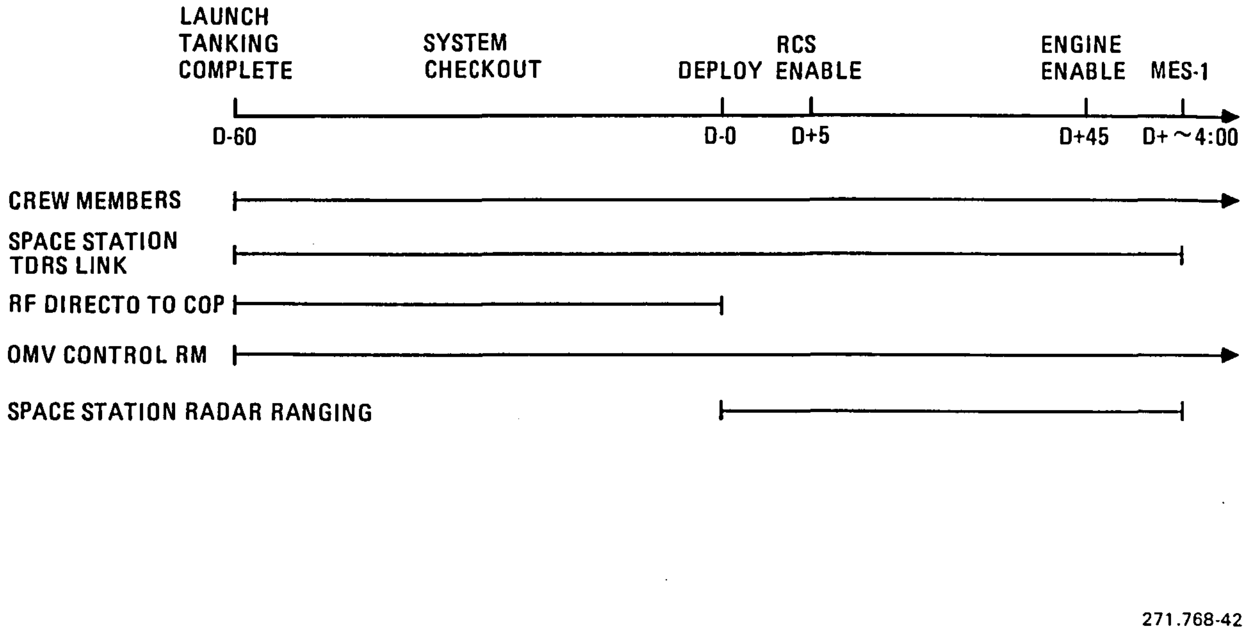

Figure 5-42. The Deployment Sequence Will Need Space Station Equipment for Only a Short Duration

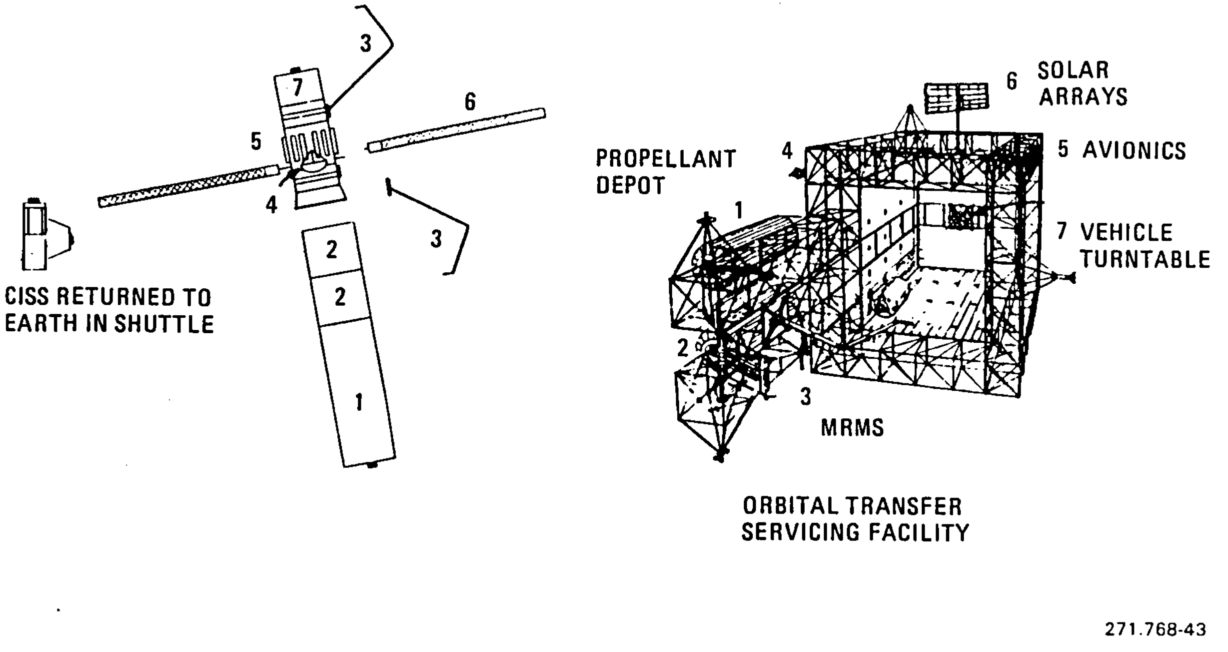

Figure 5-43. The Elements From the COP Will Be Used for the Orbital Transfer Servicing Facility

5.2.2.10 Safety and Other Issues. A fully tanked Centaur G-prime has the capability to lift 9090 kg into a geosynchronous orbit (payload and adapters). This is greater than most of the expected 1997 payloads combined. That is to say, one Centaur could launch nearly all 1997 missions at one time. Insurance considerations would not make such a mission likely.

An issue concerning Centaur deployment is the method of initiating the predeployment sequence of commands (i.e., crew- or Ground-initiated or automatic computer sequencing. The recommended approach is to use the existing software on the CISS CUs and let the crew perform the functions from a modified control panel at the Space Station.

Centaur does not presently have the capability to receive uplinked commands after separation from the CISS. While the deployment operations will technically be outside the Station control zones requiring commanding capability, it is very desirable to have control capability until after a safe geo-transfer burn. The installation of a transponder would allow emergency postdeployment commanding such as power down or MES inhibit. The estimated cost for this enhancement is $2 million (in 1986 dollars).

The Centaur IMU will need to be aligned prior to main engine burn. There are several methods of accomplishing this either autonomously by adding a GPS transponder and star scanner (most accurate), or through use of TDRS via the COP/TDRS link (least expensive).

Due to potential communications bottlenecks and conflict with Station operations, it will be necessary to schedule the TDMs and Centaur movement to ensure proper coverage.

To allow greater flexibility in payload manifesting, a larger MPA might be desirable. This needs to be analyzed in light of weight and transportation concerns.

5.2.2.11 Scarring Summary. The only Space Station scarring peculiar to the flight of a mission would be the modification of the OMV control room to be able to send the deploy commands to the CISS CUs. This could be either a software change with keyboard input or actual wiring of a control panel to provide the interface. Additionally, adjustment of the crew work schedule would be required to provide support during this time.

SECTION 6

TASK 3 - DOCUMENT TDMs IN MISSION REQUIREMENTS DATA BASE

Space Station data base input sheets are presented in Appendix A.

SECTION 7

TASK 4 - PRECURSOR TECHNOLOGY

7.1 ACCOMMODATIONS PRECURSORS

There should be two precursor demonstrations prior to this TDM, both done at the Space Station. They are as follows:

- Spacecraft Processing Facility Hangar Construction
- Orbital Replacement Unit Demonstration

7.1.1 SPACECRAFT PROCESSING FACILITY HANGAR CONSTRUCTION. The purpose of this demonstration is to gain experience assembling a protective shelter at the Space Station. The demonstration will involve Shuttle, Space Station, crew, and Ground support. The facility has already been planned. The data base will allow easier Centaur hangar design and construction.

7.1.2 ORBITAL REPLACEMENT UNIT DEMONSTRATION. The purpose of this demonstration is to optimize procedures and hardware for avionics hardware replacement. The avionics equipment will be attached and removed at the Space Station using a variety of attachment devices and techniques.

7.1.3 BERTHING, CHECKOUT, AND MAINTENANCE GROUND SIMULATION. To prepare for the TDM, a series of precursor simulations with special training will be required. These simulations will prepare ground support personnel for real-time operations (both nominal and contingency) likely to occur during the TDM. The simulations will cover the berthing activities, checkout procedures (including anomaly detection), and maintenance communication and technical support. These simulations will take place over a period of time starting in late 1995, prior to the actual activities of the TDM. This schedule will allow evaluation of procedures and flight rules before hardware is at the Space Station and will reveal any unforeseen difficulties.

7.2 CRYOGENIC PROPELLANT TRANSFER PRECURSORS

The principal precursor for the cryogenic propellant transfer TDM element is the CFMFE, and its own precursor experiments. It is anticipated that a successful CFMFE will be sufficient to proceed with the design and execution of Centaur propellant transfer. The purpose of the CFMFE, managed by the NASA Lewis Research Center, is to provide the technology required to enable the design of systems for managing subcritical cryogenic fluids in the space environment. The specific objectives are to demonstrate liquid storage, supply, and transfer. The technologies to be demonstrated include tank thermal protection system performance, tank pressure and stratification control, liquid acquisition, tank pressurization system performance, mass gauging, transfer line and receiver tank chilldown, receiver tank no-vent fill, and supply tank refill.

The CFMFE is currently undergoing redefinition to change the launch mode from the Shuttle to an ELV. This will require modification of the experiment hardware and operations, although the basic objectives of the program are not expected to change. Most recent planning shows three flights occurring in 1991, 1993, and 1995. Shown in Figure 7-1 are all of the identified experiments and programs involving orbital fluid management which have been proposed. The first four are part of the NASA/Langley data base of Space Station experiments. The test articles are OTV propellant storage depot demonstration experiments being developed by NASA/LeRC and NASA/MSFC. The storage facility is a first-cut development schedule for the full-scale propellant depot. Also shown are what are believed to be the current initial operational capability (IOC) dates for the Space Station and space-based OTV.

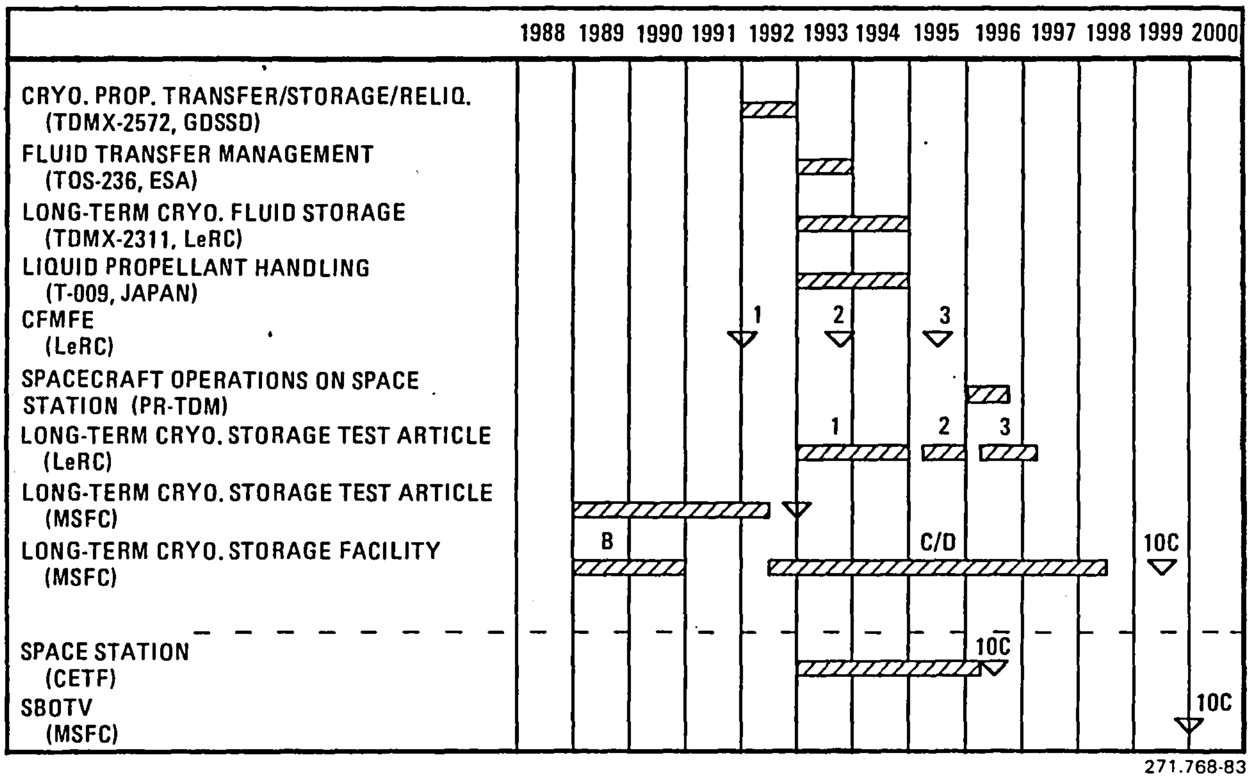

Figure 7-1. CFMFE Is the Most Important Precursor for the Propellant Transfer TDM

7.3 PAYLOAD INTEGRATION PRECURSORS

There should be two precursor demonstrations prior to payload integration, both done at the Space Station. They are as follows:

- Spacecraft Universal Interface Technology Program
  - Purpose: Develop a data base for a common spacecraft to upper stage interface.

- Approach: Analyze current and projected payload requirements to compile potential common interface configurations and construct prototypes for evaluation.

- Spacecraft Maneuvering and Grappling Evaluation Program

  - Purpose: Develop a common grappling and maneuvering capability for payloads.

  - Approach: Evaluate current and projected spacecraft designs to determine the optimum grappling and maneuvering approach. Construct dummy payloads and do ground testing and refining of procedures.

7.4 DEPLOYMENT OPERATIONS PRECURSORS

There are no precursor technology demonstrations required beyond the activities which are already a part of a normal program development.

SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

There are no show stoppers in the concept of using Centaur to demonstrate OTV Accommodations and Operations (A&O) technology at Space Station. Intuitively, a new start based on this concept for Centaur Operations at the Space Station could save NASA and our country substantial amounts of OTV development risk and money. Additionally, the previously unrealized ability to fill and/or modularize Centaur propellant tanks, and the 140-n.mi. elevation increase in its launch platform (from Shuttle to Space Station), should drastically increase expendable Centaur's launch capability. This could provide a means for NASA to recoup its investment in the two Centaur G-primes it now owns. Studies should be done to quantify the value of OTV savings, and of the increased Centaur performance.

8.2 RECOMMENDATIONS

Three studies should be funded in 1987:

- TDM Program Economic Analysis. Defines: cost of TDM program and savings to OTV development program.
- Expendable Centaur Optimization. Determines: payload capability increase, translates increase into specific payload options, addresses insurance concerns, and addresses operational contingency actions.
- Program Feasibility Study. This would provide full predesign optimization and trade data for hardware, software and operations.

NASA LeRC's Centaur Operations At The Space Station Study (NAS3-24900) is in progress at General Dynamics Space Systems Division (GDSS). Its purposes are to: 1) <u>conceptualize Technology Demonstration Missions (TDMs)</u>. These are experiments using Centaur to assist the development of accommodations and operations technology required at the Space Station by an orbital transfer vehicle (OTV); and 2) <u>document the Space Station scarring required by these TDMs</u>. The major tasks have been completed. What remains is to integrate the TMDs, precursor activities, and resource and transportation requirements into a cohesive program plan. We believe there would be very significant benefits to NASA if an expanded follow-on was immediately initiated.

NAS3-24900 is challenging and exciting. The TDM concepts and spin-offs are very promising. For example, a spin-off advantage is a fact verified, but not publicized, in our Deployment TDM analysis. The Centaur G-prime capability increases from the 10,000 lb quoted out of the Shuttle to 20,000 lb on geosynchronous earth orbit (GEO) from the Space Station. Of course, similar gains could be expected for escape trajectory payloads. We see this potential blossoming into numerous NASA benefits:

- Near-term freedom for NASA to design more complete spacecraft, laboratories, and construction kits for Moon or Mars bases
- Entire constellations of laboratories or GEO satellites could be placed on one launch
- Spacecraft can remove propulsion states intended for Shuttle deployment and be stacked for delivery to Space Station for Centaur launch
- This increases Shuttle's manifest density, reducing the wait to get NASA programs in space (before their budgets get reallocated)

However, the study is funded at $100,000. It cannot afford the depth to quantify the dollar value of a TDM program to NASA's OTV Development Program, to NASA's space launch capability, or to make decisions on concept alternatives to optimize feasibility and cost and engineering effectiveness. These quantifications should be done to either:

- Support a new start if this program can contribute significant cost savings to OTV, or the nation's space launch program, or
- Identify why no further energy should be spent on it.

As the GDSS Program Manager for this study, I am suggesting the following activities to determine value and feasibility.

- Economic Analysis Tasks:
  - TDM program familiarization
  - Research OTV cost data
  - Develop work breakdown structures (WBSs) for TDM and co-orbiting platform (COP) implementation alternatives
  - Determine WBS additions to Centaur and Space Station
  - Determine all other cost elements and sources
  - Develop costs for all elements
  - Determine TDM program costs and OTV development savings
  - Generate final report, monthly reports, get approvals
- Expendable Space-Based Centaur Analysis Tasks:
  - Determine Centaur Performance boundaries from Space Station
  - Develop 1997 to 2001 mission model for Space Station/Centaur
  - Candidate Operations plans, scenarios, timelines, pre and post operations
  - Determine Centaur modifications and Space Station requirements
  - Synthesize on insurance issues and solution alternatives
  - Impact assessment: shuttle manifest, national launch capability
  - Life cycle cost and payback analysis
  - Other benefits, impacts, issues
  - Generate reports, briefings, get approvals

- Feasibility Study Tasks:
  - Resolve ground rule and safety issues: dry Centaur in Space Transportation System (STS), no ascent monitoring, governing safety document and agency, single fault tolerance, etc.
  - Design passive heater for N_2H_4 and avionics heating in hangar
  - Determine STS interfacing and control modifications feasibility
  - Conduct active vs passive heating trade
  - Emergency jettison system requirements, concepts and trades
  - Multiple payload carrier: Centaur interface requirements, further concept development
  - Hangar materials, construction, telerobotic arm, and operations
  - Conduct GPS+startracker versus tracking and data relay satellite (TDRS) only, and Centaur versus COP Guidance, Navigation and Control (GNC) trades
  - Conduct transponder trades: advantages versus disadvantages, Centaur versus COP
  - Details of zero-gravity Centaur tanking and draining operation
  - Details of COP requirements and configuration
  - Review communications requirements for entire architecture
  - Define and Design further Centaur-required modifications
  - Define and Design further Space-Station-required modifications (scars)
  - Determine feasible methods for fabrication and installation of required Centaur modifications
  - Determine feasible method for COP construction and operation
  - Determine feasibility of transportation scheduling: STS, complementary expendable launch vehicle (CELV)
  - government-furnished equipment (GFE) availability for TDM program: Centaur/CISS, COP, major subsystems
  - Economic Analysis of Entire Program
  - Generate monthly, midterm, final reports and briefings, get approvals

APPENDIX A

MISSION DESIGN

MISSION CODE:

TDMX2

PAYLOAD ELEMENT NAME:

CENTAUR ACCOMMODATIONS

COUNTRY:

USA

CONTACT:

JOHN W PORTER
GENERAL DYNAMICS SPACE SYSTEMS
PO BOX 85990
SAN DIEGO CA 92138

PHONE:

619 547 7238

STATUS: 4

NASA Space Station Mission Data Base - Form 1

FLIGHTS:

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
EQUIPMENT UP (flights)				2						
EQUIPMENT DOWN (no. of times)					1					
OPERATIONAL DAYS (per flight)				273						
OTV FLIGHTS										

EARLY FLIGHT: ____________

LATE RETURN: ____________

OBJECTIVE:

LINE

1 TO USE A CENTAUR AT THE SPACE STATION TO
DEMONSTRATE AND DEVELOP SYSTEMS.

2 MISSION CONTROL,OPERATIONS AND PROCEDURE
S THAT ARE APPLICABLE TO THE OTV

3 .THIS INCLUDES ACTUAL PAYLOAD HANDLING,M
ATING AND CHECKOUT

4

5

6

7

NASA Space Station Mission Data Base - Form 1 (continued)

JSC 30000 SEC. 5

DESCRIPTION:

LINE

1 A HANGAR TO HOUSE THE CENTAUR AND ITS PA
YLOAD IS TO BE ASSEMBLED ON THE

2 STATION USING EVA METHODS. THE STATION
PROVIDES STRUCTURAL SUPPORT. ELEC

3 TRICAL POWER. SYSTEM MONITORING DATA AND
CONTROL INTERFACE FOR BOTH THE C

4 ENTAUR AND THE PAYLOAD. CREW SERVICES FOR
INTERMITTANT MONITORING, REMOTE

5 BATTERY AND CONTINGENCY EQUIPMENT MAINTE
NANCE VIA TELEROBOTIC ARMS WILL

6 BE REQUIRED. EVA MAINTANCE IS A BACK UP
OPTION. STATION EXTERNAL LIGHTIN

7 G, CREWS AND MRMS FACILITIES ARE REQUIRED
DURING HANGAR ASSEMBLY. MRMS AN

8 D OMV RESOURCES ARE USED TO TRANSFER THE
CENTAUR AND PAYLOAD FROM THE HAN

9 GAR TO AND FROM THE PLATFORM FOR THE SER
VICING TDM AND THE PAYLOAD LAUNC

10 H

11

12

13

14

NASA Space Station Mission Data Base - Form 1 (continued)

TYPE NUMBER: 15

IMPORTANCE OF SPACE STATION: 10

NON-SERVICING OMV FLIGHTS (per year): 1

ADD RESOURCES: 2

RESOURCE REFERENCE: | | | | | | | | |

NASA Space Station Mission Data Base - Form 1 (concluded)

JSC 30000 SEC. 5

ORBIT

MISSION CODE:

ORBIT: 1 (If 1 is selected, skip remainder of Form 2)

APOGEE: ____________km + ____________km / - ____________km TOLERANCE

PERIGEE: ____________km + ____________km / - ____________km TOLERANCE

INCLINATION: ____________deg + ____________deg / - ____________deg TOLERANCE

LOCAL TIME OF EQUATOR CROSSING NODE: ____________hr ____________min

ASCENDING OR DESCENDING: ____________

SPECIAL CONSIDERATIONS (ORBIT):

LINE

1

2

3

4

NASA Space Station Mission Data Base - Form 2

POINTING/ORIENTATION

JSC 30000 SEC. 5

MISSION CODE: ☐☐☐☐☐☐☐☐

POINTING/ORIENTATION: 1 (If 1 is selected, skip remainder of FORM 3)

VIEW DIRECTION: ______

If 4 selected, OTHER: ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

HOURS: ______

TRUTH SITES:

☐☐
☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

POINTING ACCURACY: ______ $\widehat{sec}$

POINTING KNOWLEDGE: ______ $\widehat{sec}$

FIELD OF VIEW: ______ deg

POINTING STABILITY RATE: ______ $\widehat{sec}$ per sec

POINTING STABILITY: ______ $\widehat{sec}$

PLACEMENT: ______ $\widehat{sec}$

SPECIAL CONSIDERATIONS:

LINE	
1	☐☐ ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
2	☐☐ ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
3	☐☐ ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
4	☐☐ ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

NASA Space Station Mission Data Base - Form 3

JSC 30000 SEC. 5

POWER

MISSION CODE: [ ]

POWER: 2

	AC	DC
OPERATING (KW):		2.2
HOURS, PER DAY (OPERATING)		0
VOLTAGE:		28
FREQUENCY:		
PEAK (KW):		3.2
HOURS PER DAY (PEAK)		0
STANDBY POWER (KW)		1.2

SPECIAL CONSIDERATIONS (POWER):

LINE	
1	POWER DURING STORAGE IS SUPPLIED TO THER MOSTATICALY CONTROLLED HEATER EL
2	EMENTS AND TO AVIONIC SYSTEMS FOR INTERM ITTANT CHECKOUT.
3	
4	

THERMAL

MISSION CODE: __________.

THERMAL: 2

	ACTIVE		PASSIVE	
	OPERATIONAL	NON-OPERATIONAL	OPERATIONAL	NON-OPERATIONAL
MIN TEMP (°C)				
MAX TEMP (°C)				
MIN HEAT REJECTION (KW)				
MAX HEAT REJECTION (KW)				

SPECIAL CONSIDERATIONS:

LINE

1 THERMAL CONTROL FROM THE STATION IS NOT
REQUIRED. THE HANGAR MITIGATES T

2 HE EXTERNAL ENVIRONMENT AND HEATER UNIT
MAINTAIN COMPONENT TEMPERATURES

3 ABOVE MINIMUM ALLOWABLE VALUES.

4

NASA Space Station Mission Data Base - Form 5

JSC 30000 SEC. 5

DATA/COMMUNICATIONS

MISSION CODE:

ON-BOARD DATA PROCESSING REQUIRED: 1

If 1 (YES), this DESCRIPTION:

HEALTH CHECKS, TANK PRESSURES, AVIONICS CHECKOUT, DEPLOY MONITORING, C&W

ON-BOARD STORAGE (MBIT): 76.8

STATION DATA REQUIRED:

LINE

1 POSITION, ATTIDUDE, ATTIDUDE RATES, ALTITUDE

2

COMMUNICATION LINKS:

1. From: Station
To: Ground

	Digital Data	Video Data	Voice
a. Generation rate (kbps)	64	10,000	NA
b. Duration (hours)	1	6	
c. Frequency (per day)	1.0	0.1	
d. Delivery time (hours)	1	1	0
e. Security (yes/no)	0	0	
f. Reliability (%)	50%	50%	
g. Interactive (yes/no)	1	0	Yes

2. From: Ground
To: Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)	16	N/A	NA
b. Duration (hours)	1		
c. Frequency (per day)	0.1		
d. Delivery time (hours)	0		0
e. Security (yes/no)	0		
f. Reliability (%)	100%		
g. Interactive (yes/no)	1		Yes

NASA Space Station Mission Data Base - Form 6

3. From: Station
To: Free Flyer

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

4. From: Free Flyer
To: Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

5. From: Station
To: Platform

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

6. From: Platform
To: Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

7. From: Platform
To: Ground

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

NASA Space Station Mission Data Base - Form 6 (continued)

JSC 30000 SEC. 5

8. From: Ground
To: Platform

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

9. From: Station
To: Shuttle

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

10. From: Shuttle
To: Station

	Digital Data	Video Data	Voice
a. Generation rate (kbps)			NA
b. Duration (hours)			
c. Frequency (per day)			
d. Delivery time (hours)			0
e. Security (yes/no)			
f. Reliability (%)			
g. Interactive (yes/no)			Yes

COMMENTS:

LINE

1

2

3

4

NASA Space Station Mission Data Base - Form 6 (concluded)

EQUIPMENT

JSC 30000 SEC. 5

MISSION CODE: ☐☐☐☐☐☐☐☐

MODULE CODE: 1

SHARED FACILITY CODE: 0

(If 1 is selected, list mission codes of sharing missions below:)

☐☐☐☐☐☐☐☐
☐☐☐☐☐☐☐☐
☐☐☐☐☐☐☐☐
☐☐☐☐☐☐☐☐

EQUIPMENT LOCATION:

If equipment location is:	1	2	3	4	5	6	7
	INTERNAL PRESSURIZED	EXTERNAL/ATTACHED PRESSURIZED	UNPRESSURIZED	FREE FLYER (REMOTE)	FREE FLYER (CO-ORBITING)	28.5 DEGREE PLATFORM	SUN SYNC/POLAR PLATFORM
DIMENSIONS (M)			10x10x20				
Length			20				
Width or Dia.			10				
Height (or blank)			5 KG				
VOLUME (M^3)			2000				
PEG DIMENSION (M)							
Length			10				
Width or Dia.			3				
Height (or blank)			5 KG				
PEG VOLUME (M^3)			120				
LAUNCH MASS (KG)			5 KG				
ACCELERATION MAX (g)			—				

ATTACH POINTS: 6

SET UP CODE: 1 2 ____

NASA Space Station Mission Data Base - Form 7

JSC 30000 SEC. 5

HARDWARE DESCRIPTION:

LINE	
1	HANGAR ASSY. IS A DEPLOYABLE TENT LIKE ST
	RUCTURE ASSEMBLED BY EVA AND ATT
2	ACHED TO STATION TRUSS MEMBERS, LOCATION
	SHOULD FACILITATE MRMS AND CREW
3	ACCESS VIA EVA. CENTAUR AND PAYLOAD HANDL
	ING USES MRMS FOR TRANSFER BETWE
4	EN STS, HANGAR AND OMV.

NASA Space Station Mission Data Base - Form 7 (concluded)

MISSION CODE: [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

INITIAL CONSTRUCTION/SET UP: 1 (If 0, skip to DAILY OPERATIONS)

TASK:

EVA ASSEMBLY OF HANGAR AND INSTALLATION OF INTERNAL EQUIPMENT.

PERIOD: 1 days

IVA TOTAL CREW TIME: 15 man-hrs

EVA PRODUCTIVE CREW TIME: 12 man-hrs

SKILLS: (See last page of Form 8 for example)

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1	3						1
2							
3							

DAILY OPERATIONS: 0 (If 0, skip to PERIODIC OPERATIONS)

TASK:

IVA CREW TIME PER DAY: ______ man-hrs

SKILLS:

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1							
2							
3							

PERIODIC OPERATIONS: 1 (If 0, skip to TEARDOWN AND STOW)

TASK:

MOVE CENTAUR TO HANGAR, AND BETWEEN OMV & HANGAR USING MRMS, REPLACE BATT

IVA OCCURRENCE INTERVAL: 30 days

CREW TIME/OCCURRENCE: 12 man-hrs

EVA OCCURRENCE INTERVAL: NA days

PRODUCTIVE CREW TIME/OCCURRENCES: 12 man-hrs

SKILLS:

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1	1						1
2							
3							

TEARDOWN AND STOW: 1 (If 0, skip this section)

TASK:

INSTALL USED BATTERYS, ORUS, & CISS IN STS PAYLOAD BAY FOR EARTH RETURN

PERIOD: 1 days

IVA TOTAL CREW TIME: 15 man-hrs

EVA PRODUCTIVE CREW TIME: TBD man-hrs

SKILLS:

Enter number of skill type/levels required:

SKILL TYPE

SKILL LEVEL	1	2	3	4	5	6	7
1	2						
2							
3							

NASA Space Station Mission Data Base - Form 8 (continued)

COMMENTS:

LINE	
1	SKILLS REQUIRE OPERATION OF MRMS FOR CE
	NTAUR AND PAYLOAD TRANSFER. UNDER
2	STANDING OF CENTAUR AND PAYLOAD SYSTEM
	IS BENEFICIAL DURING SERVICING, C
3	HECKOUT AND ORBITAL DEPLOYMENT OPERATIO
	NS
4	

Typical example of skill type/level matrix input:

Skill Types

1. No Special Skill Required
2. Medical/Biological
3. Physical Sciences
4. Earth and Ocean Sciences
5. Engineering
6. Astronomy
7. Spacecraft Systems

Skill Levels

1. Task Trainable
2. Technician
3. Professional

If two medical/biological professionals are required, put 2 in second column, third row. No more than 6 skill types can be used for a given task.

NASA Space Station Mission Data Base - Form 8 (concluded)

SERVICING

JSC 30000 SEC. 5

MISSION CODE: __________

SERVICING: 1 (If 1 is selected, skip remainder of Form 9)

SERVICE INTERVAL (days): —

CONSUMABLES

TYPE:

BATTERIES, HELIUM, AND CONTINGENCY ORW RE
PLACEMENT

WEIGHT: ________ kg

RETURN: ________ kg

VOLUME UP: ________ m^3

VOLUME DOWN: ________ m^3

POWER: TBD kw

HOURS FOR POWER: TBD hrs

EVA HOURS PER SERVICE: 0 hrs

TYPICAL TASKS (EVA):

IVA HOURS PER SERVICE: 1-4 hrs

LOCATION OF SERVICING: HANGAR

TYPICAL TASKS (IVA):

MRMS PARTS TRANSFER TO HANGAR AND INSTAL
L USING TELEROBOTIC ARMS

SPECIAL CONSIDERATIONS:

LINE	
1	BATTERIES REPLACED PRIOR TO SERVICING TD M AND PAYLOAD LAUNCH
2	HELIUM SUPPLY BOTTLE EXCHANGED ON AS REQ UIRED BASIS
3	ORW REPLACEMENT IS ON AN AS REQUIRED BAS IS
4	EVA IS NOT PLANNED BUT COULD BE USED ON A CONTINGENCY BASIS.

CONFIGURATION CHANGES

JSC 30000 SEC. 5

MISSION CODE:

CONFIGURATION CHANGES: ________(If 1 selected, skip the remainder of Form 10)

INTERVAL: ________days

CHANGE-OUT EQUIPMENT

TYPE:

WEIGHT: ________kg

RETURN: ________kg

VOLUME UP: ________m^3

VOLUME DOWN: ________m^3

POWER: ________kw

HOURS FOR POWER: ________hrs

EVA HOURS PER CHANGE: ________hrs

TYPICAL TASKS (EVA):

IVA HOURS PER CHANGE: ________hrs

LOCATION: ________

TYPICAL TASKS (IVA):

SPECIAL CONSIDERATIONS:

LINE

1

2

3

4

NASA Space Station Mission Data Base - Form 10

JSC 30000 SEC. 5

SPECIAL NOTES

MISSION CODE:

LINE | CONTAMINATION:

1 NOT A FACTOR EXCEPT POSSIBLY FOR PAYLOAD WHICH IS TBD

2

LINE | STRUCTURES:

1 NA

2

LINE | MATERIALS:

1 NA

2

LINE | RADIATION:

1 NA

2

NASA Space Station Mission Data Base - Form 11

LINE **SAFETY:**

1 N A

2

LINE **STORAGE:**

1 N A

2

LINE **OPTICAL WINDOW:**

1 N A

2

LINE **SCIENTIFIC AIRLOCK:**

1 N A

2

NASA Space Station Mission Data Base - Form 11 (continued)

JSC 30000 SEC. 5

TETHER:

LINE	
1	HANGAR COMPONENTS, CENTAUR AND PAYLOADS REQUIRE TETHERS DURING TRANSFER
2	

VACUUM VENTING:

LINE	
1	NA
2	

OTHER:

LINE	
1	NA
2	
3	
4	

NASA Space Station Mission Data Base - Form 11 (concluded)

APPENDIX B
REFERENCES

B.1 GENERAL

A Proposal for Turnaround Operations Analysis for OTV, Volume 1, "Technical Proposal/Study Plan," DR-1, GDSS, PIN-86-P-S0012, September 1986.

"A Space-Based OTV Operating From the Space Station," AIAA 86-2325, R.J. Gorski, GDSS, Reno, Nevada, 3-5 September 1986.

Findings of the Critical Evaluation Task Force (CETF), NASA LeRC, 30 September 1986.

Fundamentals of Astrodynamics, R. Bate, D. Mueller, J. White, Department of Astronautics and Computer Science, USAF Academy, 1971.

NASA Evolutionary Centaur Report to Director of LeRC Space Flight Systems, J. Porter, GDSS, 4 October 1985.

OMV Preliminary Design Document, Book 1, A.M. Frew, TRW, NAS8-36114, 30 August 1985.

OTV Servicing Study, NASA Contract NAS8-35039, J. Maloney, GDSS, 1984.

Orbital Transfer Vehicle Concept Definition and System Analysis Study: Phase II Final Review at MSFC, Executive Summary, GDSS, 2 July 1986.

Orbital Transfer Vehicle Concept Definition and Systems Analysis Study: Final Review, MSFC, Volume 5, OTV Technology and Demonstrations, J. Porter, GDSS, 20-23 August 1985.

Orbital Transfer Vehicle Concept Definition and Systems Analysis Study: Final Report, Volume 1, Executive Summary, GDSS-SP-86-011, GDSS, February 1986.

STS/Centaur Operations at the Space Station: Technical Proposal, PIN-86-P-0017S, John Porter, GDSS, 31 March 1986.

Shuttle/Centaur Delta Phase III Safety Review Data Package, Volume 1, Ground Technical Description, GDSS-SSC-85-007, GDSS, December 1985.

Ibid, Volume 2, Airborne Technical Description.

Shuttle/Centaur G-Prime Configuration, Performance, and Weight Status Report, GDC SP-83-001-13, GDSS, March 1986.

Technical Transmittals From Robert Corban, NASA LeRC, 5 November 1986.

B.2 JSC 30000 APPLICABLE REFERENCES

Section 4, 2.2.7	On-orbit traffic management. For all proximity operations, the Space Station must be able to actively monitor and assume control of any active vehicle.
Section 5, 3.2.5	Space Station support of launch and deployment. All classes of vehicles may be brought to the Station with facilities provided for servicing.
Section 5, 3.2.6	Remove maintenance, servicing, checkout, and retrieval. Remote platforms will be maintained via orbital maneuvering vehicle (OMV) or Space Transportation System (STS) activity.
Section 6, 3.2.6	Payload servicing. Payload and free-flyer servicing and refueling accommodations at servicing facility.
Section 6, 3.2.18	Space Station orbital transfer vehicle (OTV) accommodations. Station will have scars to readily allow addition of OTV accommodations, including hardware and distributed subsystems.
Section 7.3	Preliminary Design Review Document (PDRD) continues to show OTV based at Space Station.
Section 6, 3.1.A	Two co-orbiting platforms (COPs), USA and ESA, are included in Space Station initial operational capability (IOC) content definition.
Section 6, 3.2.17.A	USA platform will accommodate facility-class technology payloads.
Section 3, 3.4.3	COPs shall be designed to be transported to and from the STS or Space Station using an OMV and/or their own propulsion systems.
Section 3, 2.2.2.2.1.2.1	COPs shall provide means for docking and berthing with the Space Station, Orbiter, and OMV.

B.2.1 ACCOMMODATIONS. Several references in JSC 30000 are applicable to this TDM. In Section 6, paragraph 3.2.6, payload servicing accommodations at the servicing facility are covered. Section 6, paragraph 3.2.18 addresses Space Station scars to accommodate OTV-required hardware and distributed subsystems, many of which could be used to reduce the scarring impact of this TDM.

B.2.2 CRYOGENIC PROPELLANT TRANSFER. Pertinent JSC 30000 statements regarding Space Station scarring for the OTV and regarding the COPs are shown in Table C-1. These requirements formed the basis for the COP design and the propellant resupply TDM element developed for this program.

Table B-1. Pertinent JSC 30000 References

Section	Paragraph	Statement
6	3.1.A	Two COPs, USA and ESA, are included in the Space Station IOC content definition
6	3.2.17.A	USA platform will accommodate facility-class technology payloads
3	3.4.3	COPs shall be designed to be transported to and from the Shuttle or Space Station using the OMV and/or their own propulsion systems
3	2.2.2.2.1.2.1	COPs shall provide means for docking or berthing with the Space Station, Orbiter, and OMV

B.2.3 PAYLOAD INTEGRATION. Several references in JSC 30000 are applicable to this TDM. In Section 4, paragraph 3.2.2, platform on-orbit payload operations are addressed. In Section 5, paragraph 3.2.5, payload checkout, integration, and deployment capabilities are covered, and in Section 6, paragraph 3.2.6, payload servicing accommodations at the servicing facility are discussed.

B.2.4 DEPLOYMENT OPERATION. Several sections in JSC 30000 are applicable to this TDM. In Section 4, paragraph 2.2.7, requirements for proximity operations around the Space Station and on-orbit traffic management are covered. Section 5, paragraph 3.2.5 addresses Space Station support of launch and deployment of all classes of vehicles.

End of Document