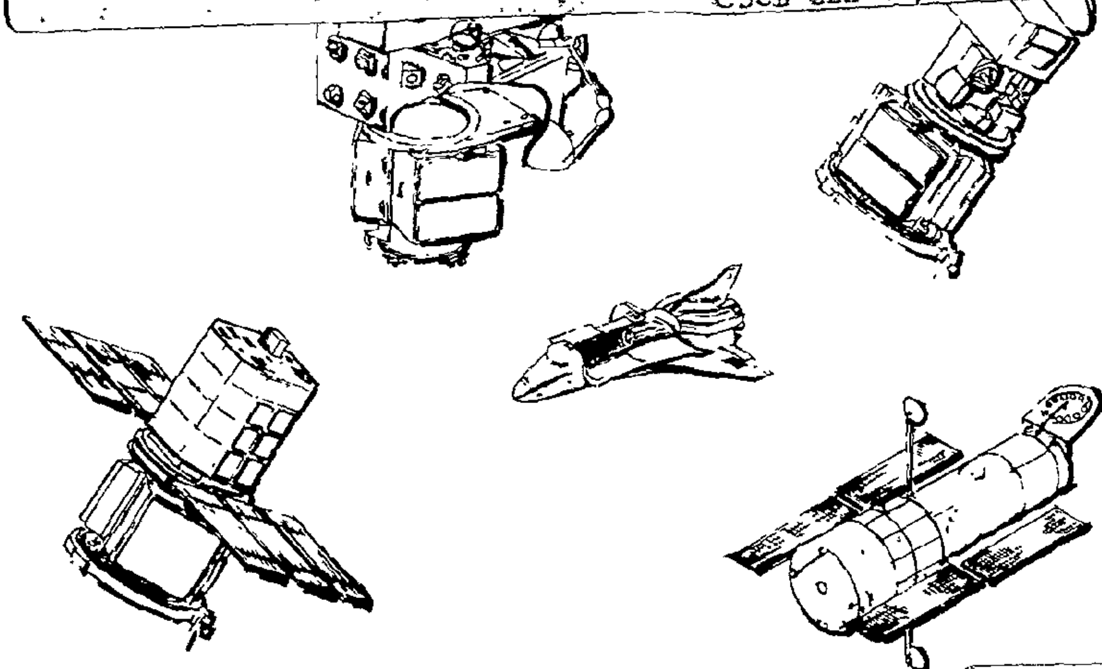
SATELLITE SERVICES SYSTEM ANALYSIS STUDY

volume 4 - service equipment concepts

(NASA-CR-167612) SATELLITE SERVICES SYSTEM ANALYSIS STUDY. VOLUME 4: SERVICE EQUIPMENT CONCEPTS Final Report (Grumman Aerospace Corp.) 112 p HC A06/MF A01 CSCL 22A G3/16 N82-27349 Unclas 25280



GRUMMAN AEROSPACE CORPORATION

147

SATELLITE SERVICES SYSTEM ANALYSIS STUDY

volume 4 - service equipment concepts

prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

by

Grumman Aerospace Corporation
Bethpage, N.Y. 11714

NAS9-16120
DRL T-1600
MA-834T
LINE ITEM 4
REPORT CSS-SSS-RP009

August 1981

ACRONYMS

Abbreviations and acronyms used frequently throughout the Satellite Services System Analysis Study (SSSAS) are defined as follows:

ACS - Attitude Control System

AFD - Aft Flight Deck

ASM - All Sky Monitor

AXAF - Advanced X-Ray Astrophysics Facility

CCTV - Closed Circuit Television

C & DH - Command & Data Handling

C & DL - Command & Data Link

C/O - Checkout

DDT&E - Design, Development, Test & Evaluation

DoD - Department of Defense

DOF - Degrees of Freedom

EMU - Extra-Vehicular Mobility Unit

EVA - Extra Vehicular Activity

FSS - Flight Support System

GAC - Grumman Aerospace Corporation

GEO - Geosynchronous Earth Orbit

GRAVSAT - Earth Gravity Field Survey Mission

GRO - Gamma Ray Observatory

GSE - Ground Support Equipment

HEAO - High Energy Astronomy Observatory

HPA - Handling & Positioning Aid

IR - Infrared

IRAD - Independent Research and Development

IUS - Inertial Upper Stage

IVA - Internal Vehicular Activity

JSC - Johnson Space Center

KSC - Kennedy Space Center

LAPC - Large Area Proportional Counter

LASS - Large Amplitude Space Simulator

LASSII - Low Altitude Satellite Studies of Ionospheric Irregularities

LEO - Low Earth Orbit

LOS - Line-of-Sight

MDF - Manipulator Development Facility

MFR - Manipulator Foot Restraint

MMS - Multimission Modular Spacecraft

MMU - Manned Maneuvering Unit

MRV - Manned Reconnaissance Vehicle

MTV - Maneuverable Television

NOSS - National Oceanic Satellite System

OAO - Orbiting Astronomical Observatory

OBC - Onboard Checkout

OCC - Operations Control Center

OCP - Open Cherry Picker

OMS - Orbital Maneuvering System

PAM A - Payload Assist Module (type) A

PAM D - Payload Assist Module (type) D

PIDA - Payload Installation & Deployment Aid

PM I/II - MMS Propulsion Module I & II

POCC - Payload Operations Control Center

CONTENTS

Preceding page blank

CONTENTS (contd)

ILLUSTRATIONS

ILLUSTRATIONS (Contd)

POM - Proximity Operations Module

RCS - Reaction Control System

RMS - Remote Manipulating System

ROM - Rough Order of Magnitude

S/C - Spacecraft

SE&I - System Engineering & Integration

SMM - Solar Maximum Mission

SRM - Solid Rocket Motor

SSS - Satellite Services System

SSSAS - Satellite Services System Analysis Study

S/S - Subsystem

S/SUM - Satellite and Services User Model

STE - Special Test Equipment

STS - Space Transportation System

TDRS(S) - Tracking & Data Relay Satellite (System)

TMS - Teleoperator Maneuvering System

TV - Television

UARS - Upper Atmospheric Research Satellite

UV - Ultraviolet

VSS - Versatile Service Stage

WBS - Work Breakdown Structure

WETF - Weightless Environment Training Facility

WIF - Water Immersion Facility

WRU - Work Restraint Unit

XTE - X-Ray Timing Explorer

FOREWORD

This study was conducted for the Lyndon B. Johnson Space Center and directed by Contracting Officer's Representatives (COR), Mssrs. Reuben Taylor and Gordon Rysavy. Grumman Aerospace Corporation's study manager was Mr. John Mockovciak Jr.

This final report is presented in seven volumes:

Volume 1 - Executive Summary

Volume 2 - Satellite and Services User Model

Volume 2A - Satellites and Services User Model - Appendix

Volume 3 - Service Equipment Requirements

Volume 3A - Service Equipment Requirements - Appendix

Volume 4 - Service Equipment Concepts

Volume 5 - Programmatics

Volume 4 contains the analysis and conceptual design efforts conducted to define the complement of satellite service equipment.

Preceding page blank

1 — Methodology

1 - METHODOLOGY

The approach used to develop service equipment concepts is illustrated in Fig. 1-1. This process was initiated using inputs from selected reference satellites and Level 1 On-Orbit Operational Scenarios (Refer to Volumes 3 & 3A). The operational scenarios identified generic equipment needs for deployment, revisit, and earth return service mission events. Both nominal and contingency situations were considered.

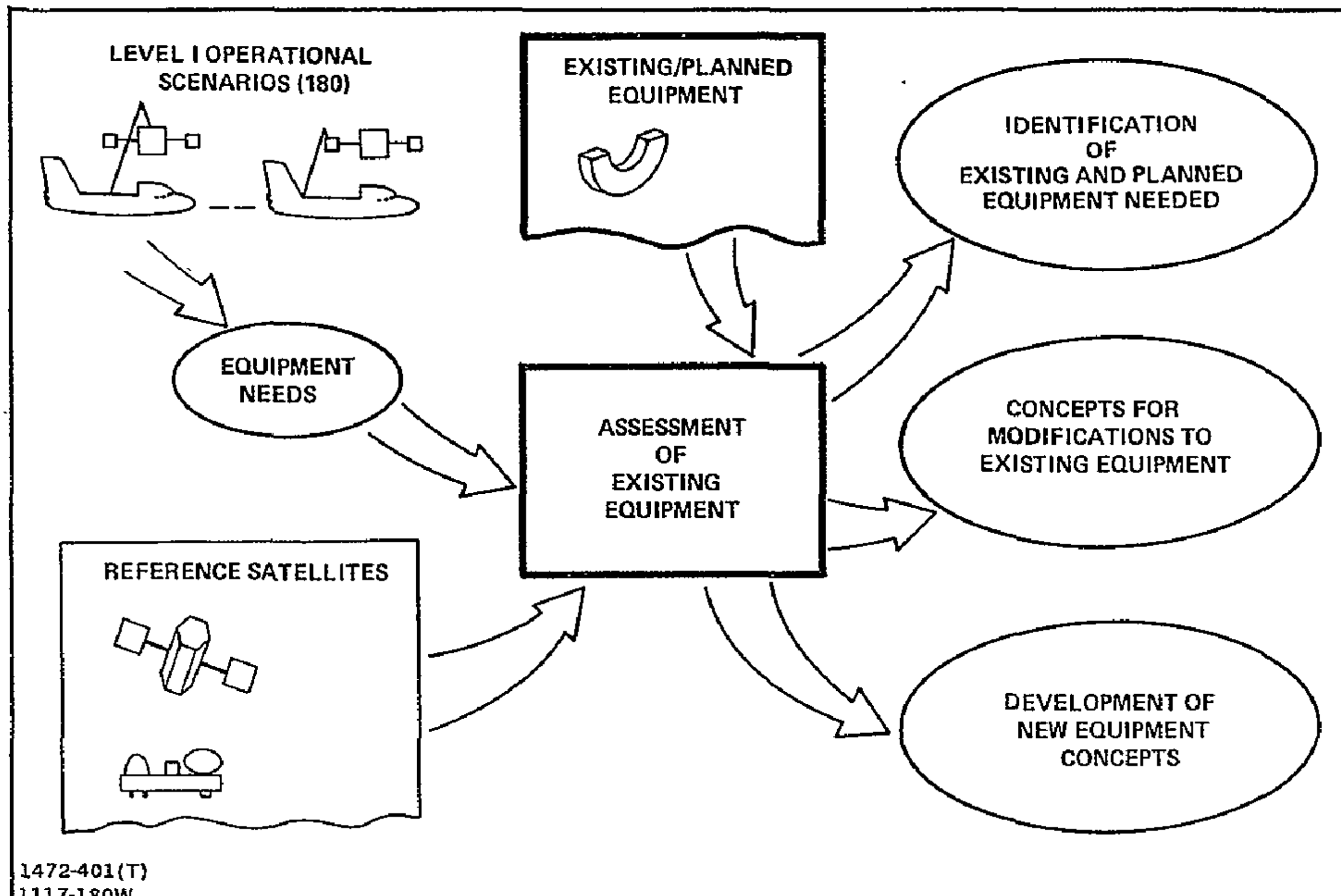


Fig. 1-1 Methodology

A list of existing equipment or equipment under development/study was compiled to relate equipment concepts that may be available in the time frame of interest; the list is documented in Appendix A of this volume. An assessment was made to evaluate the acceptability of this existing/planned equipment to satisfy the satellite service equipment needs identified in the Level 1 On-Orbit Operations Scenarios. Reference satellites representative of a class of satellites were used in the evaluation process. Where existing/planned equipment satisfy these operational needs, they were retained in the service equipment complement. Where existing/planned equipment required modification, or where new equipment items were required, concepts were developed to satisfy the operational needs.

Figure 1-2 presents a summary of the status of service equipment identified in the 180 on-orbit operations scenarios (initial launch, revisit, and earth return) considered in the study. A total of 27 service equipment items could satisfy all equipment needs of the scenarios considered. Of the 27 equipment items identified, their status is as follows:

Existing	6
Under Development/Study	5
Modifications	3
New	12*
Unique	1
Total	27

(*Four are optional)

In Figure 1-2, equipment identified with connecting lines denotes equipment needs that could be satisfied by single units of service hardware adapted with appropriate kits to perform the needed service functions.

Service equipment identified previously can be conveniently grouped within the following nominal satellite service operations:

- Payload Deployment
- Close Proximity Retrieval
- On-Orbit Servicing
- Backup/Contingency
- Delivery/Retrieval of High Energy Payloads (Leo/Propulsion Class)
- Earth Return
- [illegible]

These operations encompass all on-orbit service functions considered in the 180 service scenarios. Subsequent sections of this report illustrate service equipment [illegible] service operations.

	EXISTS (5)	UNDER DEV OR STUDY (6)	MODIF (3)	NEW (12)	UNIQUE (1)
SUPPORT STRUCTURE					
• RETENTION STRUCTURES	●				
• SPECIAL RETENTION STRUCTURE					●
ON-ORBIT EQUIPMENT					
• REMOTE MANIPULATOR SYSTEM (RMS)	●				
• TILT TABLE (FSS, IUS, PAM-A)	●				
• OPEN CHERRY PICKER (OCP) – TILT TABLE WORK PLATFORM				●	
• OPEN CHERRY PICKER (OCP) – OCP/RMS		●			
• MANIPULATOR FOOT RESTRAINT/RMS		●			
• PAYLOAD INSTALLATION/DEPLOYMENT AID (PIDA)		●			
• HANDLING & POSITIONING AID (HPA)		●			
• SPIN TABLE (PAM-A, PAM-D)	●				
• EQUIPMENT STORAGE – ON-ORBIT SUPPORT				●	
• EQUIPMENT STORAGE – EARTH RETURN					●
• FLUID TRANSFER SYSTEM				●	
• NON-CONTAMINATING ATT CONTR SYS				●	
• AFT FLT DECK CONTR/DISPL – W/RMS CONTROL	●				
• AFT FLT DECK CONTR/DISPL – W/STD SAT C/O			●		
• AFT FLT DECK CONTR/DISPL – W/CLOSE PROX CONTR				●	
FREE-FLIGHT SYSTEMS					
• MANEUVERABLE TELEVISION (MTV)		●			
• PROXIMITY OPS MODULE – MTV ADAPTATION				●	
• PROXIMITY OPS MODULE – MANNED VERSION				●	
• MANNED MANEUV UNIT/WORK RESTRAINT UNIT (MMU/WRU)	● (MMU)				
– W/END EFFECTOR			●		
– W/STABILIZER			●		
– W/PAYLOAD HNDLG			●		
– PROX OPS MODULE			●		
• VERSATILE SERVICE STAGE (VSS) – W/DELIVERY, RETRIEVAL RENDEZ, DOCKING		●			
– W/END EFFECTOR KIT		●			
– W/DEBRIS CAPTURE KIT		●			
OPTIONAL EQUIPMENT					
• SUN SHIELD				●	
• ORBITAL STORAGE				●	
• ATTITUDE TRANSFER PKG				●	
• LIGHTING ENHANCEMENT				●	
ADVANCED CAPABILITIES					
• DEXTEROUS MANIPULATORS – W/RMS				●	
• DEXTEROUS MANIPULATORS – W/HPA				●	
TOOLS					
• HANDLING/EQUIPMENT REMOVAL		●			

1472-402(T)

Fig. 1-2 Service Equipment Status

2 — Payload Deployment Equipment

2 – Payload Deployme

2 - PAYLOAD DEPLOYMENT EQUIPMENT

Satellite service equipment items associated with payload deployment operations involve the following:

- Retention Structures
- Remote Manipulator System (RMS)
- Tilt Tables
- Payload Installation/Deployment Aid (PIDA)
- Handling & Positioning Aid (HPA)
- Spin Tables
- Aft Flight Deck Controls/Displays.

Subsequent sections will discuss and illustrate the service equipment concepts.

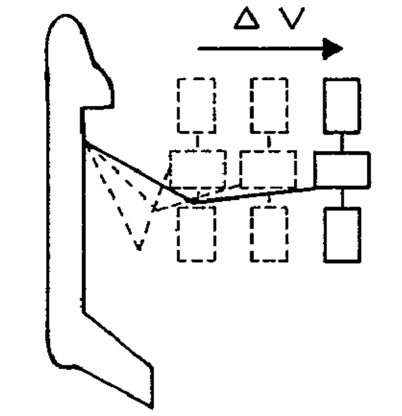
2.1 PAYLOAD SEPARATION

As part of nominal satellite deployment operations, satellites must be separated from the Orbiter with a relative velocity that provides satisfactory separation distances for subsequent satellite operations. These separation distances vary, depending primarily upon the satellite's final destination. For example, satellites deployed by the Orbiter at their operational mission altitude (direct delivery satellites) require separation maneuvers that allow the satellite to remain within reasonable proximity to the Orbiter during initial operation (up to 24 hours), and thereafter to maintain a safe separation distance during the Orbiter's on-orbit stay time. This requirement suggests a satellite separation maneuver that enables the satellite to slowly drift away from the Orbiter, so as not to require large Orbiter maneuver requirements in the event it is called upon to revisit or retrieve the satellite.

On the other hand, satellites attached to propulsion stages and destined for higher LEO orbits, or geosynchronous orbit, require separation maneuvers that will provide Orbiter with safe separation distance from propulsion plume contamination, or propulsion system malfunctions such as catastrophic explosions. Because these propulsion system maneuvers are usually performed at fixed times after separation (e.g., 45 minutes for GEO solid upper stage firings), the Orbiter may be required to maneuver after payload separation to achieve the required separation distance.

To help in understanding payload separation characteristics and the capabilities of the Orbiter to provide these functions, an analysis was performed of relative payload-Orbiter separation trajectories. Techniques for executing separation maneuvers include stored energy release mechanisms (such as spring loaded devices) and use of the RMS.

Although the RMS snare end effector is designed to release a satellite with zero velocity relative to the Orbiter, it may be possible to impart a separation impulse with the RMS. Figure 2-1 illustrates a potential "push away" operation using the RMS. During this study, Grumman requested SPAR Aerospace (the RMS contractor) to investigate the prospects for this separation maneuver. Illustrated in Fig. 2-2 are simulation results provided by SPAR that indicate that achievable velocities could vary up to about one ft/sec, as a function of satellite mass.



PROVIDING PAYLOADS WITH
RELATIVE SEPARATION VELOCITIES
1472-403(T) 0247-260P

Fig. 2-1 RMS — Potential Payload Separation

Figure 2-3 shows relative payload/Orbiter separation trajectories as viewed from a local vertical coordinate system centered on the Orbiter. In this example, the separation ΔV is applied in an orbit posigrade direction (V-bar) causing the payload to move upward and aft, and separating further from the Orbiter during each full orbit. Shown in the figure are separation trajectories for Δ Vs of one and two ft/sec for one orbital period. Figure 2-4 shows separation with 6 ft/sec Δ V, which is characteristic of

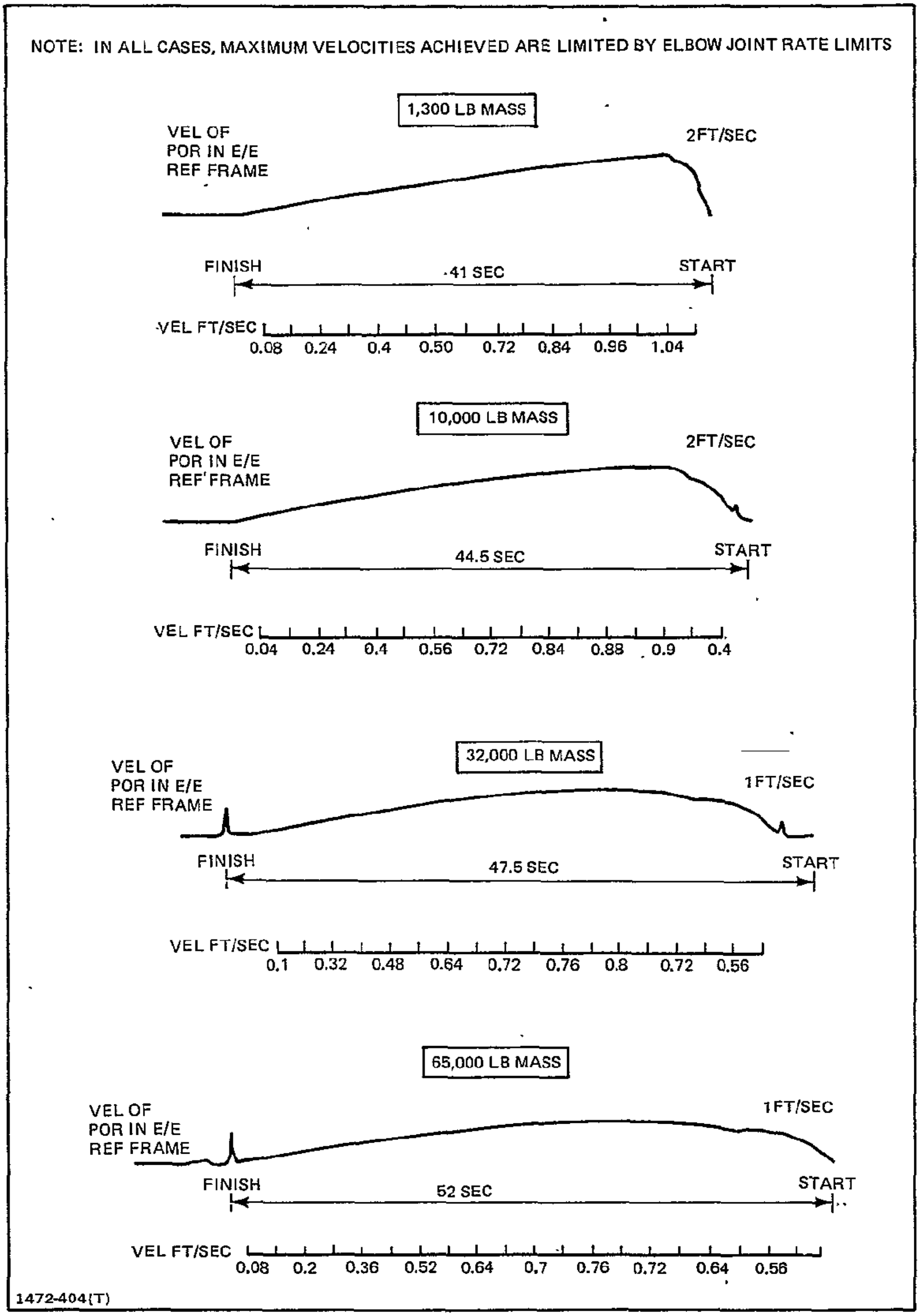


Fig. 2-2 RMS Release Velocities for Different Mass Payloads

ORIGINAL PAGE IS
OF POOR QUALITY

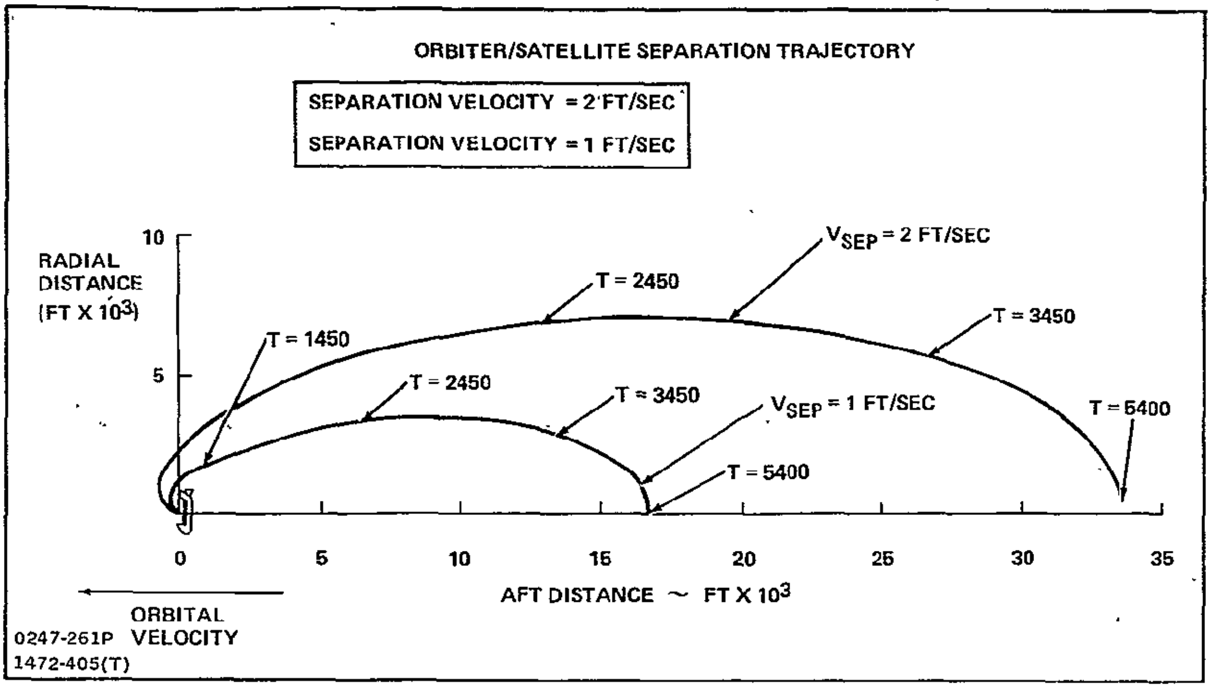


Fig. 2-3 Orbiter/Satellite Separation Trajectory — Separation Forward in Direction of Velocity Vector

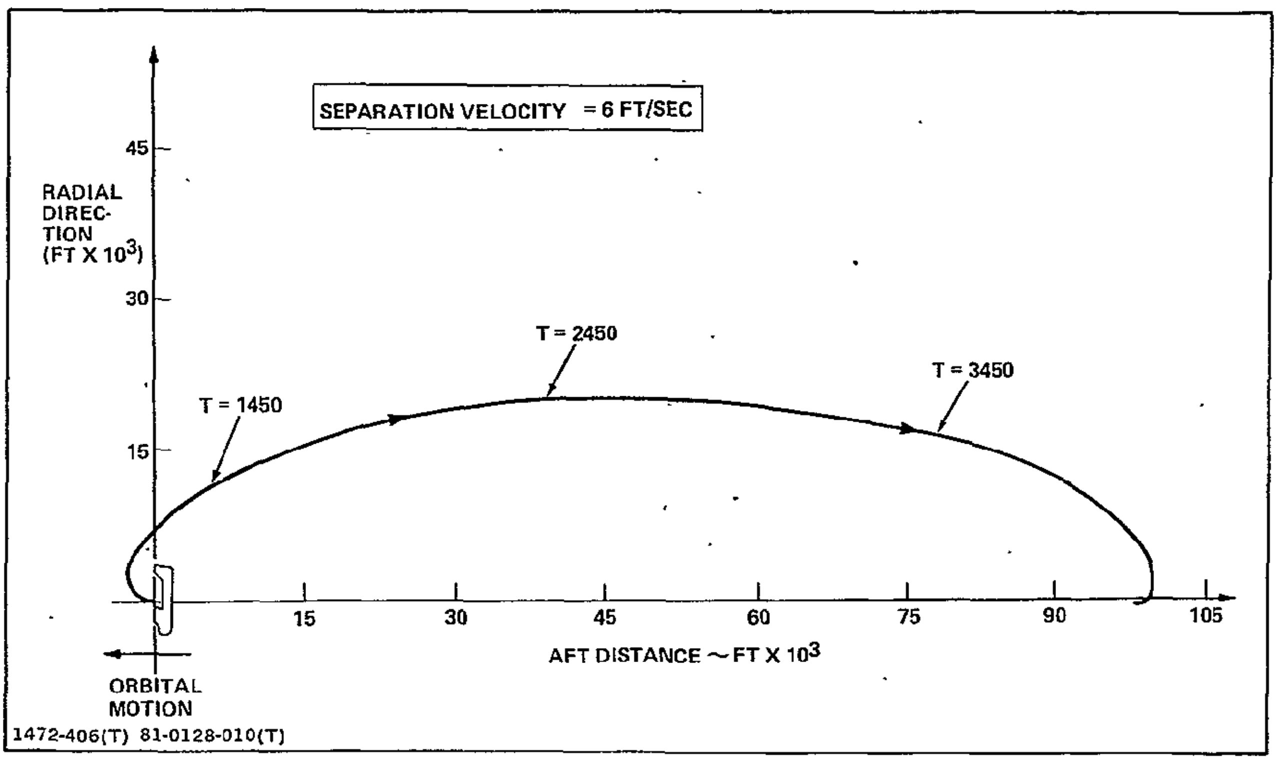


Fig. 2-4 Orbiter/Satellite Separation Trajectory — Separation Forward in Direction of Velocity Vector

separation velocities for solid propellant stages. The one ft/sec trajectory is representative of an RMS separation maneuver whereas the two ft/sec trajectory is typical of separation with stored energy release mechanisms.

Both trajectories satisfy the minimum safe separation distance within 45 minutes. Retrograde separation maneuvers (i.e., ΔV applied opposite to the velocity vector) would result in similar shaped trajectories, except that the payload would move below and in front of the Orbiter.

Figures 2-5 and 2-6 show relative payload/Orbiter separation trajectories for Δ Vs applied along the Orbiter radius vector (toward earth) over one orbital period. For these radially-applied separation maneuvers, the payload separates over one-half an orbit and then returns to the immediate vicinity of the Orbiter. These separation trajectories may be used if subsequent payload/Orbiter maneuvers are initiated within one-half an orbital period.

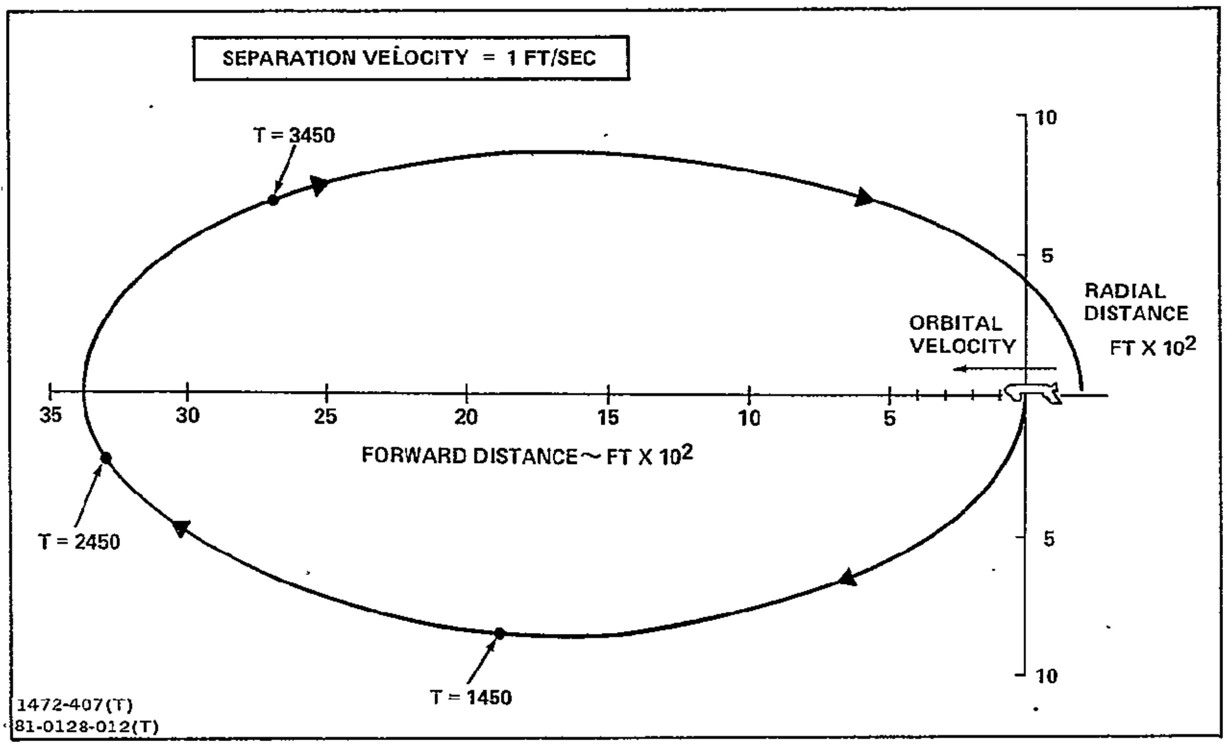


Fig. 2-5 Orbiter/Satellite Separation Trajectory — Separation Radially Down

ORIGINAL PAGE IS
OF POOR QUALITY

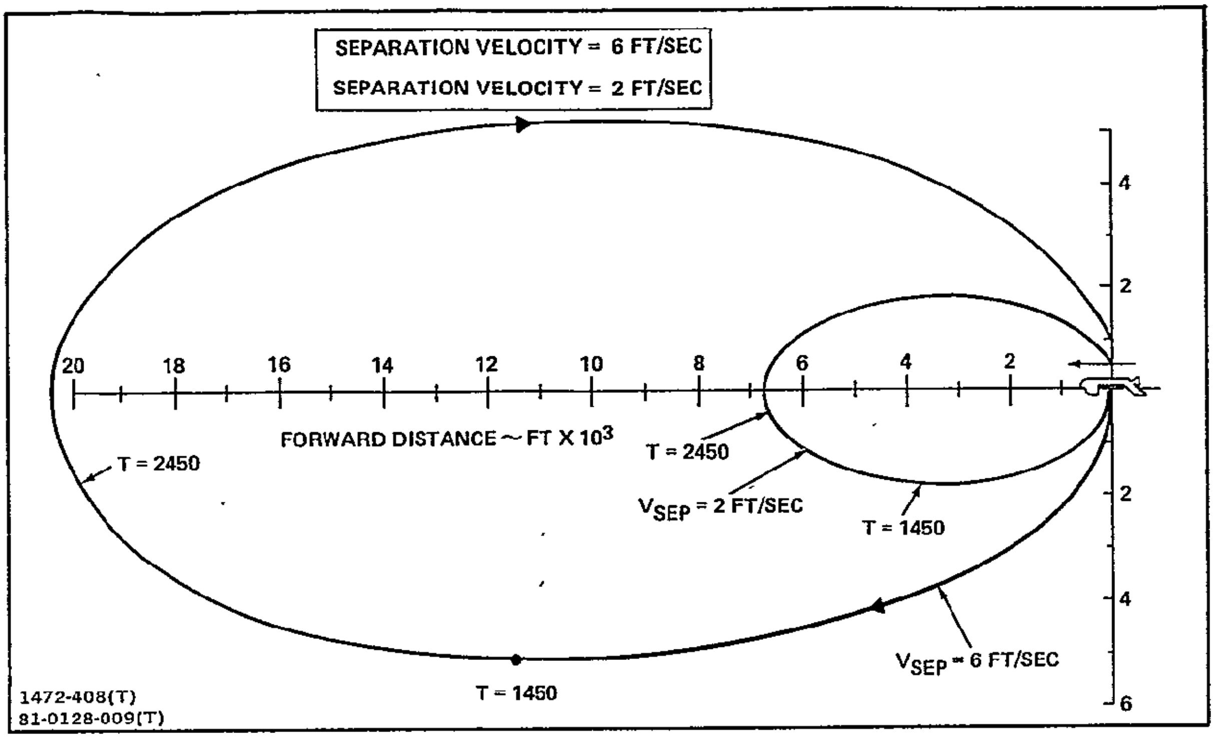


Fig. 2-6 Orbiter/Satellite Separation Trajectory — Separation Radially Down

Radially upward separation trajectories provide similar separation characteristics except with the payload separating upward and aft of the Orbiter over one-half the orbit, and returning to the Orbiter over the second half of the orbit.

2.2 RETENTION STRUCTURES

Three types of retention structures are applicable and are illustrated in Fig. 2-7. They are:

- Flight Support System (FSS) - adaptable to MMS-Type payloads and/or those that require some form of supplementary structural support in the payload bay
- Integral - satellite is sufficiently large to enable direct attachment to the Orbiter's longeron and keel fitting tiedowns. This form of integral retention structure will likely become more prominent since the minimization of Shuttle user charges favors payload shapes that occupy minimum lengths of the payload bay
- Pallet mounted - compatible with small sortie-type payloads that can be flown in the immediate vicinity of the Orbiter, or positioned outside the Orbiter payload bay on the end of the RMS and reberthed to the pallet for earth return.

ORIGINAL PAGE IS
OF POOR QUALITY

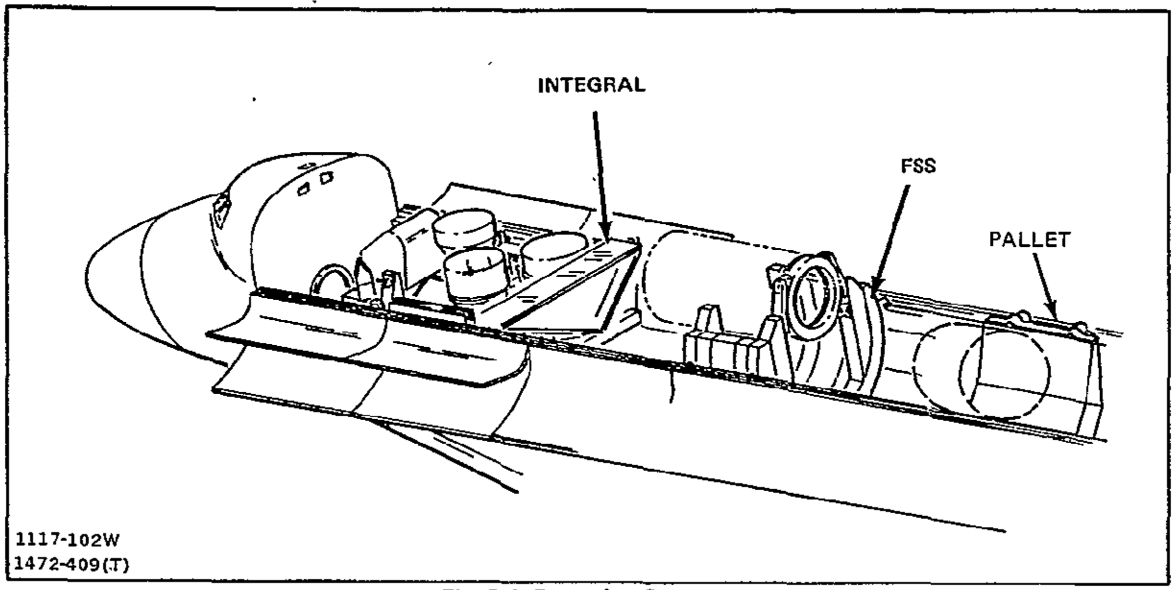


Fig. 2-7 Retention Structures

The FSS consists of three cradles (A, B, and A') that can be used individually, or as an integrated set, and can accommodate both vertically or horizontally-mounted satellites. Although the baseline FSS represents a versatile retention structure that can be readily adapted to a large number of future satellite users, an advanced version offering additional benefits is currently under study. The advanced version is a light weight system made of composite materials.

Figure 2-8 illustrates a UARS packaged within the FSS. The total mass of the satellite + (baseline) FSS is over 15,500 pounds. Since length and weight cost factors are used to determine Shuttle launch costs for the UARS-FSS launch configuration, it is clear that system weight is the dominant criteria for this example. A light-weight FSS, therefore, would reduce the weight factor and offer significantly lower launch costs to many FSS system users.

2.3 REMOTE MANIPULATOR SYSTEM (RMS)

The nominal capabilities of the RMS are shown in Fig. 2-9. Of particular interest to a satellite user are the standard RMS elements: the snare end effector and its compatible grapple fixture. These elements have been designed to release a satellite with essentially no differential velocity during deployment. Note, however, that our operational

ORIGINAL PAGE IS
OF POOR QUALITY

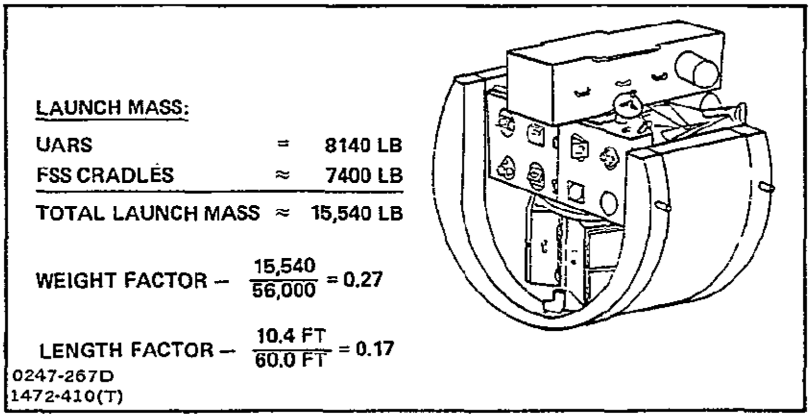


Fig. 2-8 Light Weight FSS (Composite)

scenarios call for satellites to be released by the RMS with a ΔV (of about 1 ft/sec), identifying a service capability need for which the RMS has not been nominally designed.

As discussed previously, however, Grumman requested that SPAR Aerospace investigate RMS potential for "tossing" a satellite with a ΔV during deployment. Preliminary conclusions indicate that ΔVs from 0.1 ft/sec to approximately 1 ft/sec might be achievable, depending upon satellite mass.

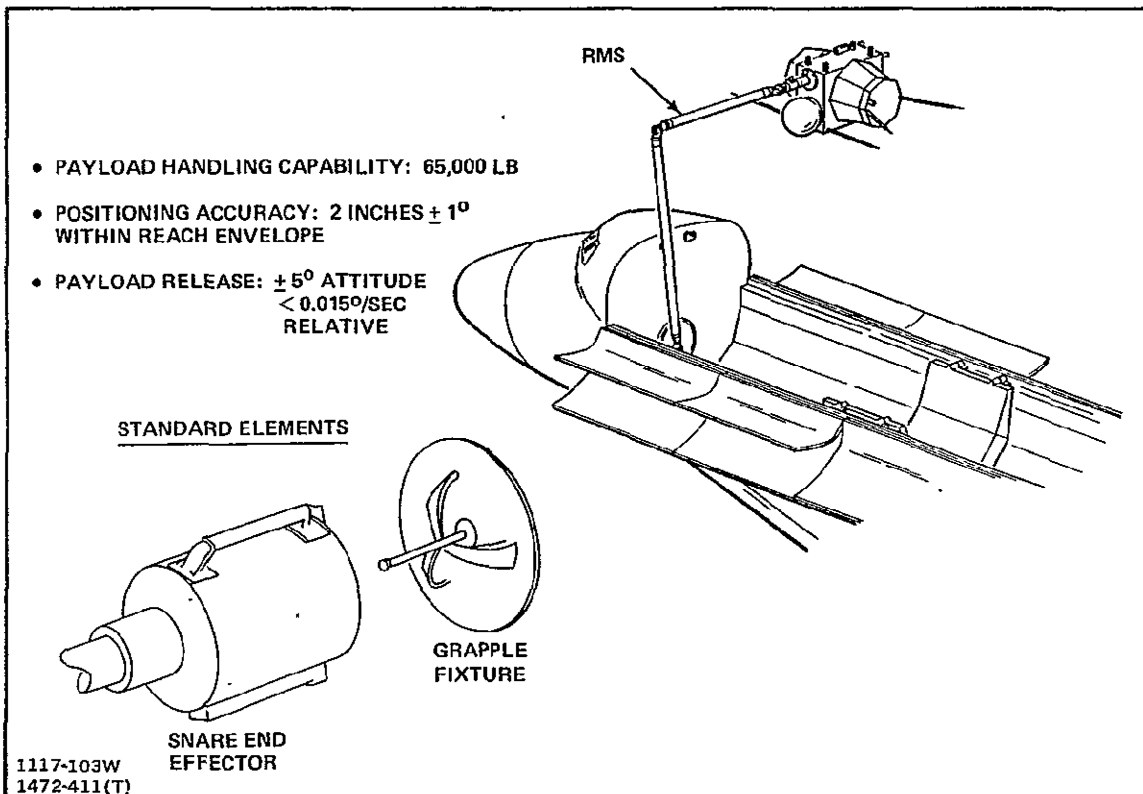


Fig. 2-9 Remote Manipulator System (RMS)

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2-10 shows the RMS deployment of dual Gravsat-A satellites. The cradle structure, which serves as the satellite retention system during Orbiter boost, is deployed from the payload bay and the separation ΔV is provided by the cradle structure. The two satellites are separated from the cradle in the same orbit at a separation distance of 100 to 300 km.

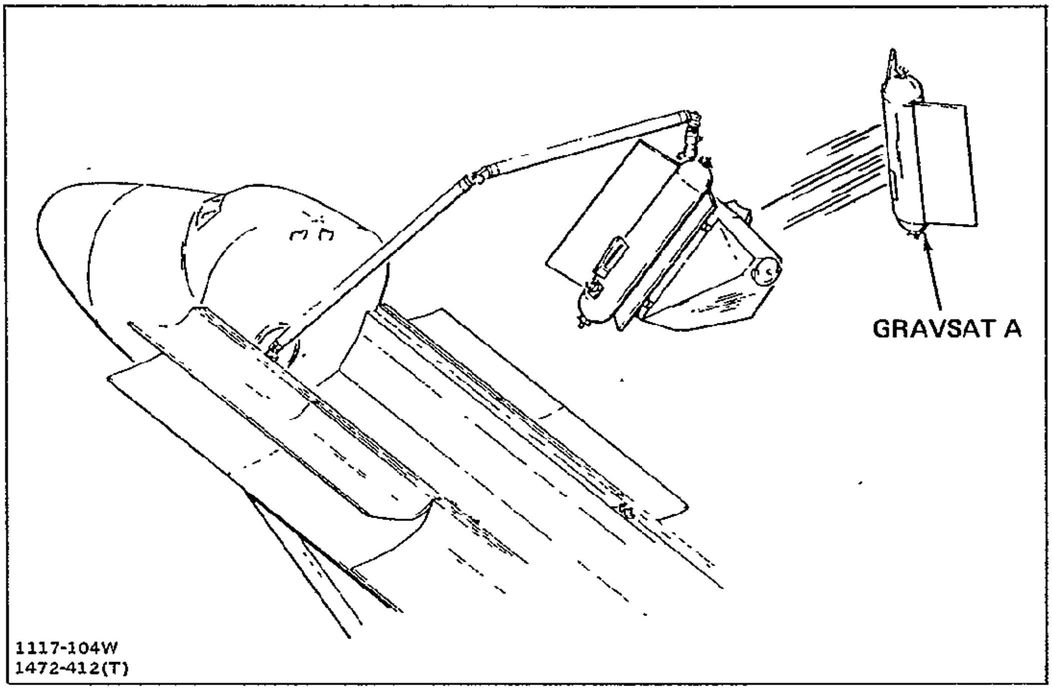


Fig. 2-10 RMS — Payload Deployment

During RMS operation, constraints are imposed upon on-orbit Orbiter control (see Fig. 2-11). Present planning forbids any RCS firing when the RMS is moving, with or without a load. Primary RCS operation is permitted for a stationary RMS with payloads less than 32,000 lb, but only using minimum impulse firing. These restrictions place the control burden on the nonredundant Vernier RCS for operations with a stationary RMS.

2.4 TILT TABLES

Two types of tilt tables are presently available in the satellite service inventory:

- Flight Support System (FSS) Adaptation
- Inertial Upper Stage (IUS) Adaptation

The FSS adaptation utilizes cradle A' and has the following features:

- Rotates payloads to upright position
- Provides interim tilt positions

RMS			RCS PRIMARY	RCS VERNIER
STATIONARY	UNLOADED		MIN IMPULSE ONLY*	OK
	LOADED	<32K	MIN IMPULSE ONLY*	OK
		>32K		OK
MOVING	UNLOADED		FORBIDDEN**	
	LOADED			

0247-263P
1472-413(T)

* 80 MILLISEC PULSE
**FREE DRIFT MODE

Fig. 2-11 Orbiter Control — RMS Operations Constraints

- Provides full 360° roll capability
- Utilizes a universal Berthing/Umbilical System
- Provides signal and power interfaces with satellite.

Figure 2-12 illustrates the FSS cradle A' with the Berthing and Positioning System Assembly adapted to the AXAF reference satellite. The Berthing and Positioning System is used to raise the AXAF clear of the payload bay for subsequent checkout and deployment operations. For this application, a modification is needed to the Tilt Table to align the centerline of the AXAF to that of the Berthing and Positioning System. To pick up cradle A' and the berthing platform, an extension structure which allows the attachment points of the berthing platform to swing to a lower position on the cradle A' would appear adequate.

The Inertial Upper Stage, which is currently under development, comes equipped with forward and aft retention frames to retain the satellites/IUS to the Orbiter payload bay. Included within the aft frame is a tilt table to raise the payload/IUS out of the payload bay (see Figure 2-13). A stored energy release system is also included to provide separation ΔV. All IUS satellite users will be compatible with this system.

2.5 PAYLOAD INSTALLATION & DEPLOYMENT AID (PIDA)

The PIDA, a mechanism that would be of benefit to the large satellite user class, is illustrated in Fig. 2-14. Currently under development at NASA/JSC, the mechanism provides automatic deployment and stowing of satellites having minimum clearance envelopes with the Orbiter payload bay. The PIDA has the following features:

- Moves payloads between stowed and deployed positions automatically, without using the RMS

ORIGINAL PAGE IS
OF POOR QUALITY

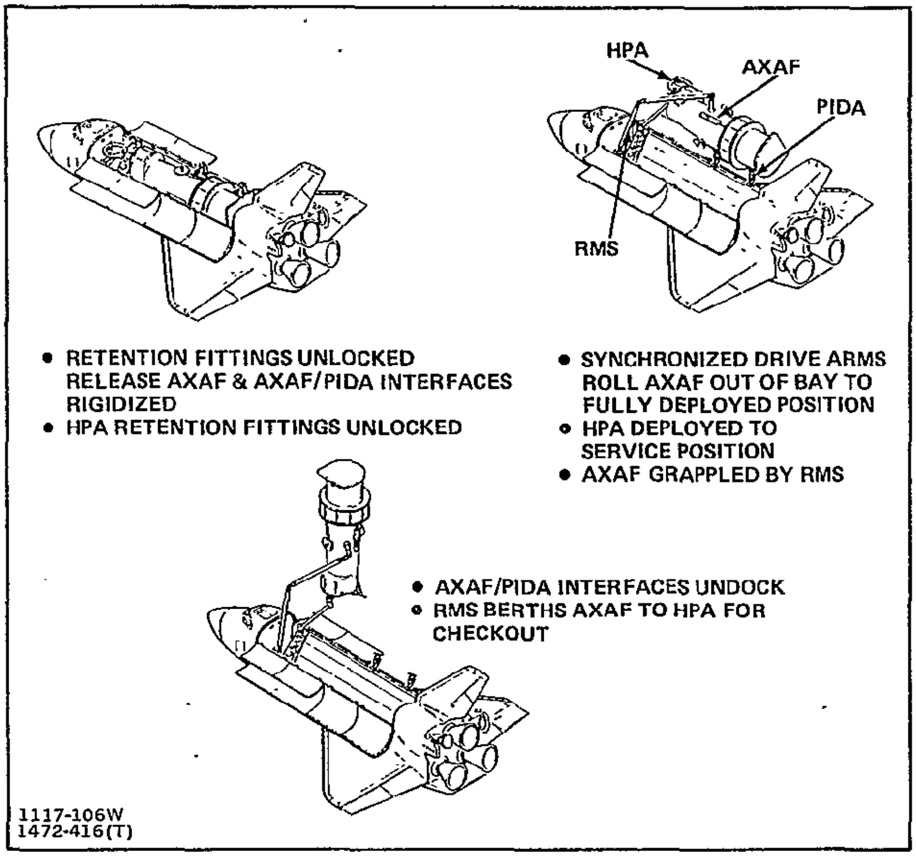


Fig. 2-14 Payload Installation & Deployment Aid (PIDA)

- Operates within 3 in. clearance envelope of payload bay
- Provides 19.5 in. clearance between payload and Orbiter in deployed position

• Mechanism stows under closed payload doors without interference with large payloads (15 ft x 60 ft)

• Incorporates energy absorption at docking interface to absorb relative payload/Orbiter motion during engagement

• Allows 3-axis payload movement during stowage to accommodate thermal deflections in payload bay.

Figure 2-14 shows the PIDA lifting the AXAF out of the payload bay, and berthing of the AXAF to the HPA using the RMS.

2.6 HANDLING & POSITIONING AID (HPA)

Figure 2-15 shows the concept of the Handling and Positioning Aid (HPA) and illustrates its capability to fully deploy UARS satellite appendages prior to Orbiter

ORIGINAL PAGE IS
OF POOR QUALITY

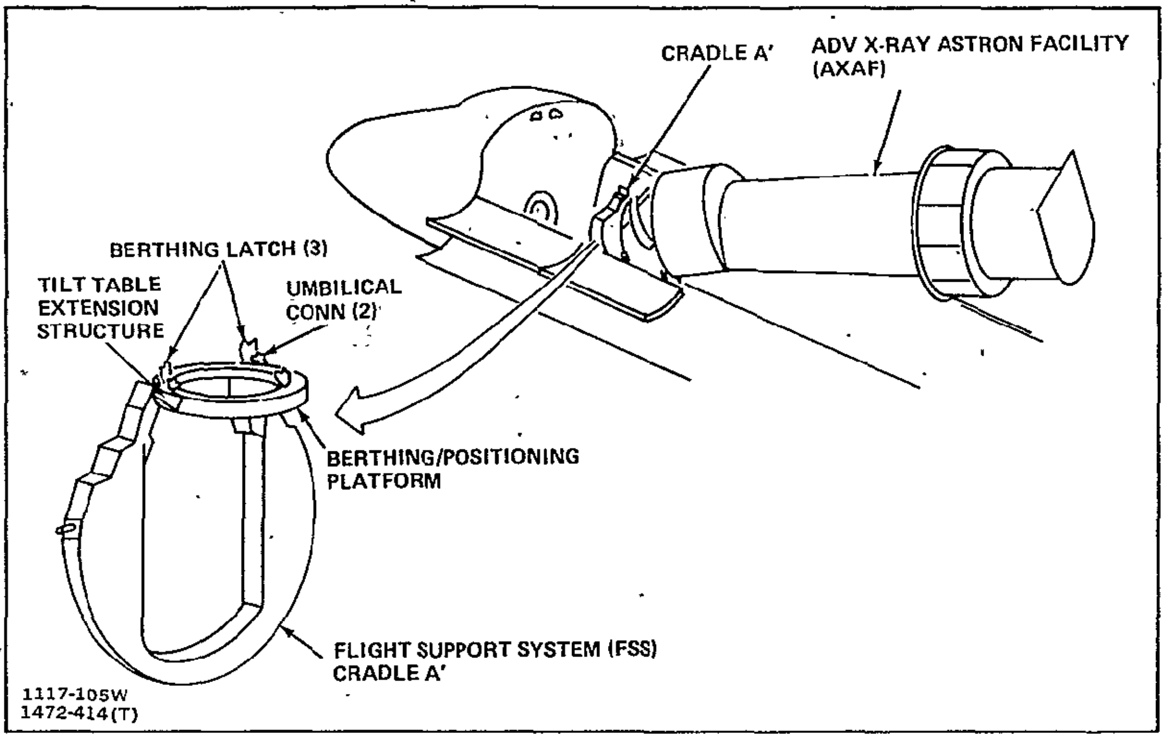


Fig. 2-12 Tilt Table – FSS Adaptation

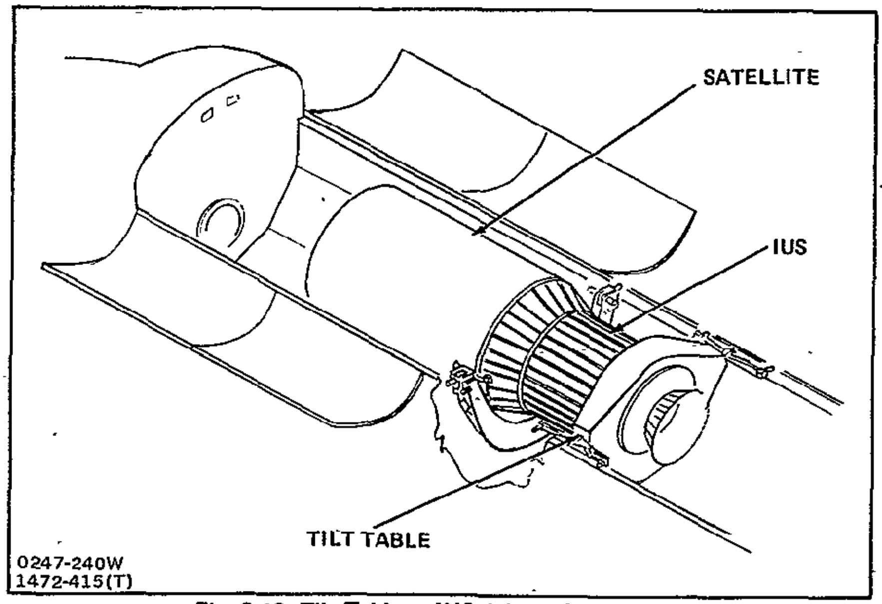


Fig. 2-13 Tilt Table – IUS Adaptation

ability to translate along the arm of the HPA, as well as vertically along the length of the satellite. For deployment situations, the HPA would contain provisions for imparting a ΔV to satellites to effect Orbiter separation; it would also provide an altitude/state vector transfer capability for all satellites. Additionally, a spin table capability could be accommodated on the HPA platform.

2.7 SPIN TABLES

Spin Tables are utilized to deploy spin-stabilized upper stage satellites. Illustrated in Fig. 2-16 are the PAM-A and PAM-D spin tables/cradles that have been adapted from unmanned launch vehicles for Orbiter payload deployment. These equipment items currently exist and have application to a large number of future satellite users.

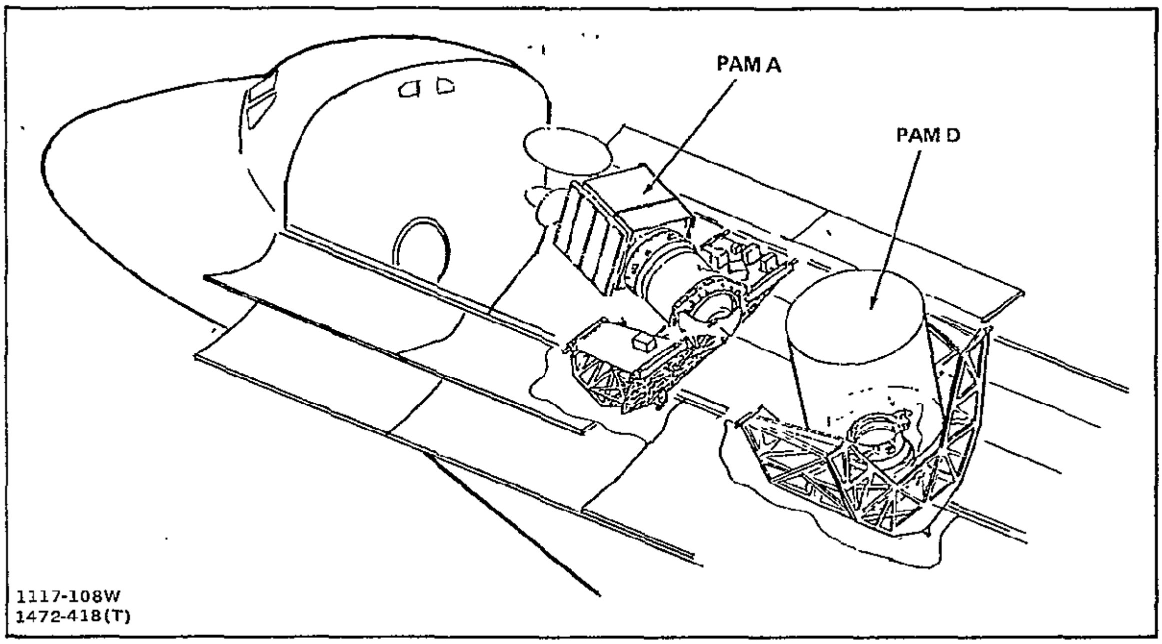


Fig. 2-16 Spin Table — PAM A, PAM D Solid Stage Adaptations

Figure 2-17 is an adaptation of a spin table to the HPA. The spin table would be equipped with a stored energy device to impart a separation ΔV for deployment. The HPA platform can also be rotated to direct the separation ΔV in a desired direction. Orbiter attitude requirements are, therefore, unconstrained in meeting separation ΔV requirements.

ORIGINAL PAGE IS
OF POOR QUALITY

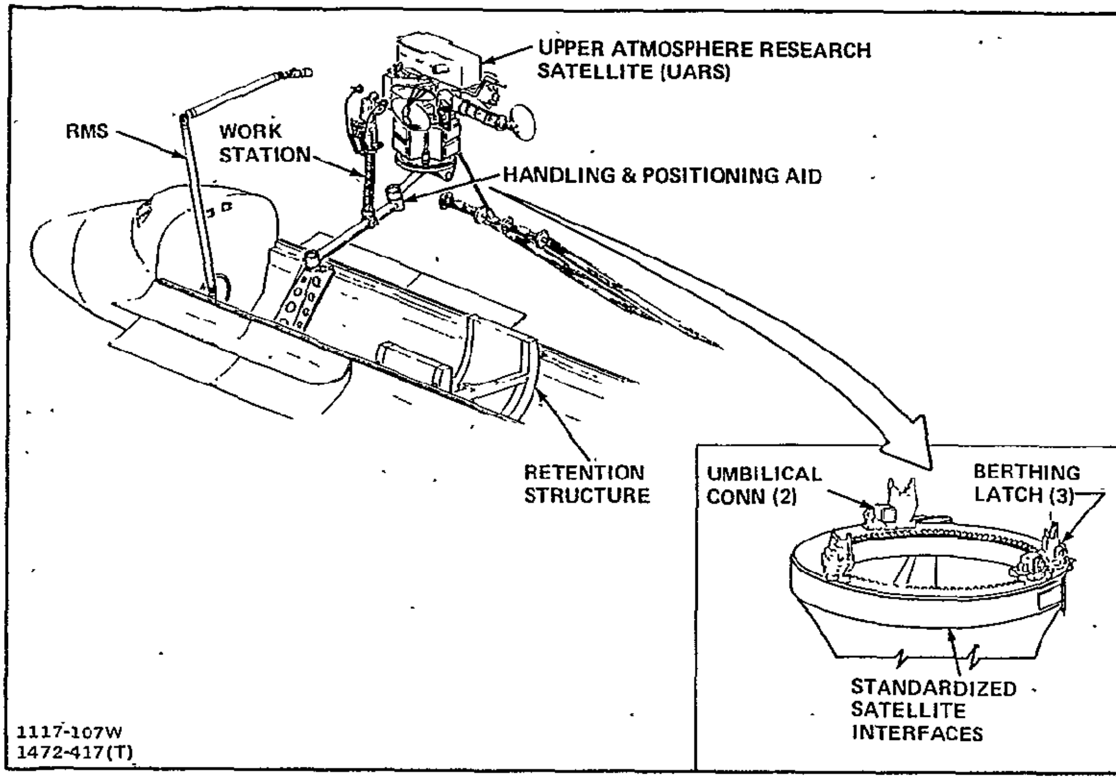


Fig. 2-15 Handling & Positioning Aid

separation. Features of the HPA are:

- Provides a platform clear of Orbiter obstructions for satellite appendage deployment, spacecraft checkout, and "best zone" of RMS operation
- Movable platform (translation and rotation) provides total access to all spacecraft locations
- Readily incorporates
  - Stored energy release deployment mechanism
  - Spin table for SSUS-type payloads
  - Improved attitude transfer alignment
  - Integrated fluid transfer system
- Provides a standardized interface (berthing/umbilical) for all spacecraft for initial launch, revisits, and earth return operations.

The HPA would contain a standardized berthing/umbilical interface for both initial checkout prior to deployment and for servicing missions. Servicing can be accommodated by rotating turn-table provisions in the HPA and via a movable work station that has the

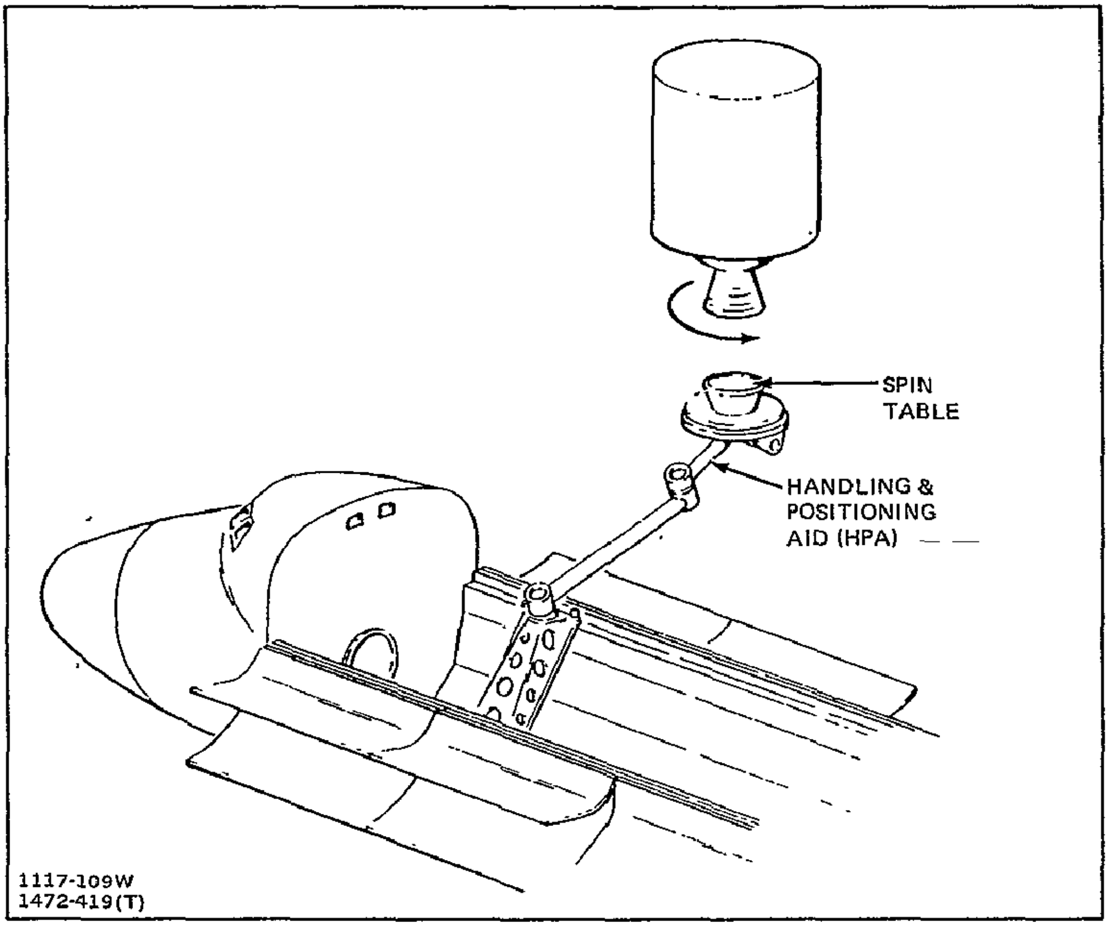


Fig. 2-17 Spin Table – HPA Adaptation

3 — Close Proximity Retrieval Equipment

3 - CLOSE PROXIMITY RETRIEVAL EQUIPMENT

Satellite service equipment items associated with close proximity retrieval operations involve the following:

- Remote Manipulator System (RMS)
- Maneuverable Television (MTV)
- Proximity Operation Modules
  - MTV Adaptation
  - Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU) Adaptation
- Aft Flight Deck Controls/Displays (AFD C&D).

3.1 REMOTE MANIPULATOR SYSTEM (RMS)

To enable the capture and retrieval of satellites, an RMS-compatible grapple fixture must be mounted to the spacecraft. The characteristics of the grapple fixture and the grapple target are shown in Fig. 3-1.

RMS capabilities for capturing satellites require the following conditions:

- Maximum Satellite Weight = 32,000 lb
- Maximum Satellite-Orbiter Relative Velocity = 0.1 ft/sec.

Additionally, for capture of actively-stabilized satellites, the following conditions are required:

- Attitude Dead Band less than ±1° about all axes
- Angular Rate Limit less than 0.1°/sec about all axes
- Maximum Grapple Point Motion less than ±3 in.

Similarly, the following are necessary for passively-stabilized satellites:

- Allowable Grapple Point Motion is to be less than 15 in.
- Allowable Grapple Point Velocity is to be less than 15 in./sec.

ORIGINAL PAGE IS
OF POOR QUALITY

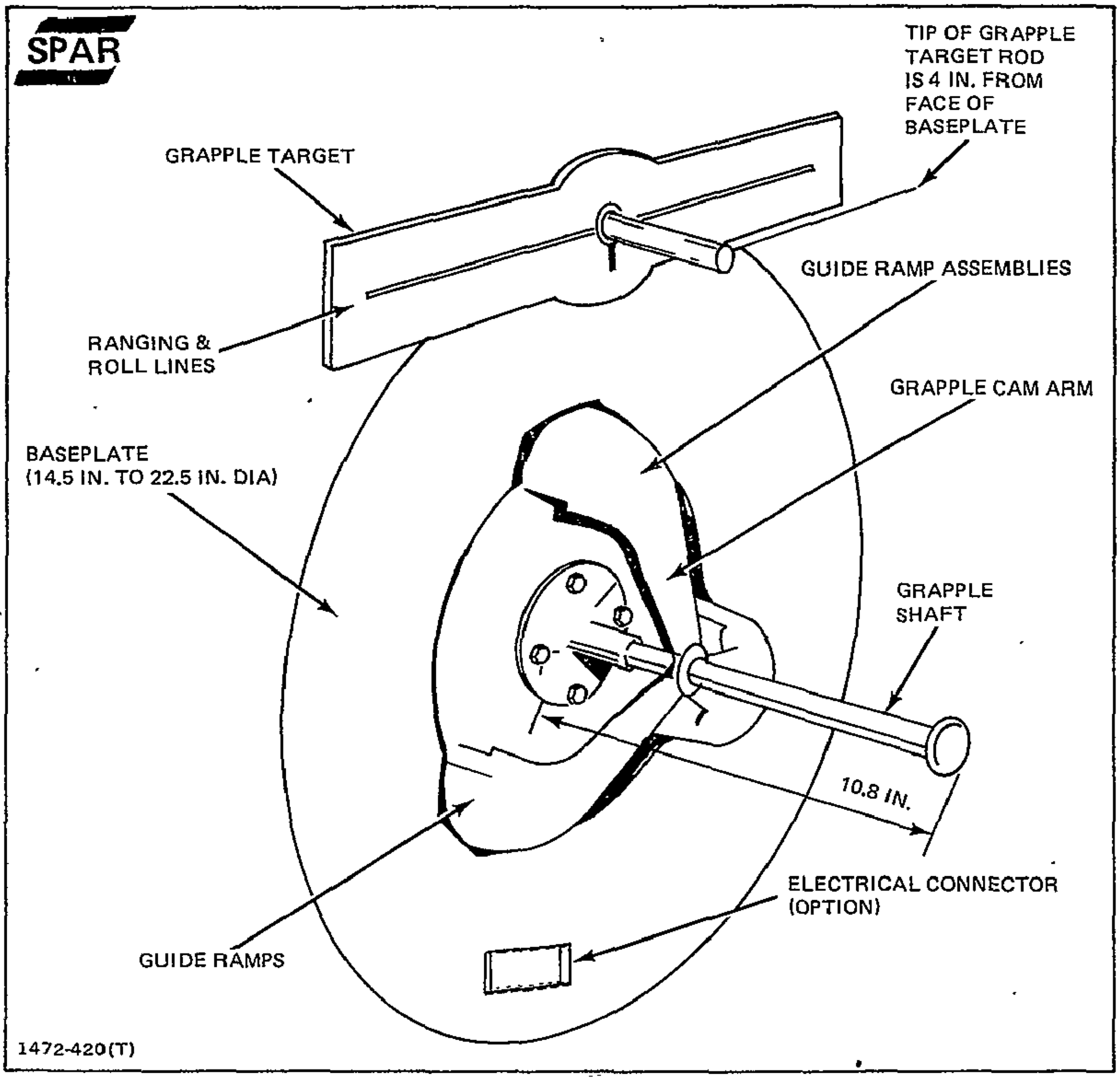


Fig. 3-1 Grapple Fixture/Target Assembly

Applying these groundrules to a passively-stabilized satellite such as LDEF (with its size, geometry, and grapple fixture location), results in the stability conditions shown in Fig. 3-2 to affect capture by the RMS.

Figure 3-3 shows the RMS grappled to the Low Altitude Satellite Studies of Ionospheric Irregularities (LASSII) satellite. The satellite is to be lifted from a pallet and deployed for free flight in the vicinity of the Orbiter. The satellite subsequently returns to the Orbiter (during the same flight) where it is grappled and reberthed to the pallet for earth return. Many LASSII missions are expected to be flown at about six month intervals.

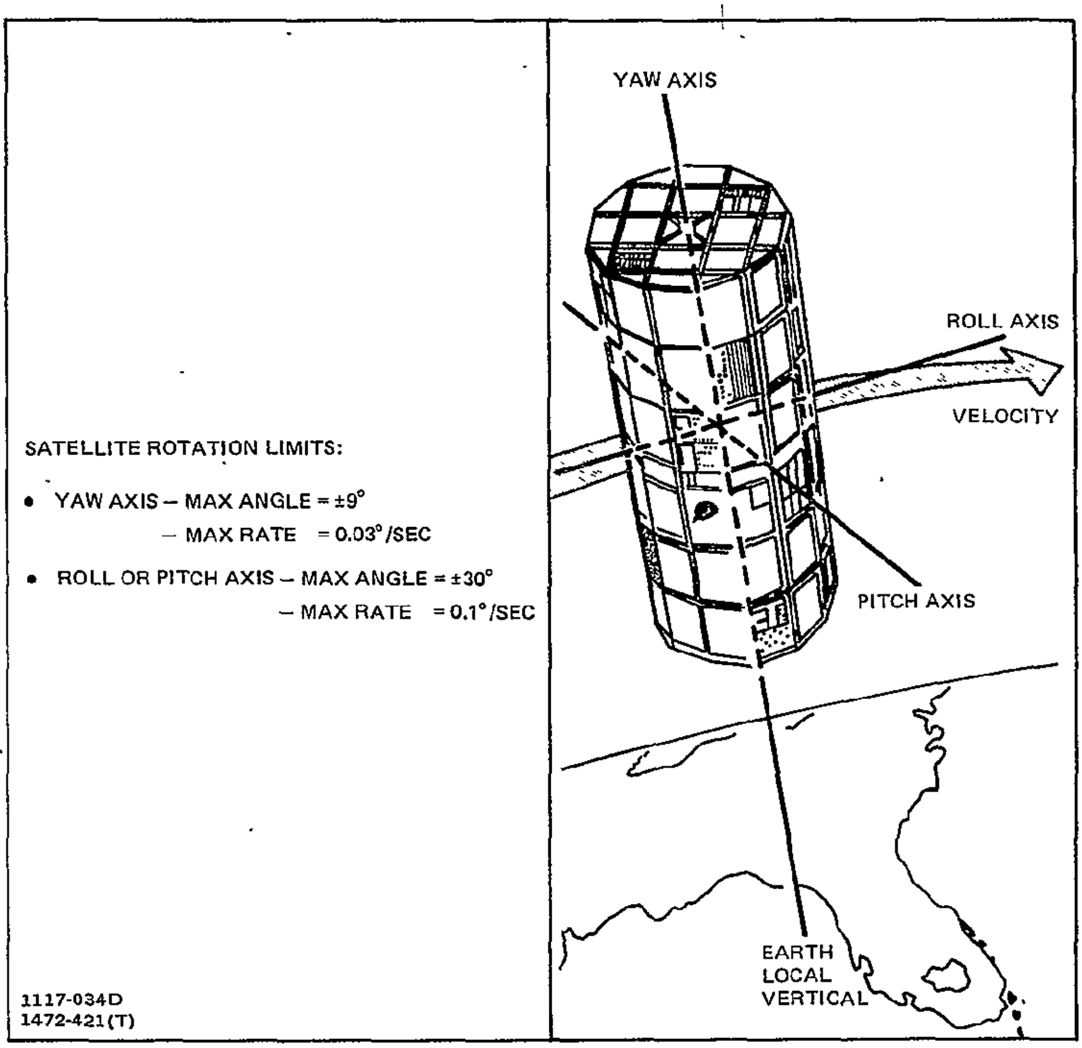


Fig. 3-2 Stability Requirements for RMS Capture of LDEF

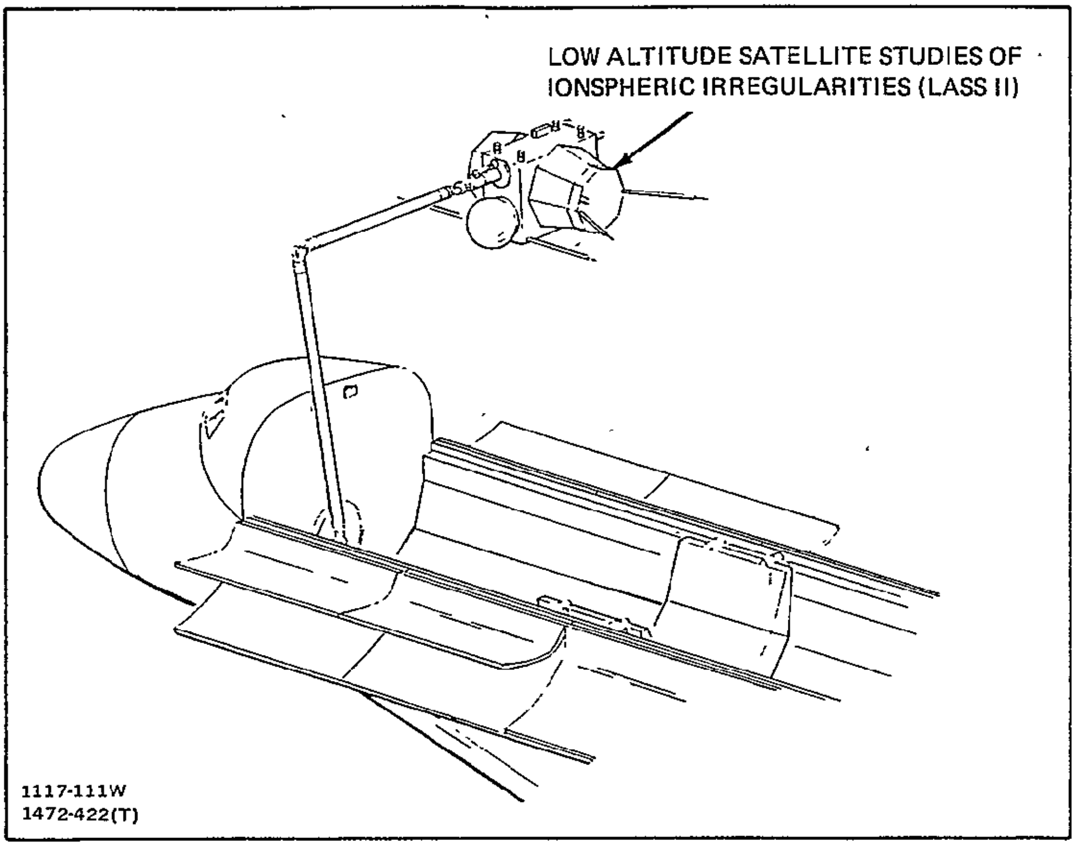


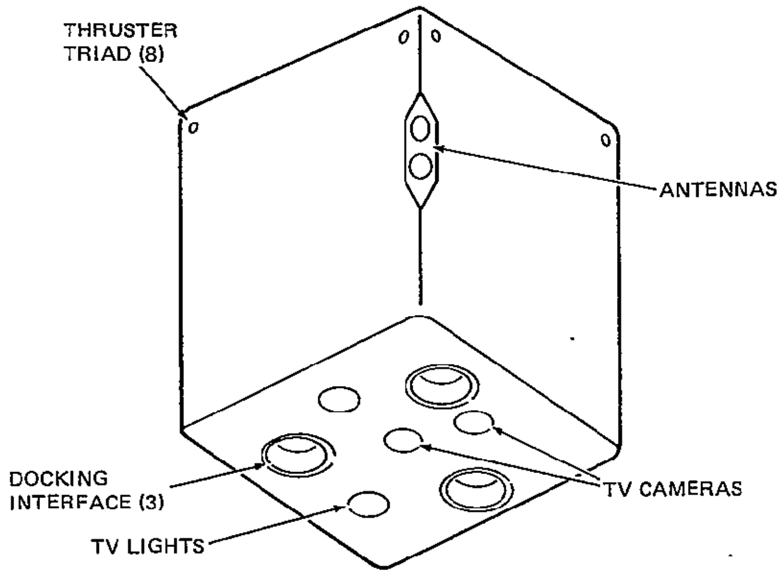
Fig. 3-3 RMS Retrieval

3.2 MANEUVERABLE TELEVISION (MTV)

The MTV shown in Fig. 3-4 will have a high utilization rate in satellite service operations and is expected to have the following features:

- Remote observation of Free Flying Payloads at stand-off distances up to 1 mile
- Fly or support sortie experiments in vicinity of Orbiter
- Small-lightweight system easily stowed in Orbiter
- Uses non-contaminating cold gas propulsion system
- Mission duration is 3 - 8 hours of free flight
- ΔV capability of 150 ft/sec
- On-Orbit refueling
- Flown remotely from Orbiter Aft Flight Deck

ORIGINAL PAGE IS
OF POOR QUALITY



• DEPLOYED TO REMOTELY EXAMINE SATELLITES PRIOR TO FINAL CLOSURE/RETRIEVAL VIA ORBITER

• DEPLOYED TO VIEW/RECORD PROPULSION STAGE FIRING

1472-423(T) 1117-112W

Fig. 3-4 Maneuverable Television – (MTV)

Currently under development at NASA/JSC, the MTV is used to remotely examine satellites prior to Orbiter retrieval, to view or record satellite upper stage firing, and to support numerous STS experiments in a free-flying mode. The system is flown remotely from the Orbiter Aft Flight Deck via translational and rotational hand controllers. Video and telemetry data recorded by the MTV is transmitted back to the Orbiter.

3.3 PROXIMITY OPERATIONS MODULES (POM)

The retrieval of cooperative satellites for either servicing or earth return is nominally accomplished by the Orbiter actively approaching the target satellite, grappling the satellite with the RMS/snare end effector, and berthing the satellite to either a work platform for servicing, or to a retention structure for earth return. In reviewing this scenario, however, several issues have surfaced which suggest that alternate approaches be considered. During close proximity operations, major issues are:

- Orbiter maneuvering limitations with the RMS unstowed
- Satellite attitude rates compatible with grappling by the RMS

- Allowable Orbiter plume impingement on the satellite within its contamination/over pressure sphere
- Orbiter RCS propellant consumption required for close proximity operations.

These issues have prompted consideration of the use of Proximity Operations Modules for satellite retrieval.

3.3.1 MTV-POM Adaptation

The Orbiter can readily rendezvous with a satellite to within a 1000 ft separation distance. Unmanned retrieval of satellites within 1000 ft of the Orbiter can be accomplished by a Proximity Operations Module (POM) that is an adaptation (or outgrowth) of the MTV (See Figure 3-5). Controlled by the crew in the Orbiter, the POM would be dispatched to capture the satellite and return it to within the reach distance of the RMS. The POM would be flown via TV (essentially using MTV equipment) to effect satellite capture by an RMS end effector on an extendable grapple fitting. TV visibility is used during the satellite capture phase; return to the Orbiter is via remote command/control from the AFD crew station.

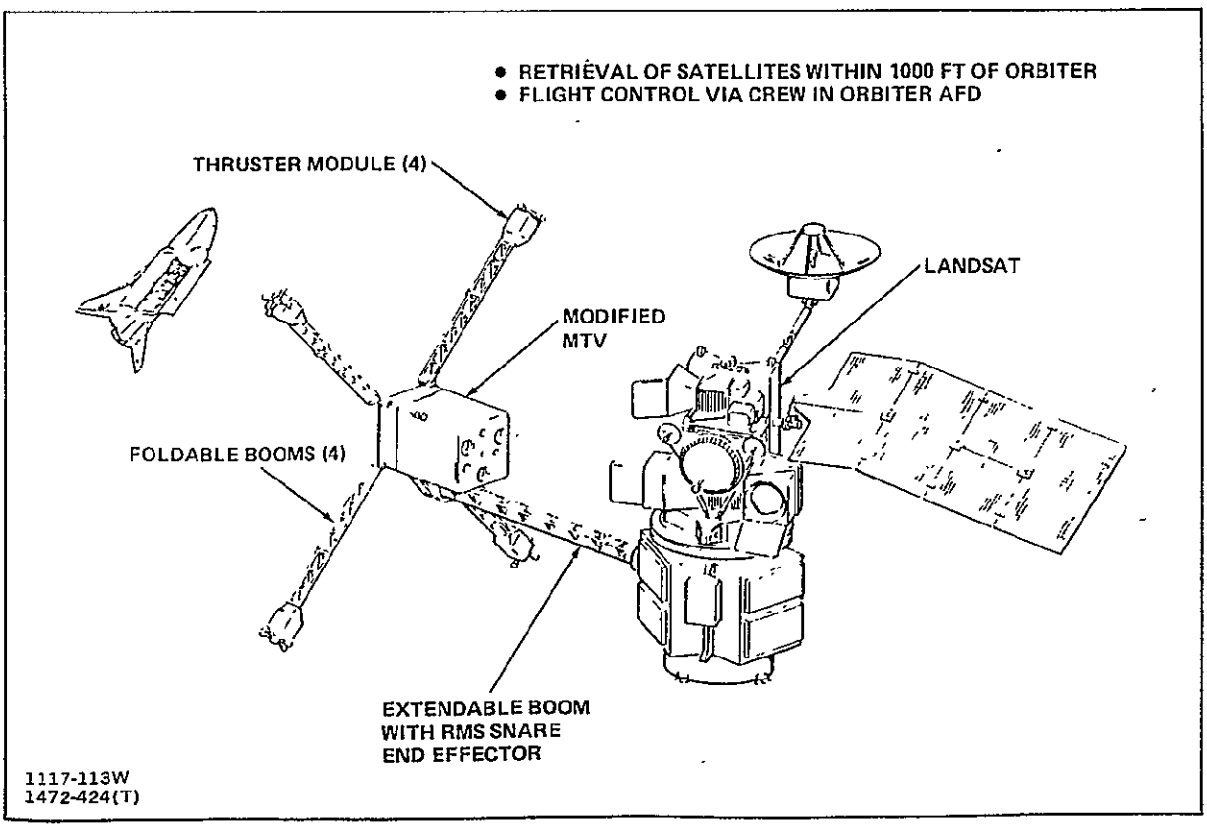


Fig. 3-5 Proximity Operations Module (POM) – MTV Adaptation

The POM could be designed to retrieve satellites of varying size/mass. It uses a non-contaminating, cold gas propulsion system that provides three axes of translation and rotation during free-flight and towing operations.

A layout drawing of the MTV-POM is shown in Figure 3-6. The drawing shows the position of the thruster booms in both the extended and stowed positions. The snare

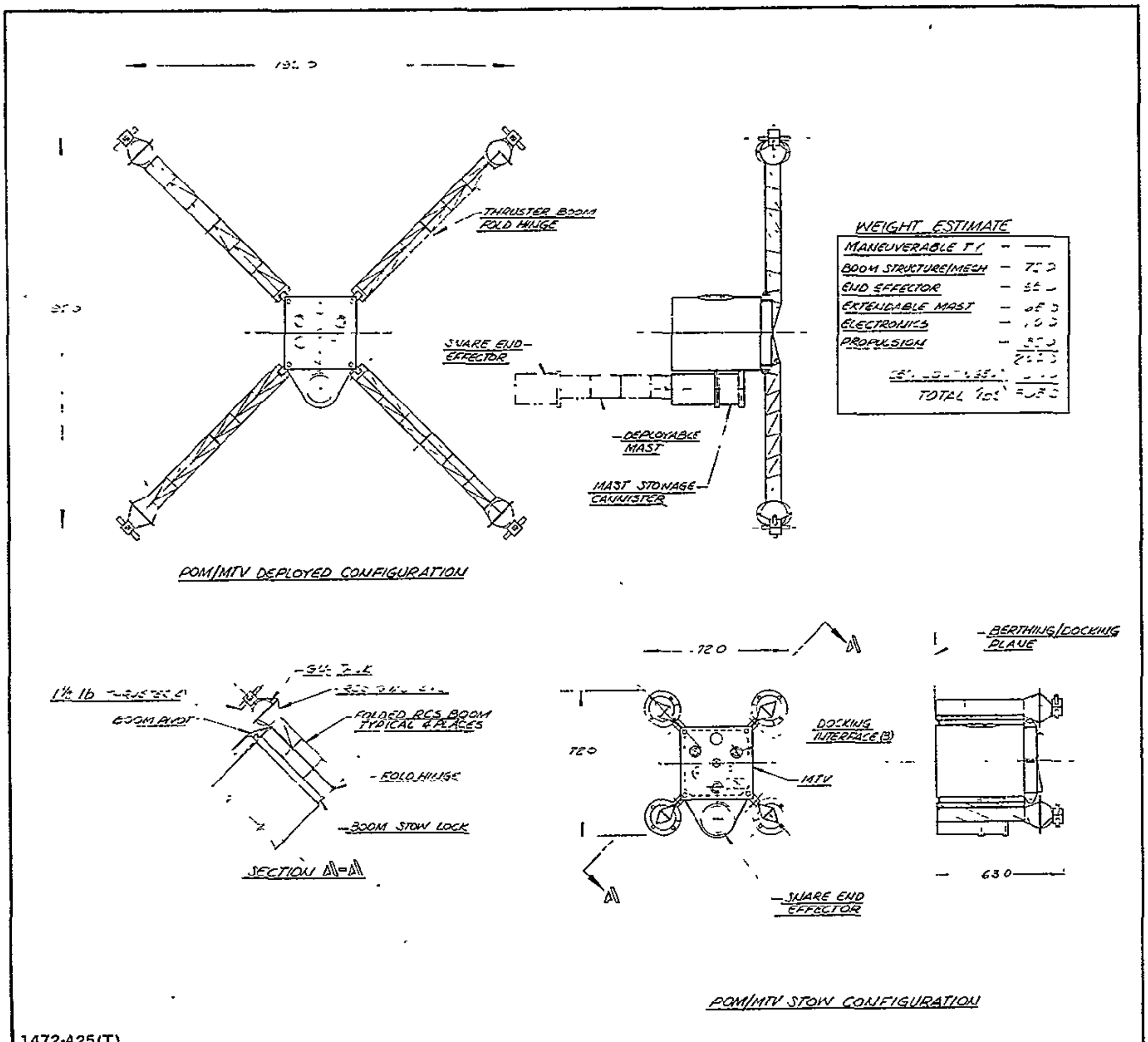


Fig. 3-6 Proximity Operations Module (POM) – Configuration Layout MTV Adaptation – SSSAS

ORIGINAL PAGE IS
OF POOR QUALITY

end effector is attached to the underside of the MTV by an extendable mast. This version of the MTV-POM is sized to tow satellites up to 10,000 lb using a clean, cold gas propulsion system. The estimated weight of the vehicle is 305 lb.

3.3.2 Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU) - POM Adaptation

Figure 3-7 illustrates the MMU/WRU Proximity Operations Module (POM) concept that could be used to retrieve satellites such as the Solar Maximum Mission satellite. The POM is an adaptation of the WRU and can be used in conjunction with an MMU to retrieve moderate-sized satellites of the Multimission Modular Spacecraft class. The WRU was developed by Grumman to support a potential on-orbit Orbiter tile repair mission and the hardware is presently in storage at JSC.

In this concept, while station-keeping with the satellite at ranges up to 1000 ft, the Orbiter guides the MMU/WRU-POM to the target satellite using voice link commands. The commands are in the form of nulling Line-of-Site (LOS) rate and adjusting range rate maneuvers, but related in terms of timed thrusting commands. At satellite arrival, the MMU/WRU-POM examines the satellite using "fly-around" maneuvers and engages the target satellite using a snare end effector attached to the WRU on the end of an extendable mast. After reducing the satellite attitude rates to nearly zero, the POM transports the satellite back to the Orbiter. In the return trajectory, the POM performs only range rate or braking maneuvers; LOS rate corrections are performed by the Orbiter.

A layout drawing of the MMU/WRU-POM is shown in Fig. 3-8. Note that the WRU

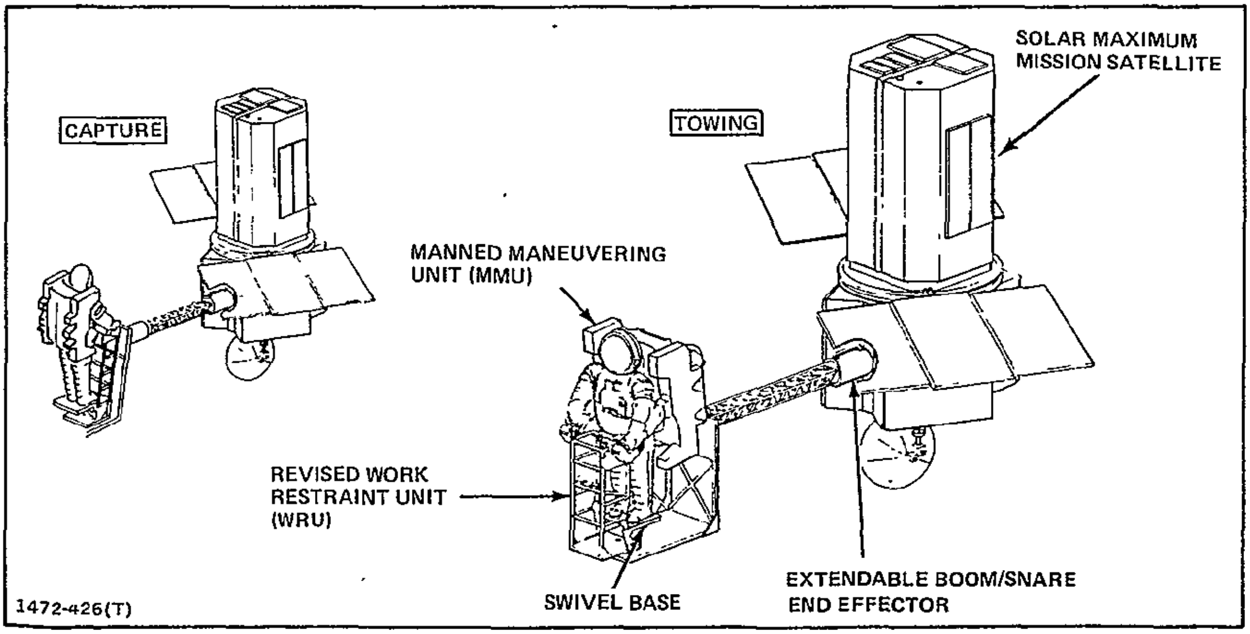


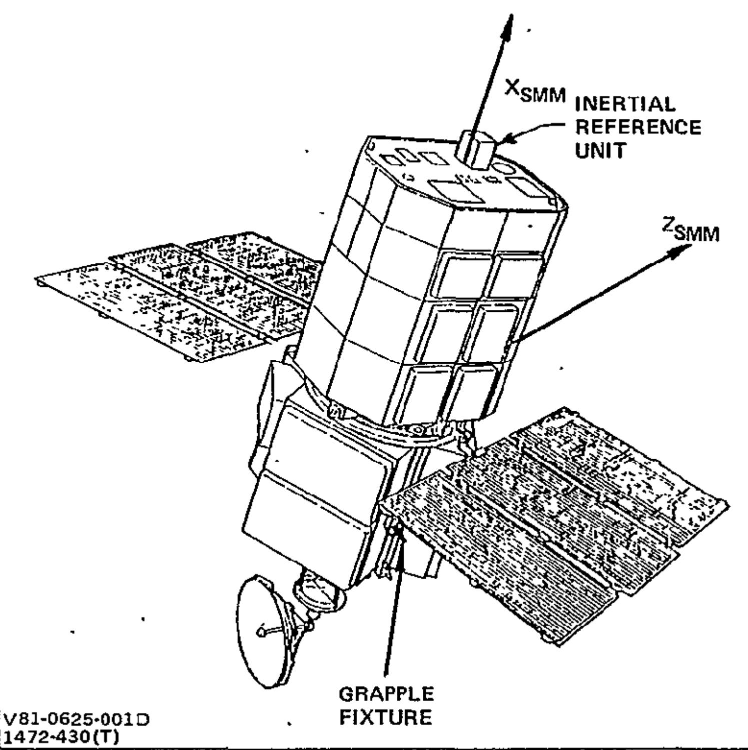
Fig. 3-7 Proximity Operations Module (POM)— WRU Adaptation

To help understand the capabilities and limitations of the Orbiter and the enhancement offered by the alternative methods, reference is made to the retrieval of the Solar Maximum Mission (SMM) spacecraft. This satellite was selected as one of the reference satellites and is used here to illustrate typical retrieval operations.

Figure 3-11 illustrates the SMM which is currently residing in a 28.5° inclined orbit, at an approximate altitude of 300 n mi, and with degraded attitude control capability. Failure of three of the four on-board reaction wheels and inactivation of the fourth has necessitated control of the spacecraft by magnetic torquing. The spacecraft is, therefore, oriented with the X-axis toward the sun, but coning at ±10 degrees and rolling at approximately 0.95 deg/sec.

Consideration has been given to revisiting the SMM in 1984 (or earlier), retrieving it, and repairing the failed components, or retrieving it for earth return. Obviously, the ability to stabilize the SMM to attitude rates that are consistent with Orbiter RMS capture capability is an issue of major importance.

In evaluating SMM retrieval operations, analysis has indicated that spacecraft rates can be nulled to near zero about all axes by reactivating the remaining reaction wheel.



CURRENT ORBITAL STABILITY

- CONING ABOUT X-AXIS AT ± 10° (PITCH AND YAW) AND ROLLING ≈ 0.95°/SEC (CONTROLLED BY MAGNETIC TORQUING)
- RATES MAY BE REDUCED TO ≈ 0.01°/SEC IF REMAINING REACTION WHEEL IS ACTIVATED
- FOR SHORT DURATIONS, RATES MAY BE REDUCED TO ≈ 0.01°/SEC USING MAGNETIC TORQUE

Fig. 3-11 Solar Maximum Mission Spacecraft

ORIGINAL PAGE IS
OF POOR QUALITY

Concern has been expressed, however, as to whether this can be operational in the time frame in which retrieval operations are planned.

Another alternative that has been successfully demonstrated in actual flight operations, is to reduce spacecraft rates to near zero using only magnetic torquers. This can be accomplished only for short durations, however, since it requires pointing the X-axis in non-solar looking directions.

It appears, therefore, that SMM can be nulled to near zero attitude rates for retrieval operations. The ability to maintain near-zero rates in the presence of on-orbit disturbances such as Orbiter thrust impingement is, however, questionable.

The information presented in Refereence 1* was used to understand the effects of Orbiter thrust impingement on satellite retrieval operations. Figure 3-12 shows several approach trajectory profiles that have been simulated for Orbiter closing to within RMS

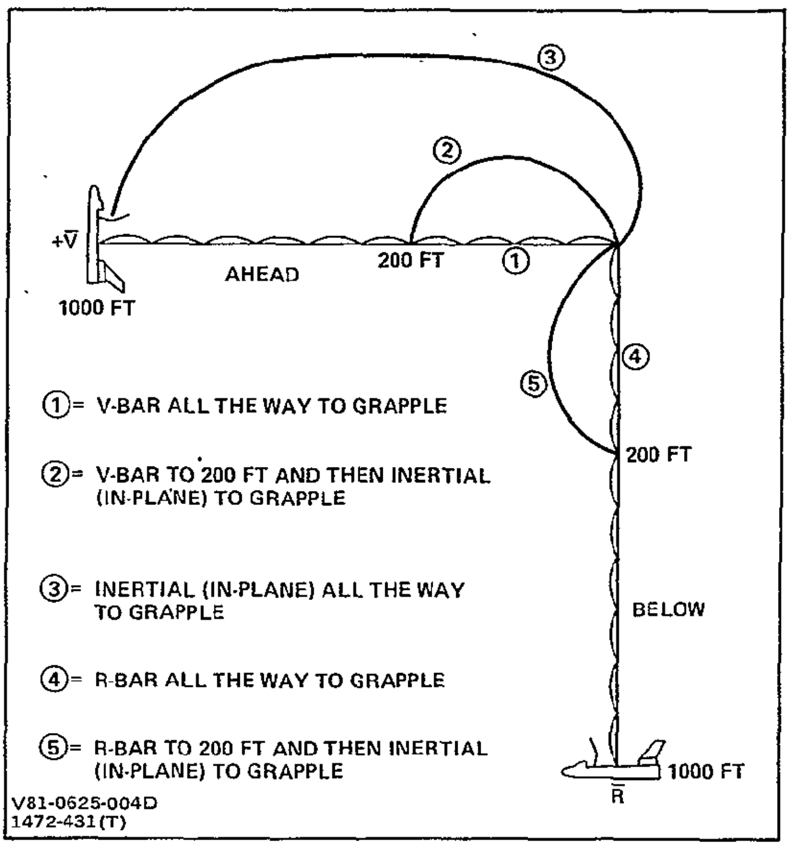


Fig. 3-12 SMM Retrieval In-Plane Approach Profile

Ref 1: NASA/JSC Report NASA-TM-81104-Proximity Operations Analysis - Retrieval of Solar Maximum Mission Observatory - April 1980 grappling distance of the SMM. Approach trajectories labeled 1, 2, and 3 are initiated assuming the Orbiter is station-keeping at a range of 1000 ft on the V-bar vector. Trajectories 4 and 5 assume that the Orbiter is station-keeping on R-bar. Combinations of V-bar, R-bar, and inertial approach trajectories have also been considered.

Results of the Orbiter closing trajectory simulations are summarized in Fig. 3-13. For each of the trajectory profiles considered, Orbiter maneuvers were executed using either normal or low-Z braking maneuvers. The data includes overall trajectory time to SMM grapple, the total momentum imparted to the SMM spacecraft about each axis as a result of Orbiter plume impingement, and the total Orbiter RCS propellant consumed. Of major significance is the control authority of the SMM compared to the disturbance momentum imparted by Orbiter thrust impingement. When the disturbance momentum exceeds the control capability, tumbling the SMM spacecraft results.

With the SMM reaction wheels operating, the control authority of the SMM about the Y and Z axis is approximately 14 ft lb/sec. In a degraded mode (i.e., with magnetic torquers and one remaining reaction wheel active), the control authority of the SMM is significantly lessened.

As shown in Fig. 3-13, the trajectory profiles result in impingement momentum in excess of the SMM nominal control capability. These are indicated in the figure by the blocked values of the SMM plume disturbance. All trajectories that utilize normal-Z braking impart a plume impingement in excess of the SMM nominal control capability.

PROFILE	ORBITER BRAKING MODE	TIME (MIN)	SMM PLUME DIST (ABS CUM): X, Y, Z) (FT-LB SEC)	ORBITER RCS PROPELLANT, (LB-MASS)
V-BAR	NORM-Z	30	6, $\boxed{18}$, $\boxed{78}$	315
	LOW-Z	28	1, 4, 8	635
V-BAR/INERTIAL	NORM-Z	35	8, 12, $\boxed{69}$	330
	LOW-Z	28	3, 8	705
	LOW-Z	24	1, 1	520
R-BAR	NORM-Z	33	$\boxed{20}$, $\boxed{65}$	350
	LOW-Z	29	2, 4	570
R-BAR/INERTIAL	NORM-Z	37	7, $\boxed{32}$	350
	LOW-Z	29	1, 2, 5	530
INERTIAL	LOW-Z	35	1, 1, 5	760

LOW-Z COMPATIBLE WITH FULL SMM CONTROL AUTHORITY

V81-0625-005D
1472-432(T)

Fig. 3-13 Simulation Results for SMM Retrieval - Orbiter Direct

This analysis suggests that Orbiter-direct retrieval of the SMM, with reduced control authority, can be accomplished using low Z braking only; if it can be accomplished at all. As the figure shows, this also requires a significant amount of Orbiter RCS propellant to effect SMM retrieval. This may preclude using the direct ascent flight mode (the Orbiter launched directly into the SMM orbit) because of overall propellant limitations.

Issues that also must be addressed when considering satellite retrieval with the RMS are the operational constraints imposed by use of the RMS during Orbiter maneuvering. Figure 3-14 summarizes the conditions under which the RMS can be operated safely. For example, it is shown that the RMS cannot be unstowed and held in a ready position until the Orbiter has completed all major approach trajectory maneuvers; only small, corrective minimum impulse maneuvers are permitted after it has been unstowed. Since it takes approximately 10 minutes to activate and unstow the RMS, approach trajectory relative conditions must be accurately achieved before unstowing the RMS. These conditions must be maintained for that interval using minimum impulse maneuvering only. The position of the satellite grapple fitting with respect to the Orbiter approach path is, therefore, an important consideration to affect RMS capture.

<table>
<tr><td colspan="3"></td><td colspan="2">RCS</td></tr>
<tr><td colspan="3">RMS</td><td>PRIMARY</td><td>VERNIER</td></tr>
<tr><td rowspan="3">STATIONARY</td><td colspan="2">UNLOADED</td><td>MIN IMPULSE ONLY†</td><td>OK</td></tr>
<tr><td rowspan="2">LOADED</td><td><32 K</td><td>MIN IMPULSE ONLY†</td><td>OK</td></tr>
<tr><td>>32 K</td><td>(forbidden)</td><td>OK</td></tr>
<tr><td rowspan="2">MOVING</td><td colspan="2">UNLOADED</td><td colspan="2" rowspan="2">FORBIDDEN*</td></tr>
<tr><td colspan="2">LOADED</td></tr>
</table>

0625-007D
1472-433(T)

† 80 MILLISEC PULSE
* FREE DRIFT MODE

Fig. 3-14 Orbiter Maneuvering Constraints with RMS Active

After unstowing the RMS, it cannot be operated during any type of Orbiter RCS maneuver, including minimum impulse maneuvers. This requires that the Orbiter/satellite relative conditions be properly established so that adequate time is available for actual RMS grappling without further Orbiter maneuvers. Although these constraints for RMS operations appear workable, the crew activities, Orbiter RCS propellant usage, and overall timeline considerations must be further evaluated before

Orbiter-direct retrieval of the SMM can be considered acceptable. Implications of a "stiffer RMS" are yet to be determined.

Another issue related to Orbiter direct retrieval of satellites is the capability of the RMS in grappling satellites within the reach envelope. The following requirements and conditions must be achieved by the satellite at the time of RMS grappling:

- Spin-stabilized payloads must be de-spun
- Passively-stabilized payloads must have grapple point motion less than ±15 in. and less than 0.05 in./second
- Actively-stabilized payloads must have
  - Attitude dead-band less than ±1 degree about all axes
  - Angular rate limit less than 0.1 deg/sec about all axes
  - Maximum grapple point motion less than ±3 in.
- Maximum allowable relative velocity of payload and Orbiter at capture less than 0.1 ft/sec
- Payload should have sufficient control authority to damp out and return to local vertical/horizontal (LVLH) attitude within two minutes after direct RCS plume impingement at 35 ft from thruster.

For actively stabilized satellites such as the SMM, the maximum angular rate must be less than 0.1 deg/sec.

Although it appears that the SMM satellite rates initially can be nulled to very low values, it is questionable that they can be maintained with the SMM's limited control authority in the presence of Orbiter thrust impingement.

If it is assumed that the remaining skewed reaction wheel is operable during retrieval operations, and used to null the momentum imparted by Orbiter thrust impingement about a given axis, in doing so it also applies a torque about the other two spacecraft axes, in proportion to the direction cosines. This suggests that the SMM would probably realize a rotational motion about at least one axis which is greater than the RMS grappling capability during Orbiter approach to SMM, even with an Orbiter low Z axis approach.

If it is assumed that only magnetic torquers are used to null disturbances from Orbiter thrust impingement, it is estimated that they are not capable of nulling the Orbiter thrust impingement resulting from the low-Z approach.

3.4.2 Proximity Operations Module - Retrieval

An alternate approach to Orbiter-direct retrieval of satellites is retrieval with the assistance of a Proximity Operations Module (POM). In this concept, a small module (either manned or unmanned) is dispatched from the Orbiter, which is station-keeping at ranges up to 3000 ft, to capture the target satellite and return it to the immediate vicinity of the Orbiter. The Orbiter RMS would then grapple the satellite while it is positioned and stabilized by the POM.

In developing this concept, emphasis was placed on both near-term needs (such as the SMM retrieval) and the potential operational needs of future satellites in the 1980 and 1990 time frames. Consequently, several POM concepts were developed from existing or planned systems to meet both near-term and long-term requirements.

Functional requirements for both a POM/WRU adaptation and a POM/MTV adaptation follow. Note that the operation range for the unmanned POM/MTV is 3000 ft, whereas the manned POM/WRU is limited to 1000 ft.

For the SMM retrieval mission, it is expected that Orbiter stand-off range will be less than 1000 ft. The minimum acceptable range, where Orbiter plume disturbances would be negligible, is yet to be determined. Functional requirements include:

- Translate to payloads station-keeping at ranges up to 1000 ft (POM/WRU); or 3000 ft (POM/MTV)
- Inspect payloads at close proximity (25 - 50 ft)
- Attach to quasi-stabilized satellite, rotating at rates up to 1°/sec
- Stabilize satellites to rates less than 0.01°/sec
- Translate payloads (up to 10,000 lb) to vicinity of Orbiter (RMS reach)
- Fly system using manual remote commands (POM/MTV)

Figure 3-15 shows the POM/WRU adaptation that can retrieve satellites such as the SMM and return them to the vicinity of the Orbiter. It consists of a frame support structure interfaced with a modified WRU. Attached to the frame support is a snare end effector which is mounted on the end of an extendable mast. The WRU can be rotated relative to the frame support to allow an astronaut to assume forward-facing or aft-facing positions for fly-in or towing operations (see Fig. 3-16). The system is fabricated using existing flight qualified components and could be made operationally available for early retrieval missions such as the SMM.

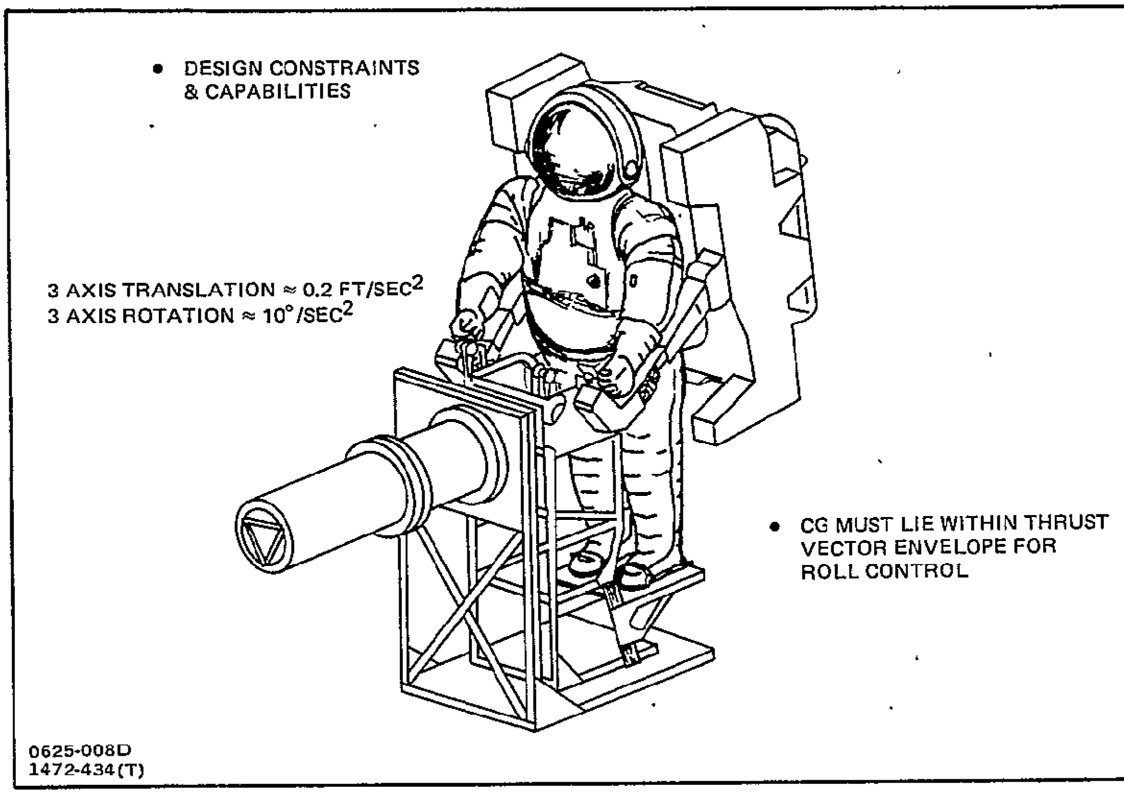


Fig. 3-15 POM/WRU Adaptation

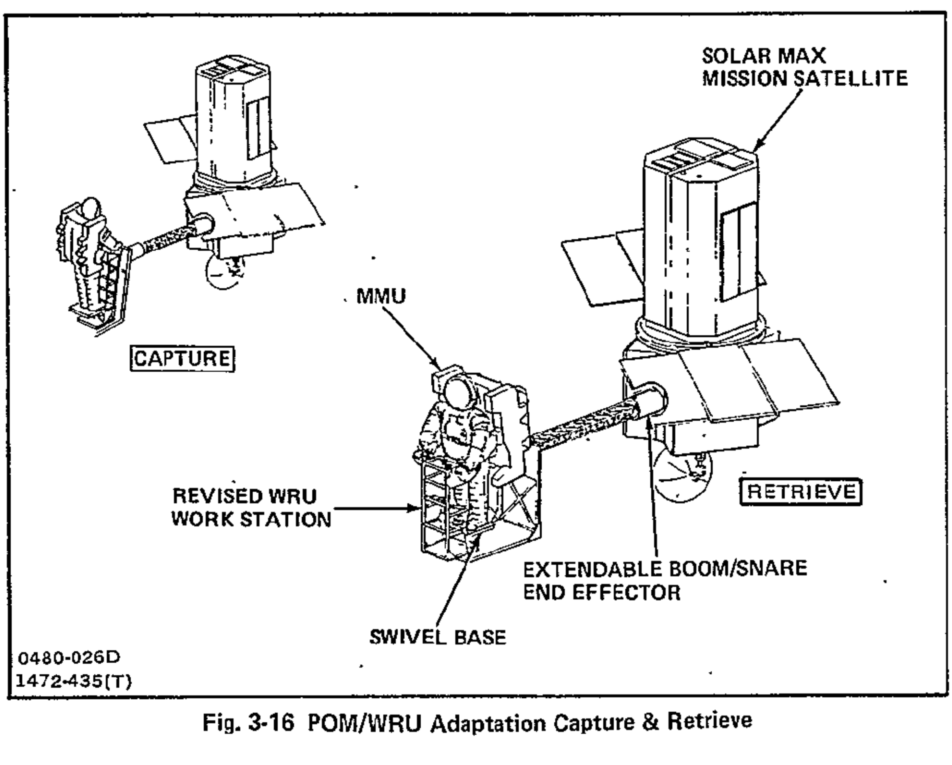


Fig. 3-16 POM/WRU Adaptation Capture & Retrieve

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3-17 shows a design constraint required for thrust vector/tow force alignment during satellite tow operations. A large misalignment between the fore and aft translational thrust vector and the tow force vector results in unwanted applied torques during translational maneuvers. These torques can only be nulled by downward firing thrusters, which then incur large increases in propellant usage.

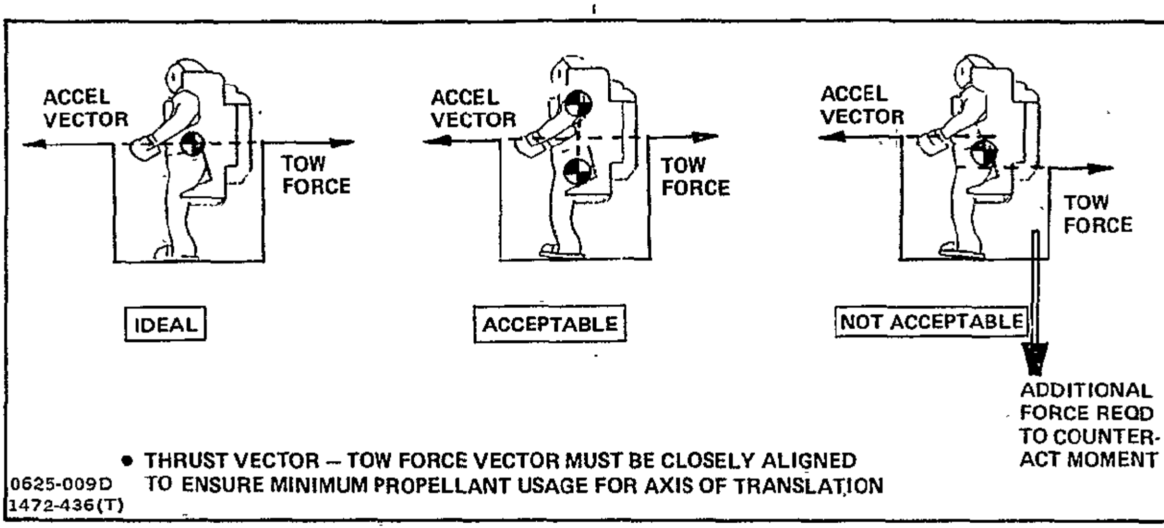


Fig. 3-17 POM/WRU Adaptation — Satellite in Tow Design Constraint

Figure 3-18 shows POM/WRU adaptation performance characteristics when towing satellites in the 5000 lb weight class. Translation is limited to one axis, the fore and aft direction, which is used for towing the satellite to the Orbiter and braking at arrival. Capabilities for three axes of rotation are provided by translating in the upward-downward direction for pitch, and the lateral direction for yaw. The large moment arm provided by the extendable mast ensures that only small translational effects are experienced during rotational maneuvering. Roll is accomplished using balanced couples.

Figure 3-19 illustrates a design feature incorporated into the POM/WRU adaptation for towing payloads such as SMM. The snare end-effector is attached to an extendable mast and is allowed to pivot relative to the mast centerline so that the payload can align itself with the thruster axis/tow force vector. In the case of SMM, the payload cg is displaced from the grapple fitting by approximately 50 in. Without this capability, the cg would remain misaligned from the thrust vector and a rotation would be induced during translational maneuvering. This could only be nulled by downward firing thrusters and the result is an almost two-fold increase in MMU propellant usage. The pivot mechanism also locks the payload in the newly aligned position so that the payload does not rotate out of the aligned position during braking.

ORIGINAL PAGE IS
OF POOR QUALITY

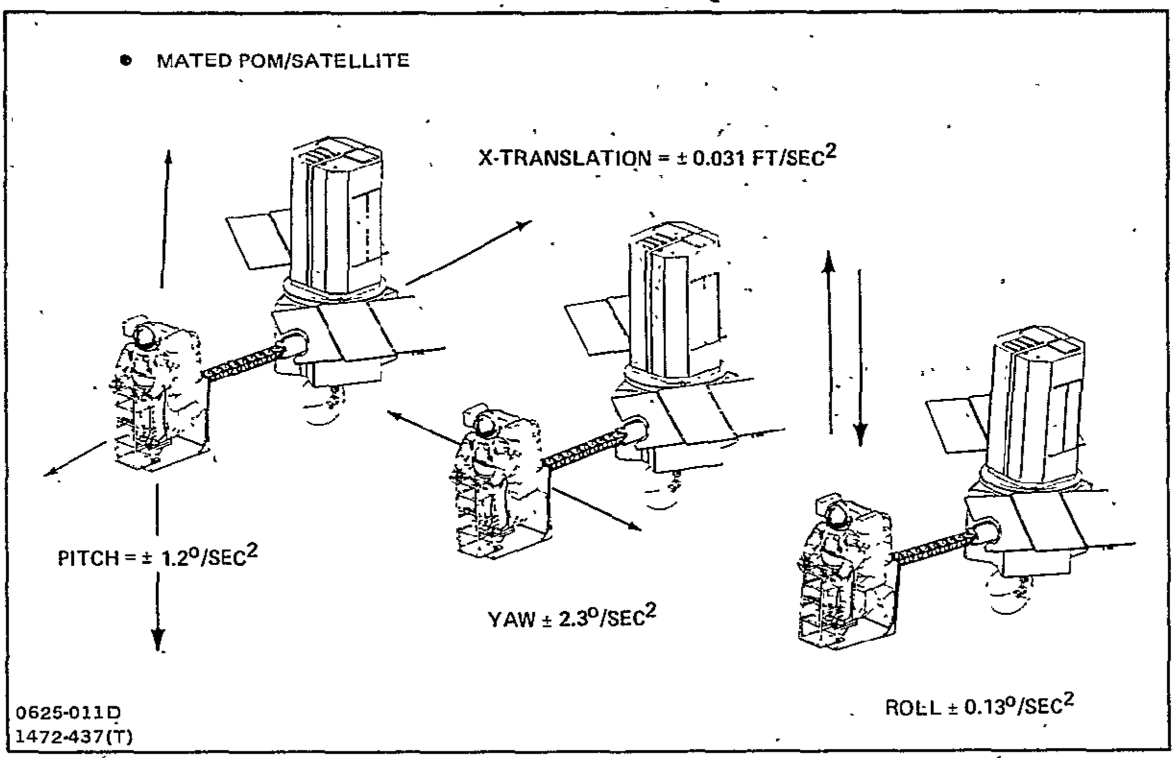


Fig. 3-18 POM/WRU Performance Characteristics

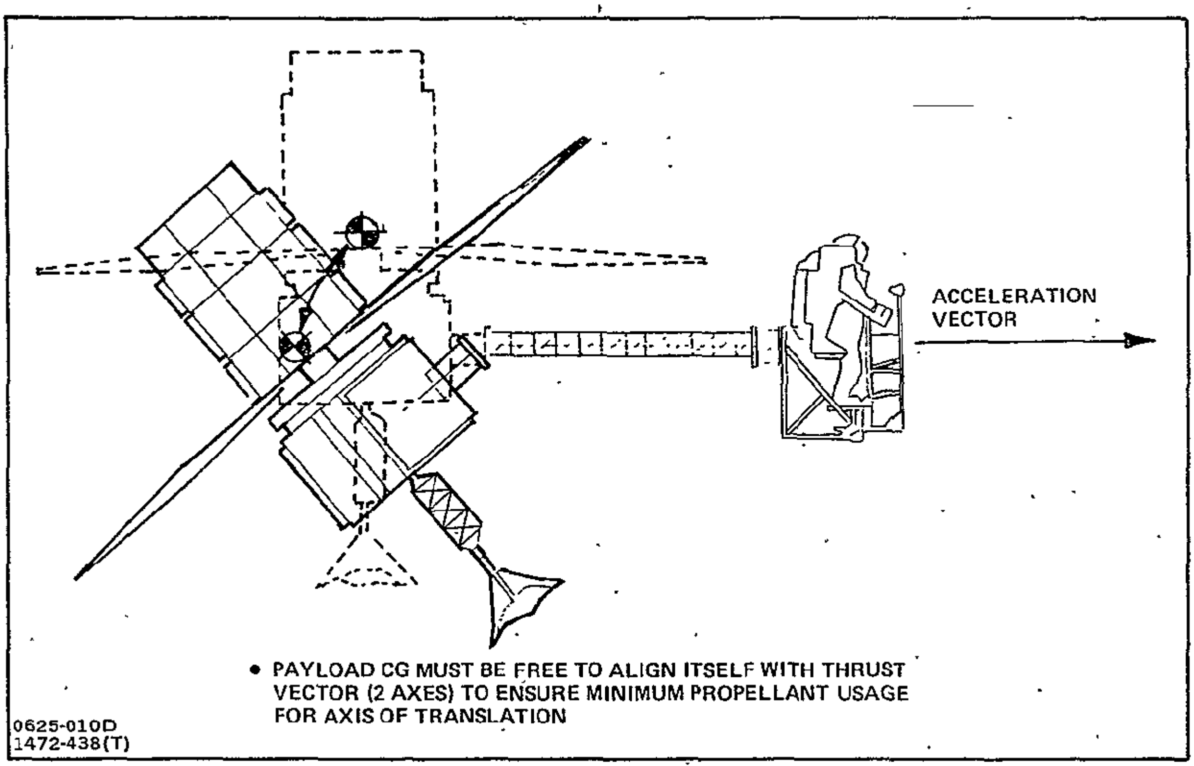


Fig. 3-19 POM/WRU Adaptation — Thruster Axis Alignment

Figure 3-20 illustrates the POM/MTV adaptation that can be used to retrieve satellites of varying mass/size. It consists of a basic core module containing a television system, lights, and communication and control system electronic packages. Attached to the corners of the core module are four extendable masts which support the thruster quads and associated propellant tanks for a clean-burning gaseous thrust system. Propellant tanks are located with the thruster quads to eliminate propellant transfer through rotating joints. Attached to the underside of the core module is a snare end effector mounted on an extendable mast that is used to grapple satellites during retrieval operations.

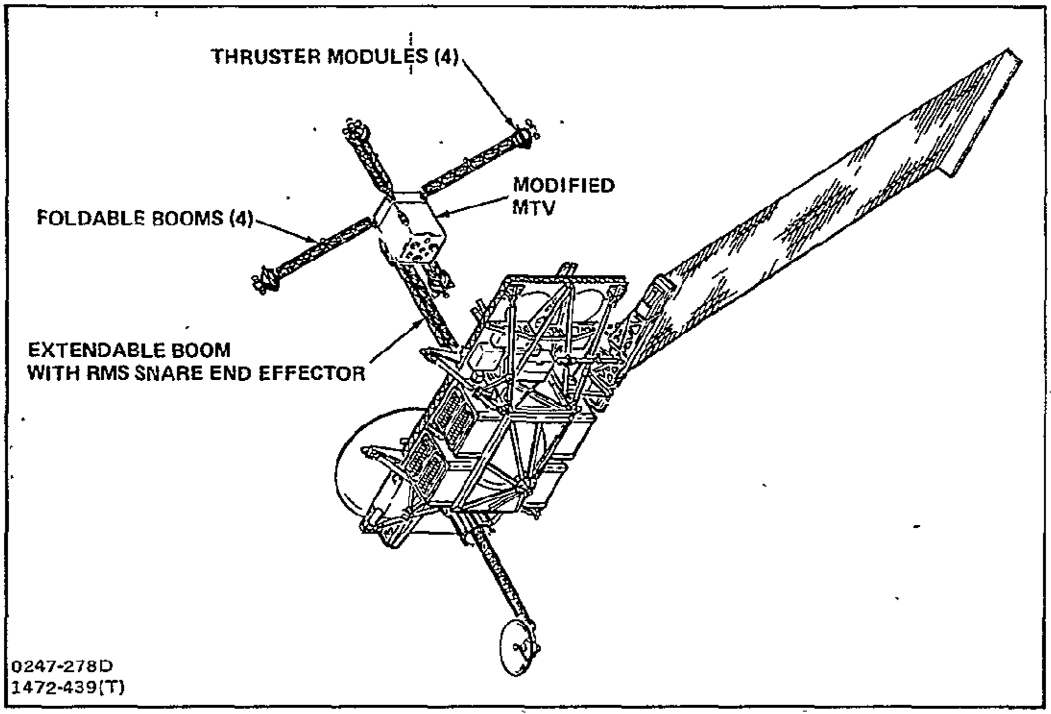


Fig. 3-20 POM/MTV Adaptation

The POM/MTV is dispatched from the Orbiter, which is station-keeping at an offset range from the target satellite. Maneuvers are executed by remote commands initiated from the Orbiter AFD using both visual and recorded data transmitted to the Orbiter from the POM/MTV.

Figure 3-21 illustrates the pure translational performance capability of the POM/MTV about all three axes when faced with a satellite cg offset from the thrust axis. X-axis translation is accomplished by continuous thrusting of the lower thrust quads (or upper) while the upper (lower) thrusters are pulsing (see Fig. 3-21). This results in pure X-axis translation while maintaining nulled attitude rates.

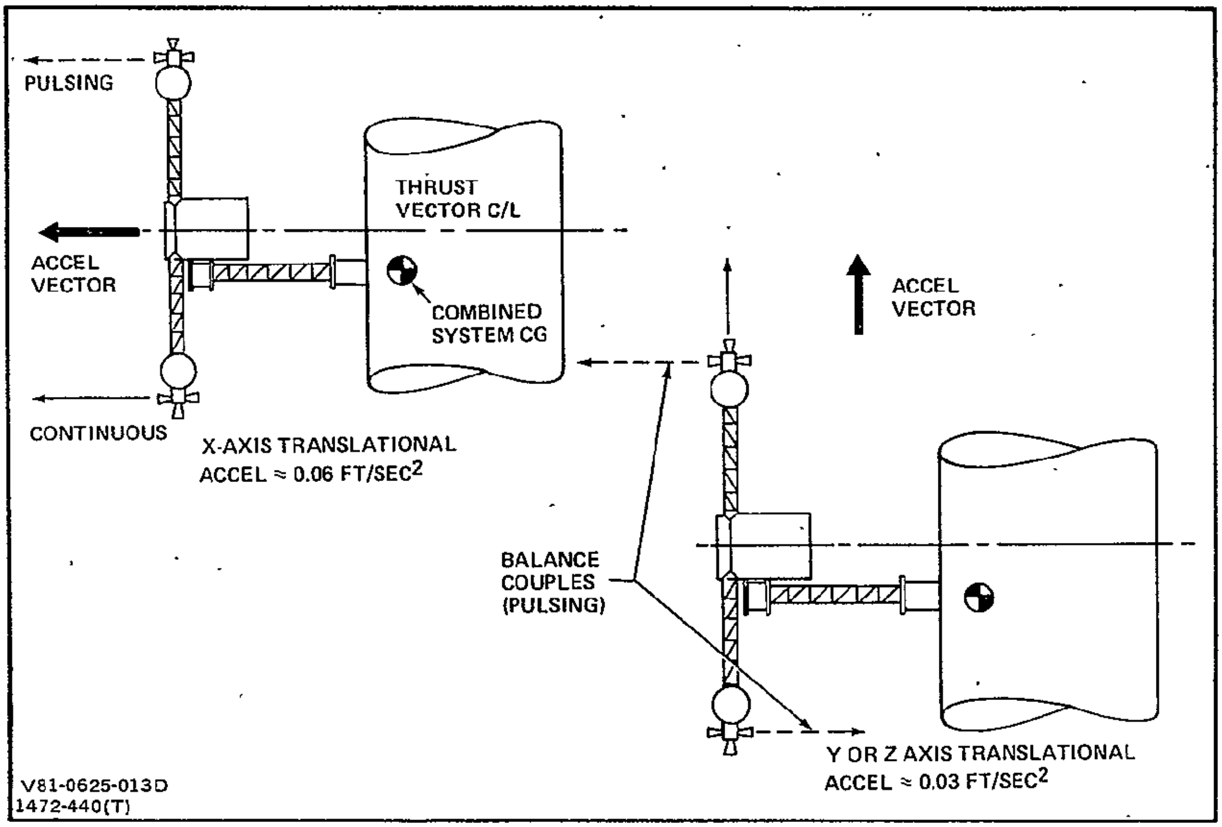


Fig. 3-21 Thruster Firing for 3-Axis Translation

Similarly, for Y-or Z-axis translation, pure translation is achieved by applying balanced couples to null rotational acceleration caused by satellite cg offsets.

Procedures used by the POM/WRU adaptation to translate from the Orbiter to the target satellite are:

- Orbiter station-keeps at $\rho = 1000$ ft with Z-axis to target (Orbiter on V, R, Inertial, or Local Horizon LOS)
- POM/WRU-adaptation translates to target in accordance with predefined range rate-LOS rate schedule along LOS
- Orbiter tracks POM/WRU using any of the following sensors:
  - Rendezvous Radar
  - COAS
  - CCTV Keel Camera
  - Star Tracker
- Orbiter relates thrust commands to POM/WRU (via voice link) until satellite range of approximately 50 - 100 feet

- POM/WRU flies direct from $\rho = 50$ ft on in.

Similar procedures are used for translating the POM/MTV adaptation except that maneuvers are executed remotely from the Orbiter rather than directly. They require control of the inertial LOS rate and range rate in accordance with a predefined schedule.

Operations are initiated after the Orbiter has completed rendezvous with the target satellite to a range of approximately 1000 ft (3000 ft for the POM/MTV) and has achieved station-keeping. Station-keeping could be performed on the R-bar or V-bar vectors, or on an inertial or local horizon LOS vector. The POM-WRU is translated along the LOS, correcting LOS rates and adjusting range rates until it arrives within a few hundred feet of the target.

LOS rate is determined by Orbiter tracking of the POM/WRU relative to the target satellite using one of several available sensors. Thrust maneuvers are related via a voice link in terms of timed thrusting maneuvers.

As the POM/WRU arrives within approximately 100 ft of the target, the pilot assumes full maneuvering control using visual cues only. Man-in-the-loop simulations have shown that a pilot can readily fly a closing trajectory from a range of 100 ft in with reasonable propellant expenditures using visual cues only.

Figure 3-22 illustrates the POM/WRU LOS approach trajectory. The Orbiter effects station-keeping on the LOS prior to releasing the POM.

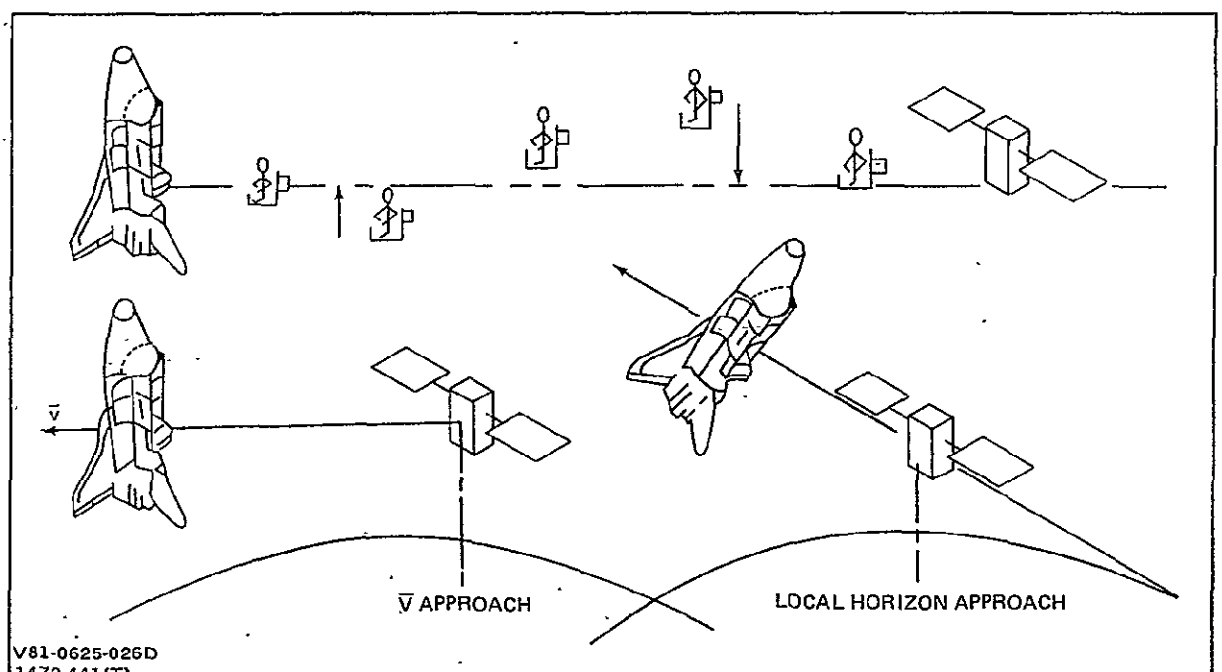


Fig. 3-22 SMM Retrieval – Translation to Satellite Stand-off Distance

The LOS vector may be either the R-bar or V-bar vectors, an inertial line of sight, or a local horizon LOS vector. Similar trajectories are flown by the POM/WRU and the POM/MTV; LOS rates are controlled along the entire approach trajectory.

Figure 3-23 shows a typical approach trajectory for the POM/WRU adaptation translating to a target satellite in a 300 n mi orbit. For this example, it was assumed the Orbiter was station-keeping on a reference vector that was aligned with the target satellite and the local horizon. This guides the POM/WRU to approach the target satellite along the local horizon vector and also allows the POM/WRU to use the local horizon as a reference path.

A maneuver schedule, to guide the POM/WRU to the satellite, follows:

RANGE (ft)	RANGE RATE (ft/sec)	LOS RATE (mrad/sec)	LOS RATE ERROR (mrad/sec)
1000	5	1.11	±0.5
700	4-6	1.11	±0.5
400	4-6	1.11	±0.5
200	3-3.5	1.11	±0.5
100	2-2.5	1.11	±0.5

Operational procedures required the POM/WRU first to correct the LOS rate at each of the range check points, and then adjust the range rate if required. In this example, it was assumed that the desired LOS rate could be controlled to within an accuracy of ±0.5 mrad/sec to reflect accuracies in both measuring and executing LOS rate corrections.

Figure 3-23 shows time histories (in terms of range-rate and inertial LOS rate) of the MMU/WRU approach from an initial range of 1000 ft to the standoff range of 25 ft. Also shown is the value of LOS rate required to maintain an approach along the initial local horizon line-of-sight vector (LOS rate ≐ 1.11 millirad/sec). Solid lines were used to represent thrusting maneuvers, and dashed lines for coasting flight. Range rate, for example, is shown to increase from zero to a closing velocity of 5 ft/sec at an initial range of 1000 ft. Thereafter, range rate remains fairly constant to a range of 200 ft where braking is initiated. LOS rate corrections are required, however, at each of the range check points to maintain control of the approach trajectory. It is assumed that, for the last 100 ft of closing, the POM/WRU flies direct using only visual cues without tracking assistance from the Orbiter.

ORIGINAL PAGE IS
OF POOR QUALITY

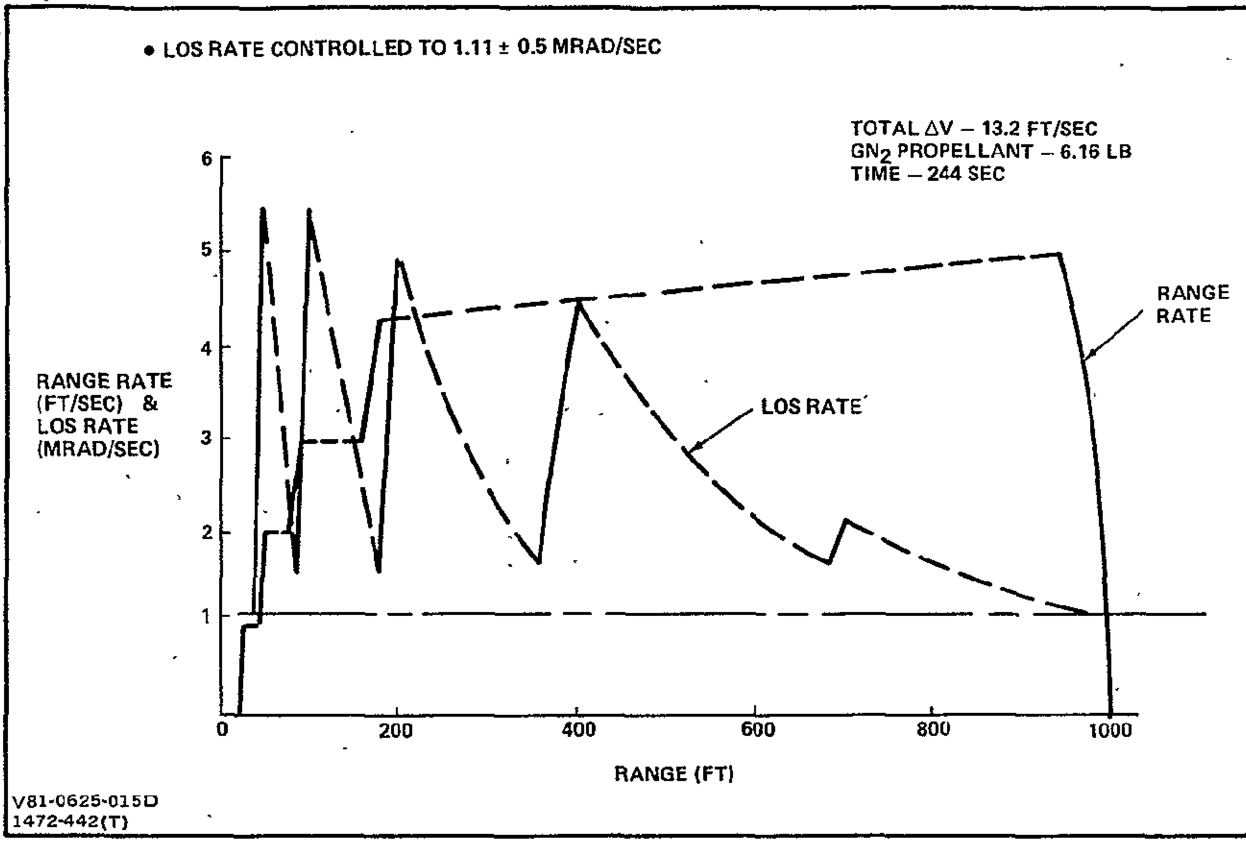


Fig. 3-23 POM/WRU Adaptation – Outbound Trajectory to SMM

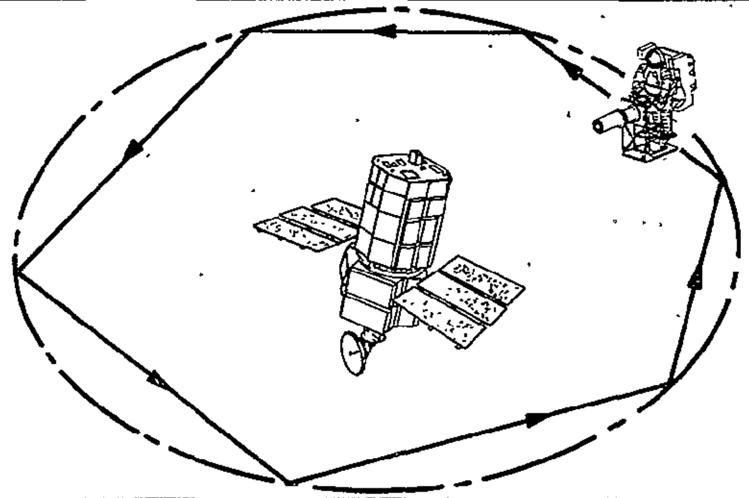
The POM/WRU Δ V and propellant requirements are also shown in Fig. 3-23. From these representative trajectory simulations, it was concluded that the POM/WRU can readily translate up to 1000 ft to retrieve satellites without the need of additional on-board sensors.

At target satellite arrival, the POM/WRU and, similarly, the POM/MTV adaptation come to a halt at a standoff range of approximately 25 ft where fly-around maneuvers are performed to inspect the satellite.

Figure 3-24 illustrates a typical fly-around maneuver. In this example, (SMM retrieval) it was assumed that two fly-around maneuvers are performed about two normal planes. The tabular data gives estimates of the Δ V and propellant requirements to perform satellite inspection, rotational synchronization, and target satellite grappling. The total time for these operations is estimated at 16 minutes.

After satisfactorily examining the target satellite and closing the capture, the POM/WRU returns to the Orbiter. Operational procedures used to return the target satellite to the immediate vicinity of the Orbiter are as follows:

ORIGINAL PAGE IS
OF POOR QUALITY



FUNCTION	MANEUVER	$\Delta\dot{V}$ (FT/SEC)	WT OF GN_2	TIME
INSPECTION	2 FLYAROUNDS (δ = 25 FT)	6.3	2.9 LB	10 MIN
SYNCHRONIZATION WITH SMM	1/2 FLYAROUND	0.6	0.3 LB	5 MIN
APPROACH AND SAT ENGAGEMENT	TRANSLATE	0.6	0.3 LB	1 MIN
	TOTALS	7.5	3.5 LB	16 MIN

1472-443(T) V81-0625-016D

Fig. 3-24 Initial Standoff to SMM Capture

- POM/Satellite orients thrust axis along LOS
- POM thrusts along LOS to achieve desired closing rate
- Orbiter tracks POM/Satellite using any of the following sensors (rendezvous radar, COAS, CCTV - Keel Camera, Star Tracker)
- Orbiter performs LOS rate corrections
- POM performs braking maneuvers using Orbiter tracking data (voice link)
- Orbiter aligns POM approach trajectory with payload bay
- POM brings satellite to zero relative velocity in vicinity of payload bay (10 - 20 ft) and releases satellite grapple fitting
- Orbiter RMS attaches to satellite grapple fitting.

Procedures are similar for both the POM/WRU and POM/MTV adaptations except that LOS rate corrections are applied. For the POM/WRU, because of its poor translational capability normal to the LOS vector while towing, the Orbiter tracks and nulls the LOS rate. The POM/WRU performs only initial range rate and braking maneuvers. For the

POM/MTV adaptation, because of efficient translational maneuvering both on and normal to the LOS vector, it performs both range rate and LOS rate corrections.

Figure 3-25 illustrates the difference in POM/WRU and POM/MTV satellite return trajectories. The Orbiter executes all LOS rate corrections for the POM/WRU return.

Typical characteristics of the POM/WRU trajectory when towing a satellite to the Orbiter are shown in Figure 3-26. A reference maneuver schedule was devised for the return trajectory as follows:

RANGE (ft)	RANGE RATE (ft/sec)	LOS RATE (mrad/sec)	LOS RATE ERROR (mrad/sec)
1000	2.0	0	±0.2
600	1.5-2.5	0	±0.2
300	1.5-2.5	0	±0.2
150	1.0	0	±0.2
50	0.5	0	±0.2
25	0.1	0	±0.2

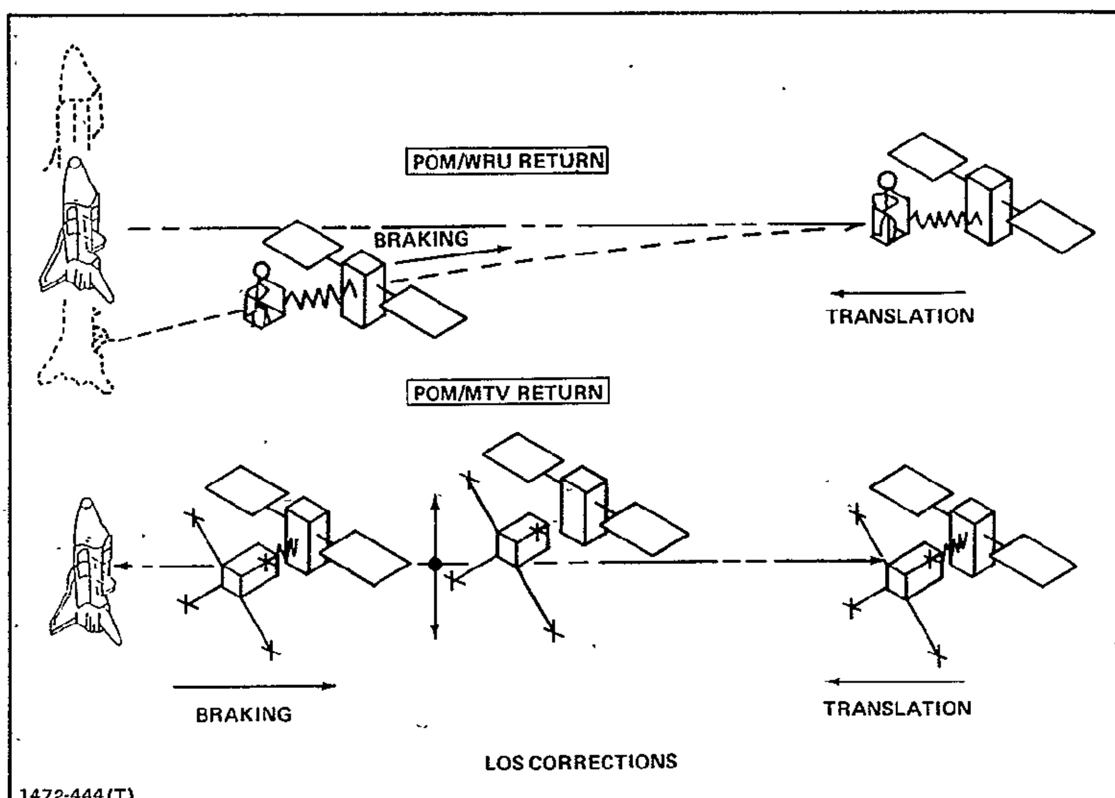


Fig. 3-25 SMM Retrieval – POM Return to Orbiter

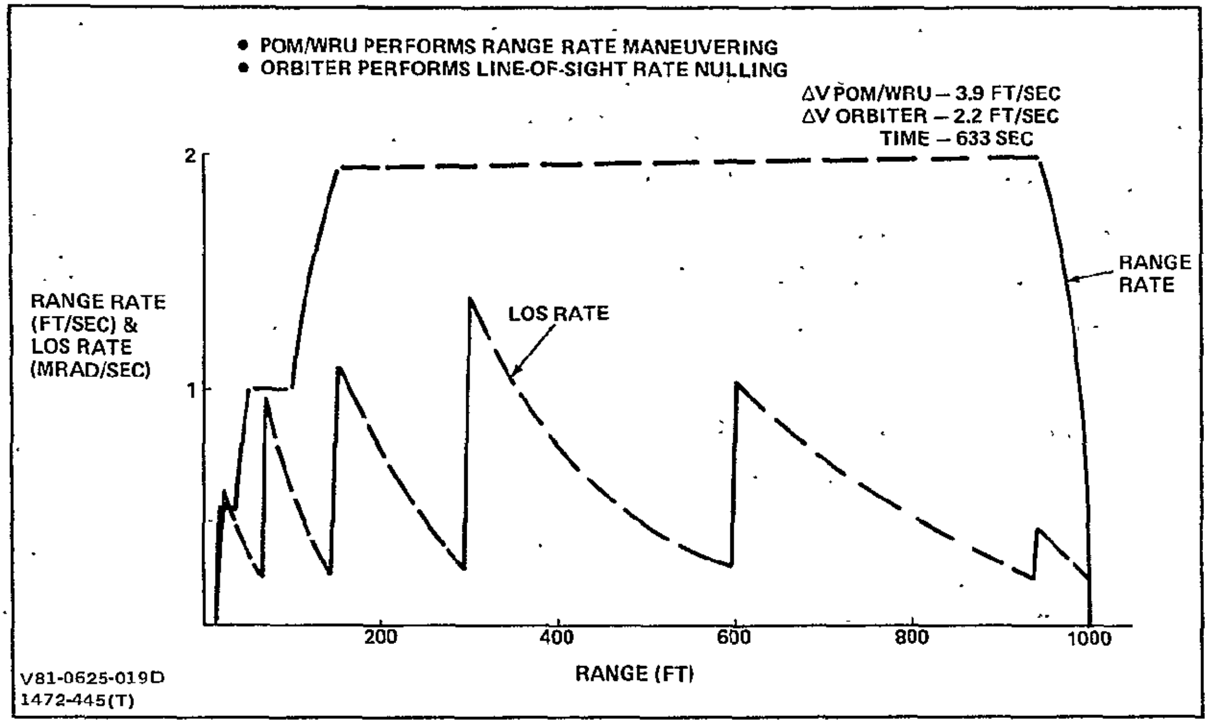


Fig. 3-26 POM/WRU – Return Trajectory to Orbiter

In this simulation, it was assumed that the Orbiter nulled the LOS rate to within an error tolerance of 0.2 mrad/sec.

Summarized in Figure 3-26 are the ΔVs expended by the POM/WRU and Orbiter. The overall time was estimated to be approximately 10 minutes.

Figure 3-27 summarizes overall performance characteristics and propellant utilization of the POM/WRU and Orbiter during SMM retrieval. These results are based on

MANEUVER	TIME (MIN)	V (FT/SEC)	POM/WRU PROPELLANT (LB)	ORBITER PROPELLANT (LB)
POM TRANSLATION TO STAND OFF RANGE (25 FT)	4.1	13.2	6.2	5 (STATION-KEEPING)
FLY-AROUND INSPECTION, TARGET GRAPPLING, ALIGNMENT FOR RETURN	16 0	7.5	3.5	20 (STATION-KEEPING)
POM TRANSLATION TO ORBITER – RMS GRAPPLE	10.5	3.9	11.8	12.5 + 67 (LOS RATE NULLING & STATION-KEEPING)
SUB-TOTALS	33.6	24.6	21.5	104
UNCERTAINTIES (10%)	3.3	2.6	2.5	11
TOTALS 1472-446(T)	36.5	28.3	24.0	115

Fig. 3-27 POM/WRU Flight Profile Summary

trajectory simulations that included nominal error tolerances in sensing, and maneuvers executed during the approach to satellite and return to Orbiter trajectory paths. A 10% contingency was included to account for other uncertainties.

These results indicate that SMM retrieval using the POM/WRU adaptation is a feasible alternative to Orbiter-direct retrieval. Favorable comparisons can be made in terms of retrieval trajectory time, MMU propellant capacity available, and Orbiter RCS propellant usage. POM/WRU propellant is estimated at 24 lb, well within the MMU User's Guide capacity of 40 lb (Reference 2)*.

A comparison of the propellant requirements and mission event times for Solar Max retrieval, using the Orbiter direct mode and the POM/WRU and POM/MTV adaptations, is presented in Fig. 3-28. Although Orbiter RCS propellant is only one of many criteria to be used in comparing these respective modes, the results suggest that significant savings in Orbiter RCS propellant consumption can be realized for satellite retrieval operations using a POM. This can be an important factor on long missions when rendezvous and satellite retrieval is only one of many events in the mission flight plan.

RETRIEVAL MODE	ORBITER PROPELLANT (LB)	POM PROPELLANT (LB)	TIME (MIN)
ORBITER – DIRECT (LOW Z THRUSTING)	*650	–	28
POM/WRU ADAPTATION	115 (STATION-KEEPING & LOS RATE CORRECTION)	24.0	33.5
POM/MTV ADAPTATION	40	20	30
1472-447(T)			*AVERAGE

Fig. 3-28 Summary of Orbiter RCS Propellant Consumption

Minimum propellant is incurred for retrieval with the POM/MTV adaptation although significant savings are also shown for the POM/WRU adaptation. These savings can be realized with little effect on overall mission event time.

3.4.3 MMU/Powered Winch Retrieval

Another concept that appears feasible for effecting satellite retrieval is the MMU/Powered Winch concept (see Fig. 3-29). This concept features use of a tether to

---

*Ref. 2: "Manned Maneuvering Unit, User's Guide", May 1978, NAS9-14593

ORIGINAL PAGE IS
OF POOR QUALITY

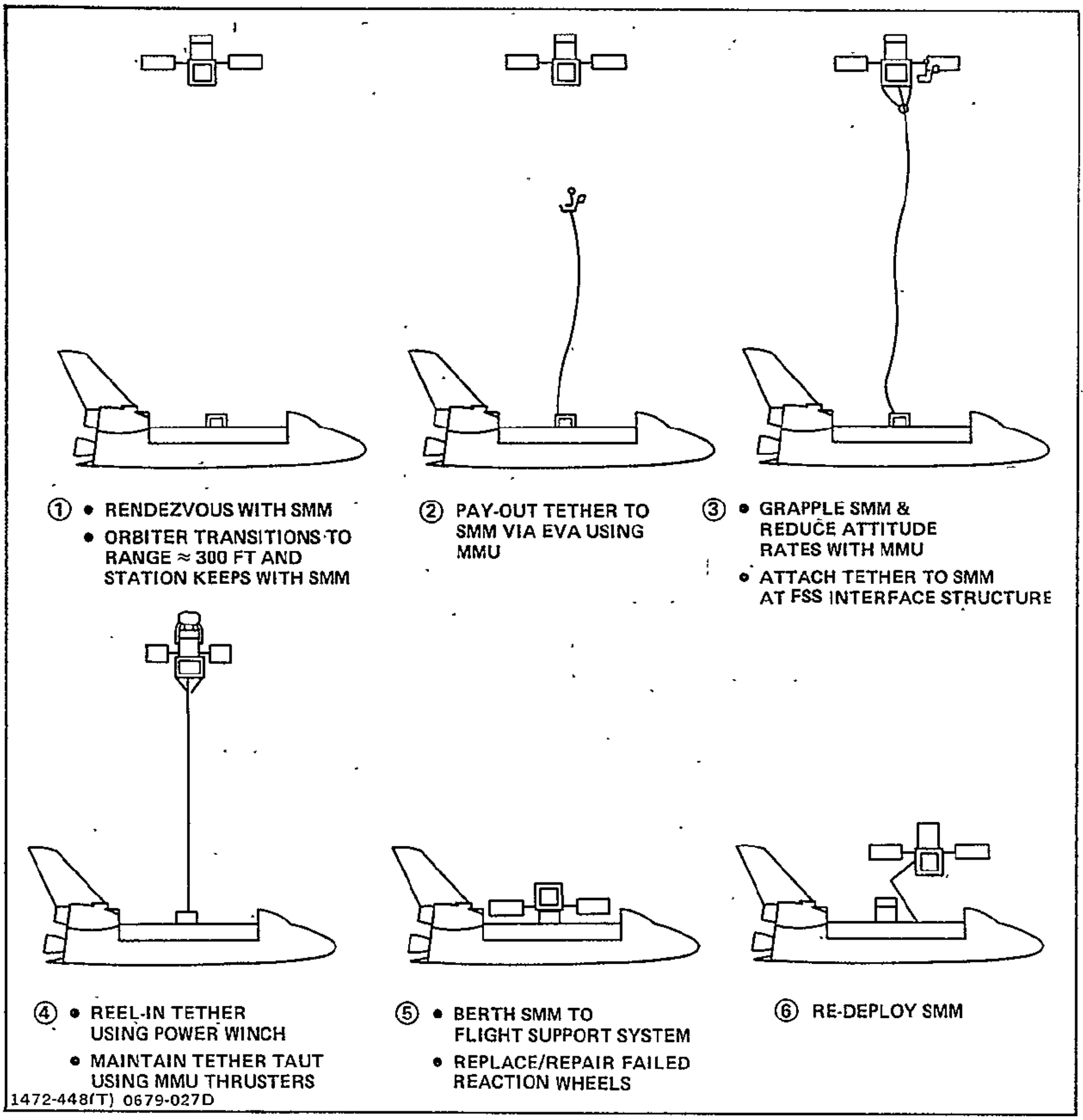


Fig. 3-29 Manned Maneuvering Unit/Powered Winch Retrieval

translate the satellite to the immediate vicinity of the Orbiter. The tether is payed out to the satellite by EVA using the MMU.

Also shown in Fig. 3-29 is the operational sequence of events required for SMM retrieval using this concept. If necessary, satellite attitude rates are nulled using MMU thrusting and maintained during reel-in of the tether. MMU thrusting would also maintain the tether taut during this operation.

ORIGINAL PAGE IS
OF POOR QUALITY

This concept offers advantages similar to the POM Mode in that the Orbiter transitions to an initial offset distance from the satellite (nominally about 300 ft) and stationkeeps at that range. This avoids much of the Orbiter plume impingement on the satellite that is normally experienced during very close range maneuvering. It also reduces Orbiter RCS propellant requirements; the extent of these savings, however, is yet to be determined.

Figure 3-30 illustrates a concept for modifying the FSS to assist berthing the spacecraft to the FSS tilt table. The concept consists of adding a cable guide to the tilt table latching mechanisms to align the spacecraft latching pins with the latching mechanisms as the tether lines are reeled in.

Tether lines are attached to the spacecraft latching pin by inserting pip pins into each of the spacecraft latching pins. D-rings are mated to the attachment fittings to secure the three tether lines to the pip pins.

After attaching the tether lines to the spacecraft, retrieval is accomplished by reeling in the tether using a powered winch. Astronaut assist is required to maintain the tether taut during reeling operations.

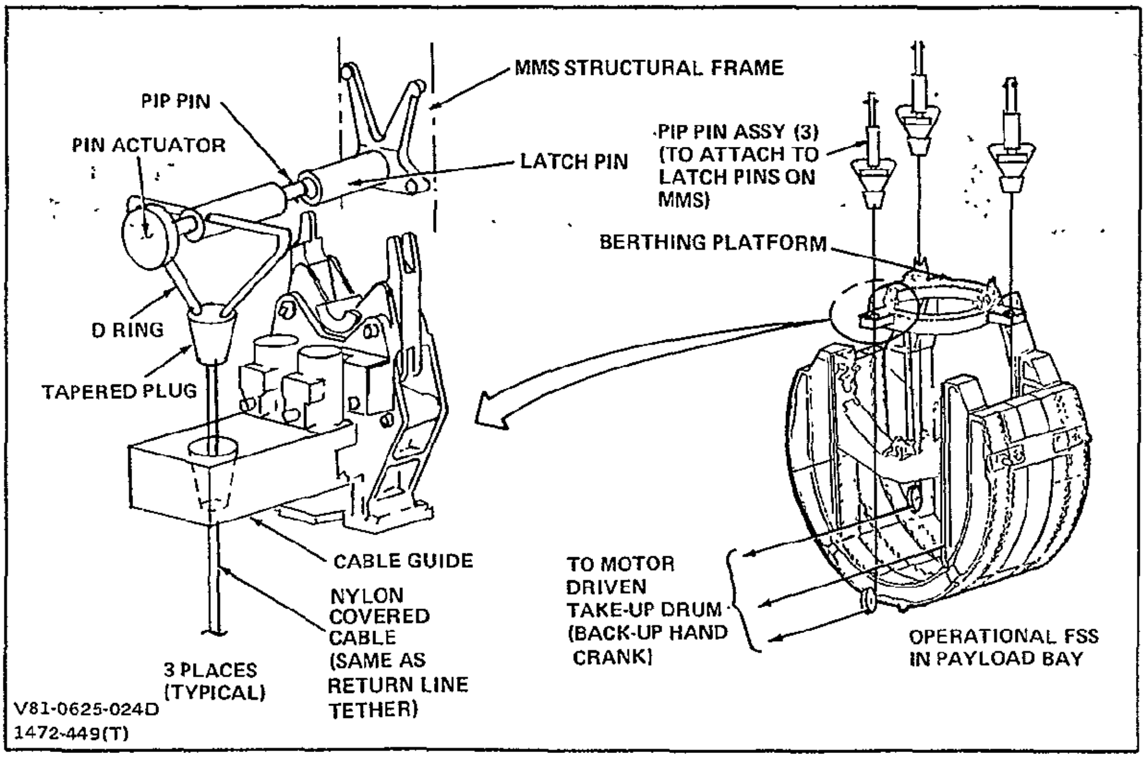


Fig. 3-30 Manned Maneuvering Unit/Powered Winch Retrieval

3.4.4 Conclusions & Recommendations

After completing a review of the baseline close proximity operations and analyzing alternative concepts for effecting satellite retrieval, the following conclusions have been drawn:

- The practicality of retrieving satellites via the Orbiter Direct Mode requires further assessment. The major issues to be resolved are:
  - Effect of Orbiter thrust impingement on satellite's attitude stability
  - Orbiter maneuvering limitations after RMS is unstowed
  - RMS capability to grapple satellites
  - Orbiter RCS propellant requirements
- The use of Proximity Operations Modules (POMs) to assist the Orbiter in satellite retrieval appears to be a viable alternative. A manned POM, an adaptation of the Work Restraint Unit, could probably be developed to assist the SMM retrieval in the '83-'84 time period. An unmanned POM, an outgrowth of the Maneuverable TV, could be developed for later retrieval mission needs
- Orbiter retrieval of satellites with the aid of a powered winch may also be a viable alternate, however, further evaluation is needed to fully understand the issues related to this concept.

To ensure that a satellite retrieval capability will exist in the time frame required by the user community, the following recommendations are offered:

- Perform early demonstration of satellite retrieval to convince the user community of STS capabilities; SMM retrieval appears to be the most viable opportunity available
- Continue in-depth evaluations of Orbiter-direct satellite retrieval mode and compare potential readiness/practicality with close proximity alternates
- Initiate development of the POM/WRU adaptations as a prime backup to Orbiter-direct SMM retrieval
- Study and develop other alternate concepts (such as POM/MTV adaptation) to ensure STS readiness to demonstrate satellite retrieval in an early time frame.

4 — On Orbit Servicing Equipment

4 — On Orbit Servicing Equipment

4 - ON-ORBIT SERVICING EQUIPMENT

Satellite service equipment associated with on-orbit servicing operations involves the following items:

- Open Cherry Picker/Remote Manipulator System (OCP/RMS)
- FSS Tilt Table/OCP Work Platform
- Handling and Positioning Aid (HPA)
- Equipment Storage
- Fluid Transfer
- Non-Contaminating Attitude Control System (ACS)
- Aft Flight Deck (AFD) Controls/Displays.

Subsequent sections will discuss and illustrate the service equipment concepts.

4.1 OPEN CHERRY PICKER/REMOTE MANIPULATOR SYSTEM (OCP/RMS)

The Open Cherry Picker (OCP) shown in Fig. 4-1 is a movable work station controlled by an astronaut on the tip of the RMS arm. Features of the OCP include:

- Work platform interfaces with the RMS
- Enables RMS control from the work platform
- Work platform provides
  - Lighting
  - Tool storage
  - Payload handling mechanisms
  - Stabilizer to dampen RMS motion
  - Rotating foot restraint.

Figure 4-2 depicts an astronaut replacing an equipment module on a representative Multimission Modular Spacecraft (MMS). The OCP's movable foot restraint reduces the

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

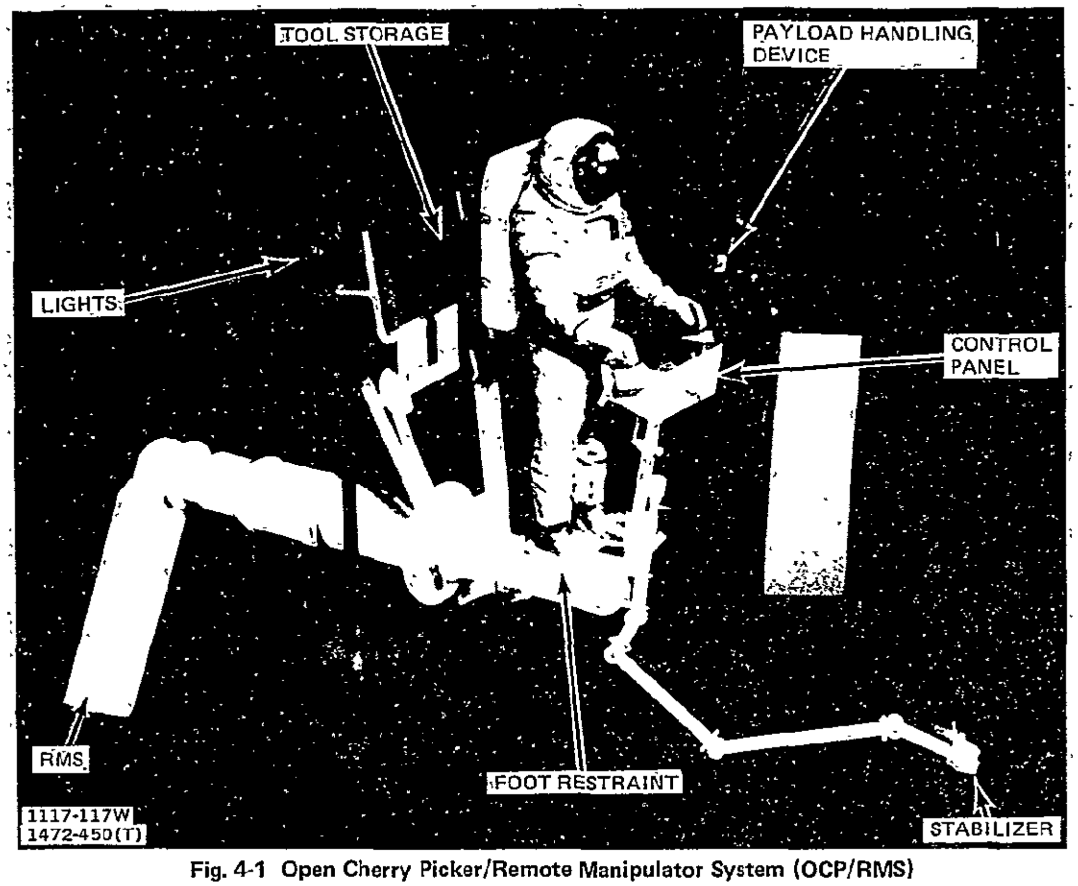


Fig. 4-1 Open Cherry Picker/Remote Manipulator System (OCP/RMS)

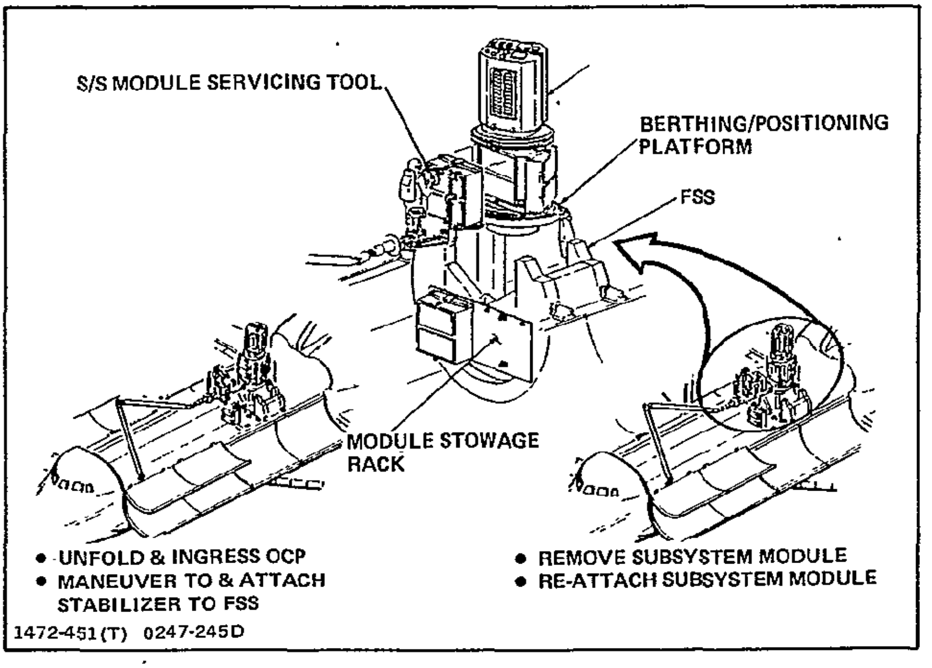


Fig. 4-2 Open Cherry Picker – Servicing

physical effort required to perform EVA and, with its control station, allows the astronaut to fly himself to the most convenient position to perform service functions within the Orbiter payload bay.

4.2 OPEN CHERRY PICKER - FLIGHT SUPPORT SYSTEM (FSS) WORK PLATFORM ADAPTATION

A concept that can further enhance the servicing of satellites in the Orbiter Payload bay is illustrated in Fig. 4-3. An OCP is interfaced to the FSS Cradle A' Berthing and Positioning system with extension and lift booms that allow the work platform to be positioned at variable offset and height distances from the satellite base. A full 360° satellite rotation within the berthing system provides total access to all locations on the satellite.

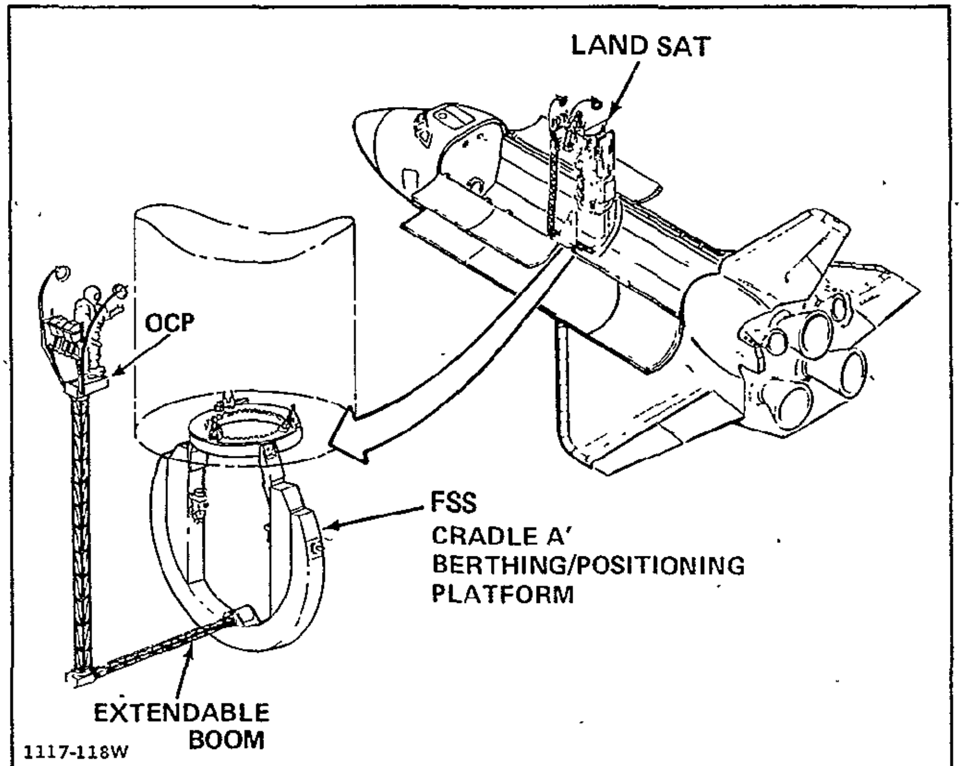


Fig. 4-3 Open Cherry Picker — FSS Work Platform Adaptation

Equipment racks mounted on the Cradle A' provide stowage for components and modules needed for servicing. This concept provides all the features of an Open Cherry Picker within the immediate area of the satellite work site, while freeing the RMS for supporting operations. The illustration shows application of the system to servicing of LANDSAT.

A layout drawing of the FSS work platform adaptation is shown in Fig. 4-4. As shown, its estimated weight is 395 lb.

4.3 HANDLING AND POSITIONING AID (HPA)

The HPA will support satellites outside the confines of the payload bay and, with its "over-the-side" features, could enable full deployment of satellite appendages (if desired) prior to release from the Orbiter (see Fig. 4-5). For initial launch missions, the HPA contains a standardized berthing and umbilical interface for checkout prior to deployment. It also has provisions for transferring attitude/state vector information to the satellite from the Orbiter navigation system, and provides the means to impart a separation velocity between the satellite and Orbiter during deployment. A spin table capability can also be accommodated.

On-orbit servicing is accommodated by rotating turn-table provisions in the HPA and via a movable work platform that incorporates an OCP. The work platform has translational and vertical motion capability which, in conjunction with the HPA turntable features, enables total access to all satellite locations. The standardized berthing and umbilical interface also contains a fluid coupling interface to transfer propellants during servicing missions.

A layout drawing of the HPA is shown in Fig. 4-6; its estimated weight is about 1800 lb. Figure 4-7 details the concept and operation of the OCP movable work station on the HPA.

Figure 4-8 depicts a two-astronaut servicing capability. One astronaut is shown servicing a segment of the satellite via an OCP that is mounted to the end of the RMS arm. The second astronaut utilizes the OCP work platform on the Handling and Positioning Aid.

Although not shown in the illustration, the OCP with its stabilizer feature could attach itself to the satellite, release from the RMS, and enable the RMS to transport equipment from the Orbiter payload bay to the respective work stations.

4.4 EQUIPMENT STORAGE

As identified in the Level 1 operational scenarios (Ref: Volume 3A), a need exists for equipment stowage canisters to transport components, replacement modules, instruments, and other equipment used in satellite servicing support, refurbishment, and reconfiguration. Figure 4-9 shows three concepts that have been developed for positioning/ deploying the canisters during their use. The side swing concept utilizes a

ORIGINAL PAGE IS
OF POOR QUALITY

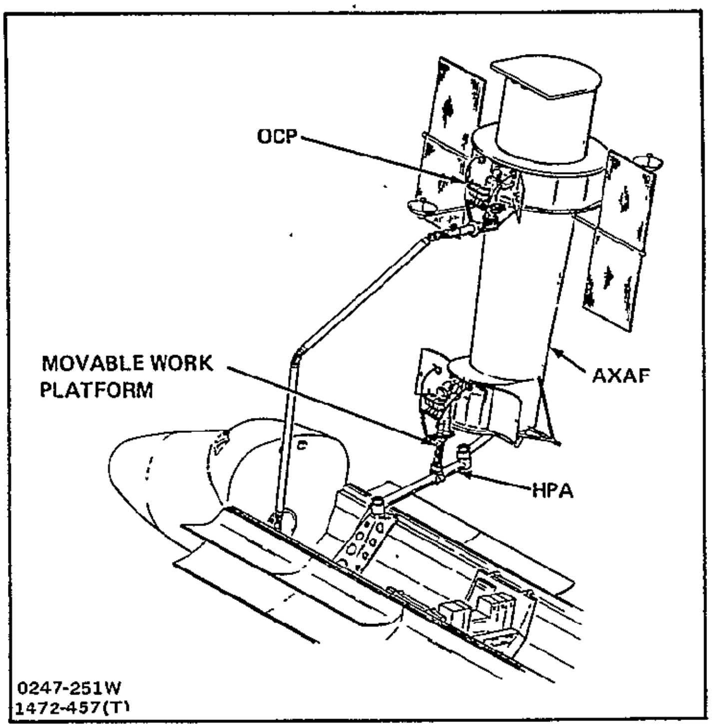


Fig. 4-8 Dual Servicing Capabilities

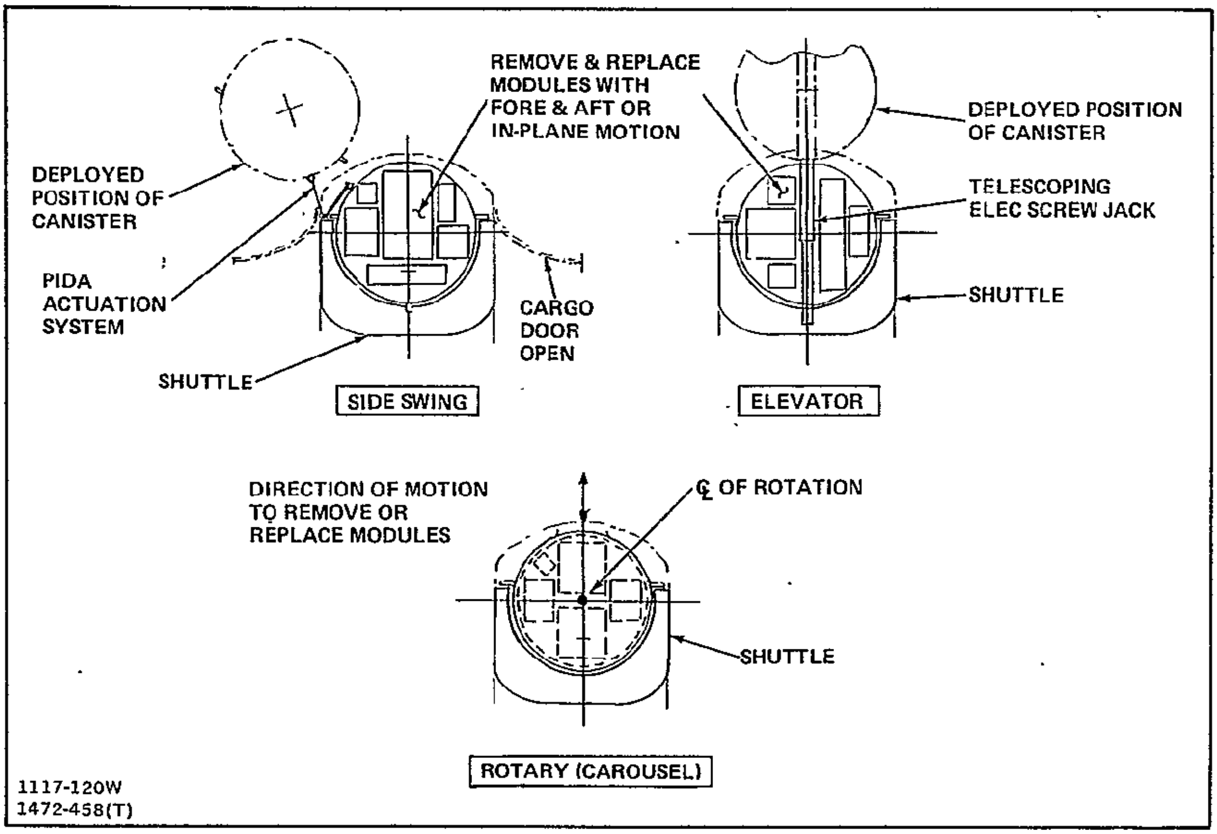


Fig. 4-9 Equipment Stowage Concepts

ORIGINAL PAGE IS
OF POOR QUALITY

RELATIVE SYSTEM FEATURES			
CONCEPT	ROTARY	SIDE SWING	ELEVATOR
ACTUATION MECHANISM	NEW	EXISTING	NEW
CANNISTER COMPLEXITY	ACTIVE MECHANICALLY	PASSIVE SYSTEM	PASSIVE SYSTEM
INTERFERENCE WITH RMS WORK ENVELOPE	NO	YES	YES
RELATIVE DEVELOPMENT COST	2	1	2
RELATIVE PROCUREMENT TIME	1.5	1.0	1.5
RELATIVE WEIGHT	1.2	1.0	1.0
VOLUMETRIC EFFICIENCY	45%	65%	55%
1472-459(T) 0247-274W			

Fig. 4-10 Equipment Stowage Evaluation

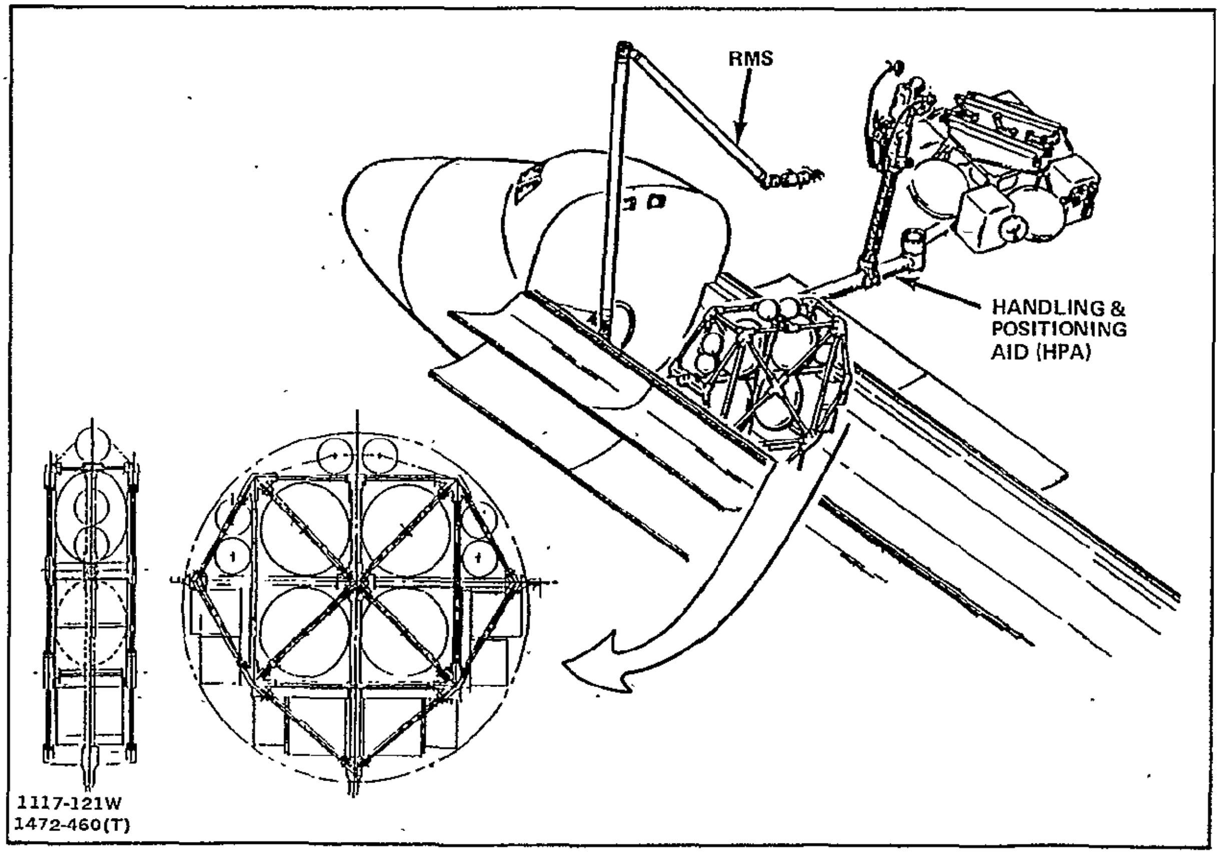


Fig. 4-11 Fluid Transfer

Figure 4-12 is a conceptual layout of a propellant fluid transfer system as it interfaces in the Orbiter payload bay. An aluminum tubular weld assembly, which attaches to the Orbiter with two longeron trunnion fittings and a keel attachment fitting, serves as the overall structural support. Features of this concept are:

- Pressure regulated, bladdered fluid transfer system capable of delivering up to 5000 lb hydrazine
- Off-the-shelf tankage
  - Propellant system uses five TDRSS tanks at 370 psi
  - Pressurization system uses two Viking Orbiter gaseous nitrogen tanks at 4000 psi
- PVT gauging system with loading accuracy of ±1/2% full load; flow meter backup
- Gaseous and liquid transfer provisions with associated mechanical and electrical hardware for control, self-check, and servicing
- Support structure capable of handling various sized tankage depending on mission need
- Potential for integrating fluid transfer within HPA service functions and standardizing propellant transfer interface.

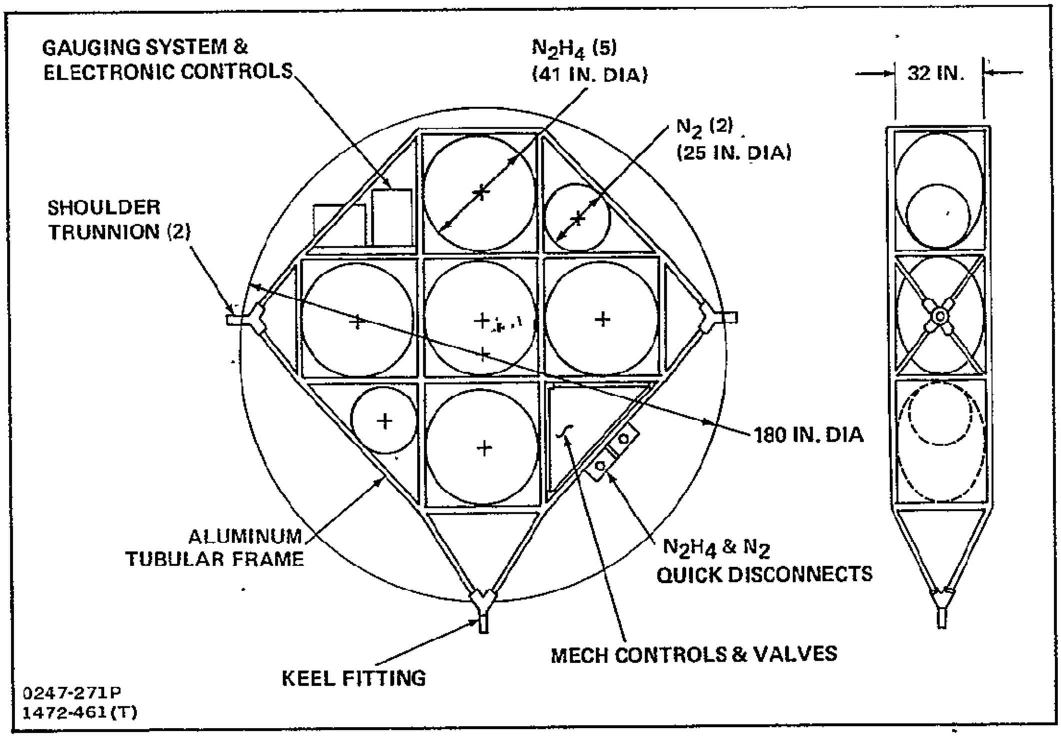


Fig. 4-12 Orbital Refueling System

ORIGINAL PAGE IS
OF POOR QUALITY

4.6 NON-CONTAMINATING ATTITUDE CONTROL SYSTEM (ACS)

Orbiter servicing of contamination-sensitive satellites can be accomplished by providing a non-contaminating ACS package in the payload bay. The package would provide precision, long-term attitude control without the use of the Orbiter's primary or vernier reaction control systems. Alternatively (and if acceptable), the Orbiter could be placed into a free drift mode.

Figure 4-13 shows a non-contaminating ACS concept of Skylab-type CMGs located in the payload bay with cold gas thrusters/N_2 propellant mounted on extensible arms to serve as momentum unloading devices.

An arrangement of the CMG/N_2 control augmentation system concept, as packaged in the Orbiter payload bay, is shown in Fig. 4-14. The CMGs are mounted to a structural pallet located immediately aft of the forward bulkhead. The extendable masts, which house the nitrogen propellant tanks, are stowed directly above the CMGs. The total system volume (stowed) is confined to that occupied by one spacelab pallet.

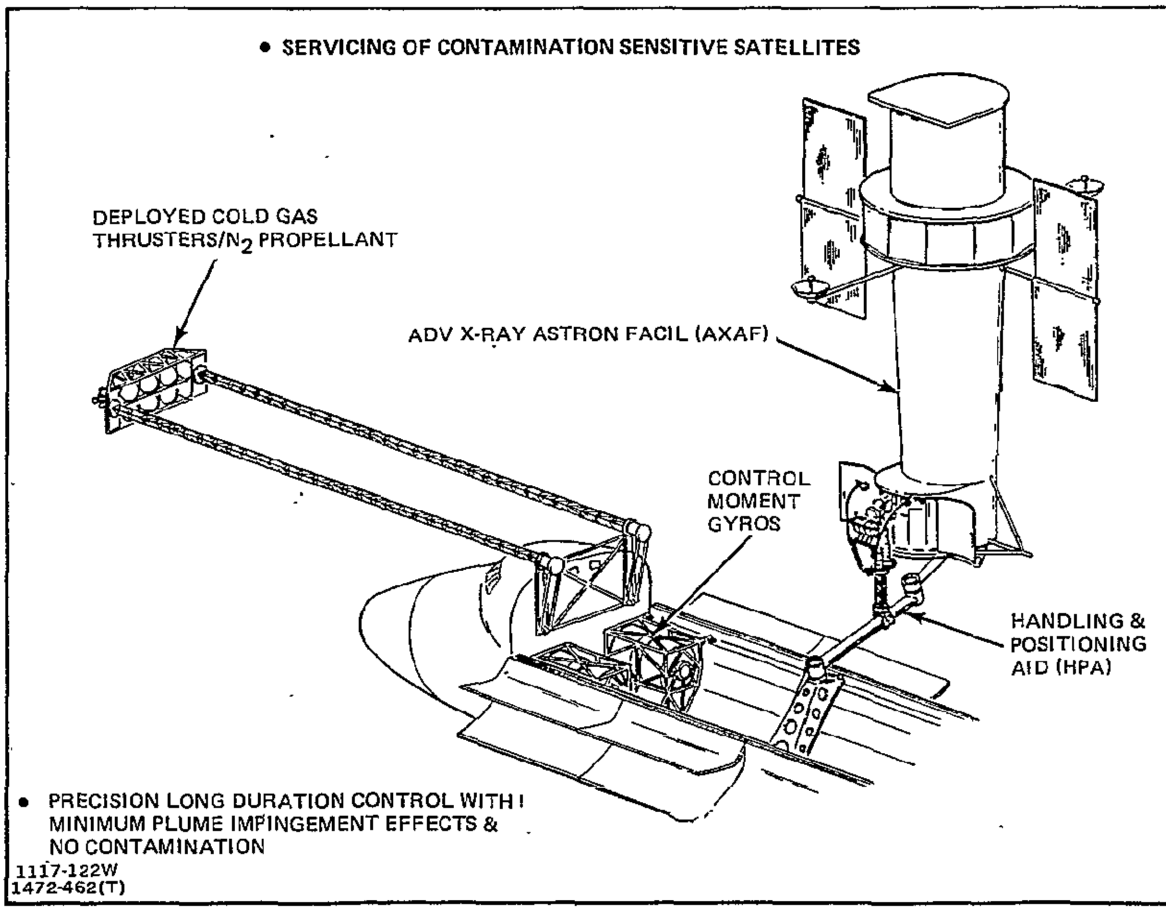


Fig. 4-13 Non-Contaminating Attitude Control System

ORIGINAL PAGE IS
OF POOR QUALITY

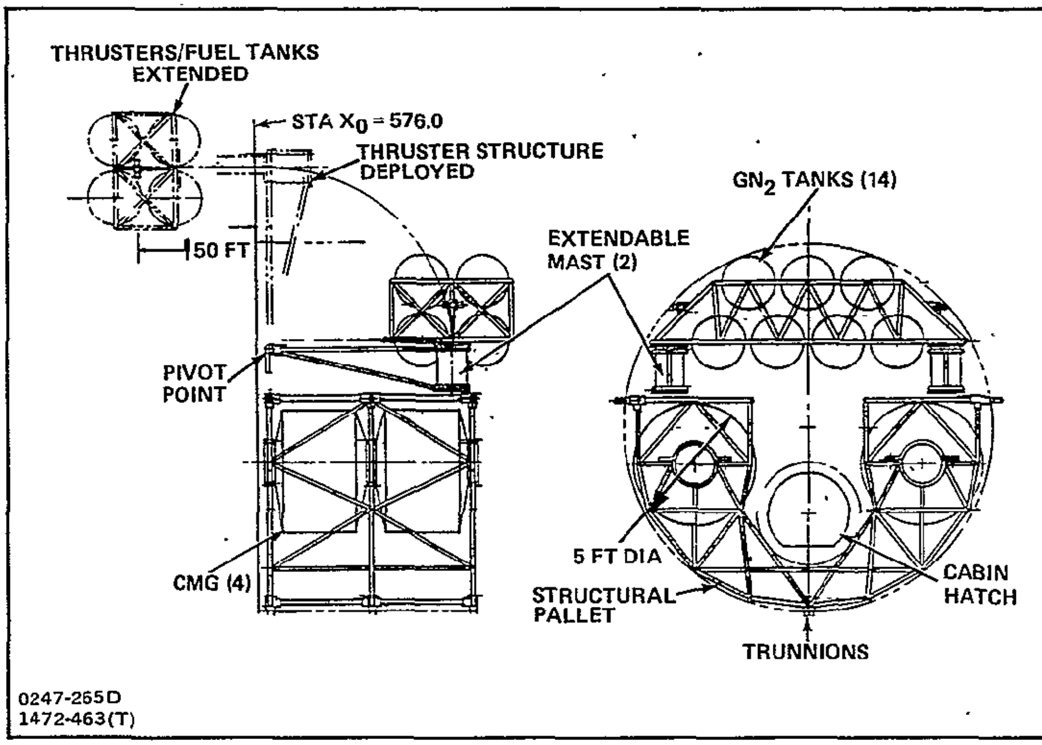


Fig. 4-14 Orbiter Control Augmentation Package

The system provides momentum management control of the Orbiter and features:

- Reliable, long term Orbiter attitude control without the use of the primary or vernier reaction control systems
  - Four skylab-type CMGs
  - Nine GN_2 tanks (40 lb each)
  - Six redundant pairs of deployed thrusters
  - Minimized cargo bay volume
- Minimum contamination environment for orbital operations
  - CMG momentum management
  - Periodic jet unloading
- Reduced Orbiter propellant consumption on-orbit with precision, low torque control.

Six redundant pairs of thrusters are deployed well forward of the Orbiter's nose (to maximize moment arms and minimize plume effects) by two rotating arms which are stowed along the cargo bay sill. The nitrogen is stored in a tank pod which integrates the thrusters and tankage into a module mounted on the deployed arms.

An alternate non-contaminating attitude control concept is the Annular Momentum Control Device (AMCD) shown in Fig. 4-15. The AMCD provides momentum bias stabilization for long-term attitude holding without thruster firing. The AMCD features are:

- Long-term attitude stability without use of RCS
  - Large X-axis momentum wheel
  - Pitch/Yaw stability
  - Roll orientation capability
- Laboratory version built and tested.

The AMCD consists of a large diameter, magnetically-suspended wheel which is spun-up about an axis parallel to the Orbiter's longitudinal (X) axis. The large momentum of the wheel provides gyroscopic stiffness which resists the disturbing effects of external torque. The normal Orbiter attitude for the use of this device would be with the X-axis perpendicular to the orbit plane and the payload bay oriented toward the earth.

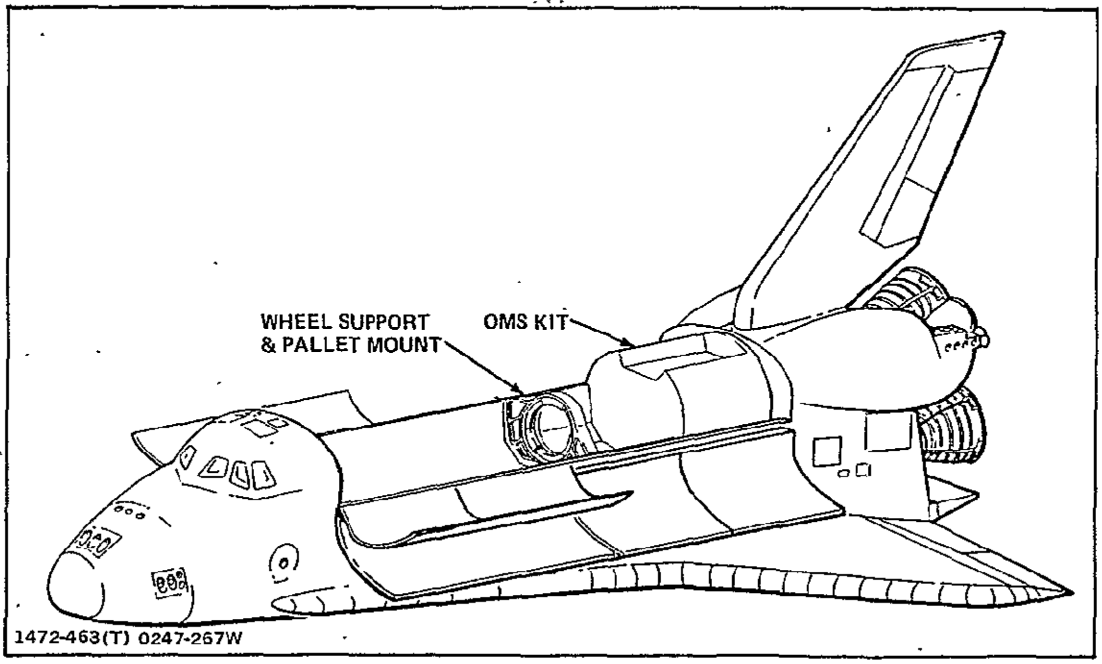


Fig. 4-15 Annular Momentum Control Device (AMCD)

5 — Backup & Contingency Equipment

5 — Backup & Contingency Equipment

5 - BACKUP & CONTINGENCY EQUIPMENT

Satellite service equipment associated with backup/contingency operations includes:

- Manipulator Foot Restraint/Remote Manipulator System (MFR/RMS)
- Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU) adaptations
  - End effector for satellite deployment
  - Stabilizer for mechanical hangup situations
  - Payload handling for on-orbit servicing support.

5.1 MANIPULATOR FOOT RESTRAINT/REMOTE MANIPULATOR SYSTEM (MFR/RMS)

The Manipulator Foot Restraint (MFR) is mounted on the end of the RMS arm and used to support contingency operations in the payload bay which require EVA. The MFR/RMS serves as a backup for potential hangup of retention latches, mechanical hangup situations associated with satellite appendage deployment, and EVA support of sortie missions.

Figure 5-1 shows an astronaut being deployed on the MFR to manually release a retention latch. This concept features the following:

- Rotating foot restraint mounted to RMS using standard end effector
- Stores in forward cargo bay in area reserved for EVA support systems
- Includes rotating tool bin and hand hold to carry supporting tools
- Reduces on-orbit EVA time
- Simplifies tether management
- Reduces physical effort required to perform EVA tasks.

In addition to providing the astronaut with a foot restraint which reduces physical effort required to perform EVA tasks, the MFR includes a tool bin to carry supporting tools that may be needed for backup operations.

ORIGINAL PAGE IS
OF POOR QUALITY

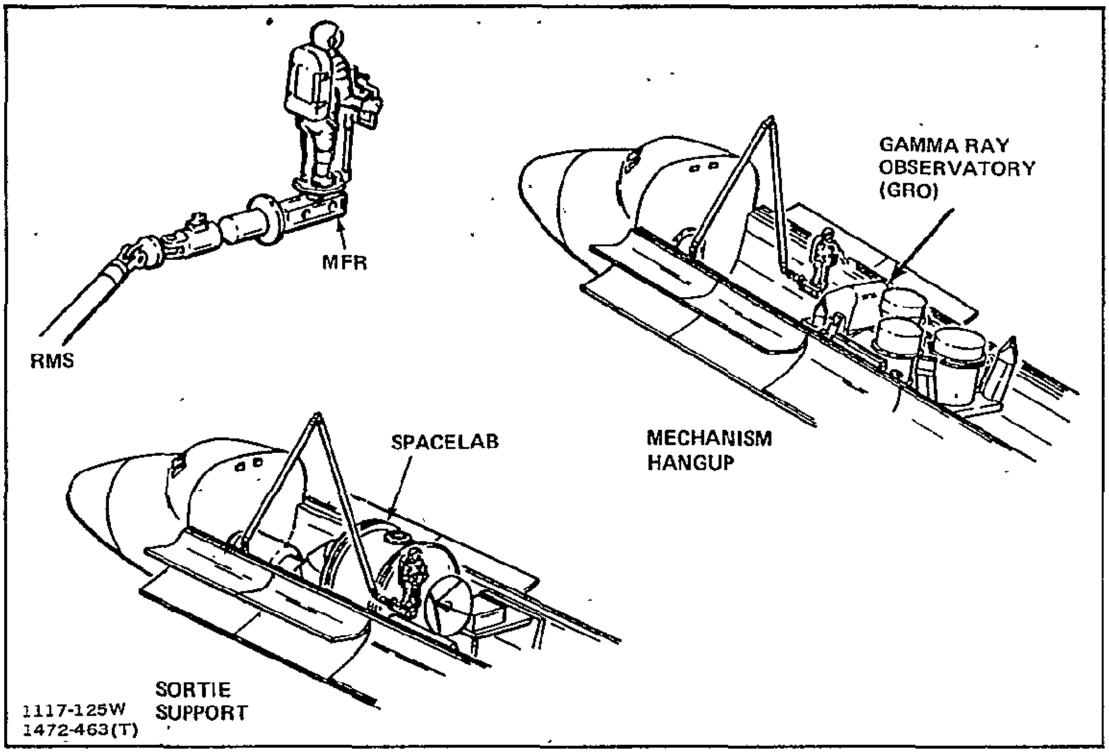


Fig. 5-1 Manipulator Foot Restraint (MFR)

Figure 5-2 presents a comparison of typical EVA times needed for servicing the Plasma Diagnostics Package (PDP) using standard EVA procedures and the Manipulator Foot Restraint. As indicated, using the MFR reduces EVA time by a factor of 4.

5.2 MANNED MANEUVERING UNIT/WORK RESTRAINT (MMU/WRU) ADAPTATIONS

Three variations of MMU/WRU adaptations that have been identified in this study are shown in Fig. 5-3. The WRU adaptations feature:

- "Kit" adaptations that are applicable in all situations when the RMS is inoperative
- Lifts-out/deploys payloads for RMS inoperative modes
- Provides portable work station (in and about payload bay) for planned and contingency servicing operations
- Enables transport of equipment/components to work sites
- Utilizes existing, space-qualified components.

ORIGINAL PAGE IS
OF POOR QUALITY

EVA		MFR	
Operation	Time (min)	Operation	Time (min)
1 – EGRESS AND TRANSLATE PDP WITH MESA TOOLS & FOOT RESTRAINT	10	1 – EGRESS ORBITER & TRANSLATE TO MFR*	4
2 – ATTACH PORTABLE FOOT RESTRAINTS & RELEASE PDP FASTENERS (3 PLACES)	78	2 – MANEUVER RMS TO PDP	2
3 – RETURN TO MESA	5	3 – REMOVE PDP (3 PLACES) & SECURE TO MFR	15
4 – RMS/PDP OPS	–	4 – RMS/PDP OPS	–
5 – TRANSLATE TO PDP POSITION WITH MESA TOOLS & FOOT RESTRAINT	6	5 – REINSTALL PDP (3 PLACES)	15
6 – ATTACH PORTABLE FOOT RESTRAINT & SECURE PDP (3 PLACES)	78	6 – MANEUVER MFR TO RETENTION STATION & SECURE	5
7 – RETURN TO MESA & SECURE TOOLS & FOOT RESTRAINT	5	7 – RETURN TO SHUTTLE	4
8 – RETURN TO SHUTTLE	4	TOTAL	45
TOTAL	186		

0247-248P
1472-464(T)

*ASSUMES TOOL IS STOWED ON MFR

Fig. 5-2 Timeline Comparison – Major Time Savings in Foot Restraint Operations

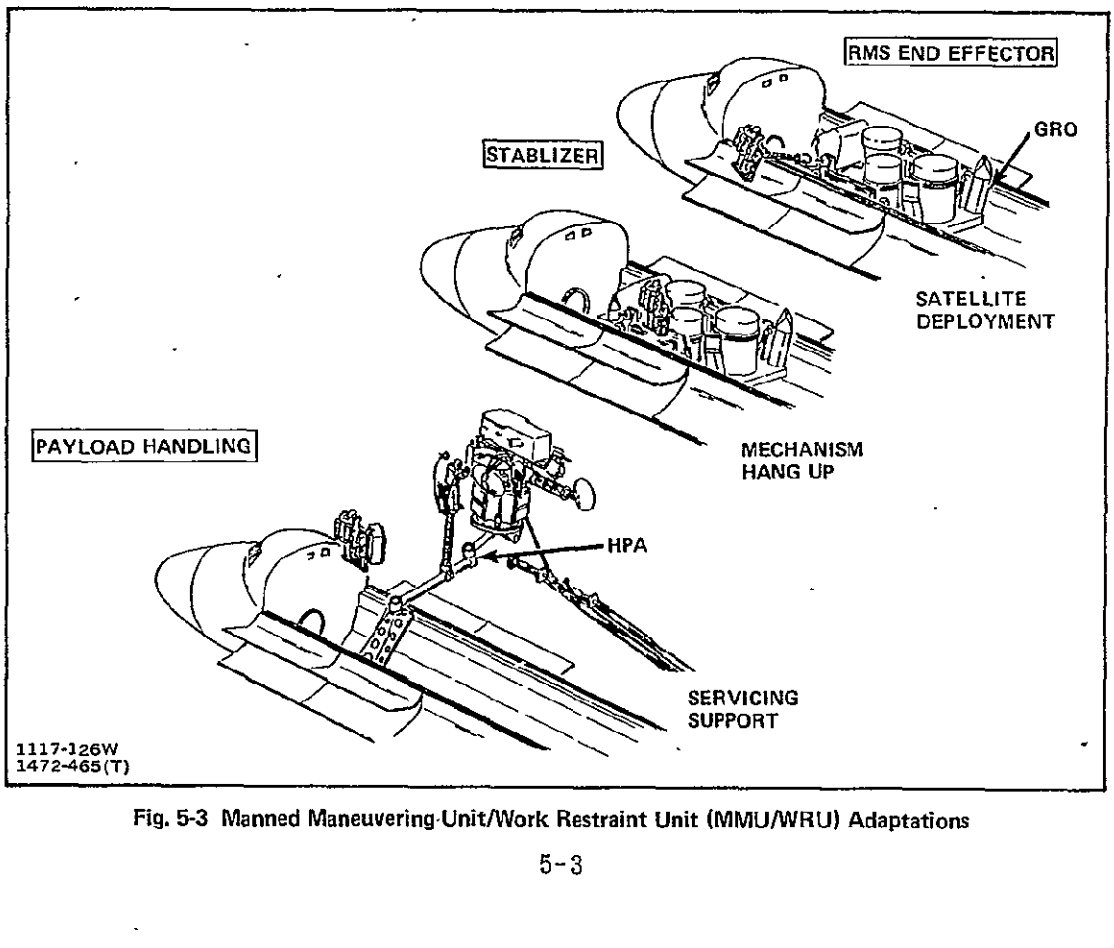


Fig. 5-3 Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU) Adaptations

An adaptation of a WRU, used in conjunction with an MMU, would serve as a backup for satellite deployment if the RMS is inoperative or malfunctioning. The WRU is adapted with an extensible mast and an RMS snare end effector that is compatible with the satellite's grapple fixture used for deployment. Figure 5-3 shows an astronaut within the MMU/WRU in the process of attaching to the satellite's grapple fixture. Following attachment, the astronaut would "fly" the satellite out of the payload bay. The astronaut would then orient the satellite for deployment and, with the MMU's propulsion system, impart a separation velocity of about 1 ft/sec to the satellite.

Figure 5-4 shows a side view of the MMU/WRU end effector adaptation. As shown, the WRU is modified to accommodate a snare end effector attached to an extensible mast. All components are space-qualified equipment items that exist or are currently under development. In addition, this WRU adaptation (which is applicable to RMS inoperative situations) is identical to the MMU/WRU - POM adaptation discussed in Section 3.3.2.

Once again, if the RMS is inoperative or malfunctioning on a satellite deployment mission, an adaptation of the WRU (in conjunction with an MMU) would also serve as a backup for hangups of spacecraft retention latches. The WRU is adapted with a stabilizer to position the astronaut rigidly to a work site. Figure 5-3 shows an astronaut within the MMU/WRU with the stabilizer attached to hand rails along the payload bay. The astronaut is preparing to manually release a payload retention latch.

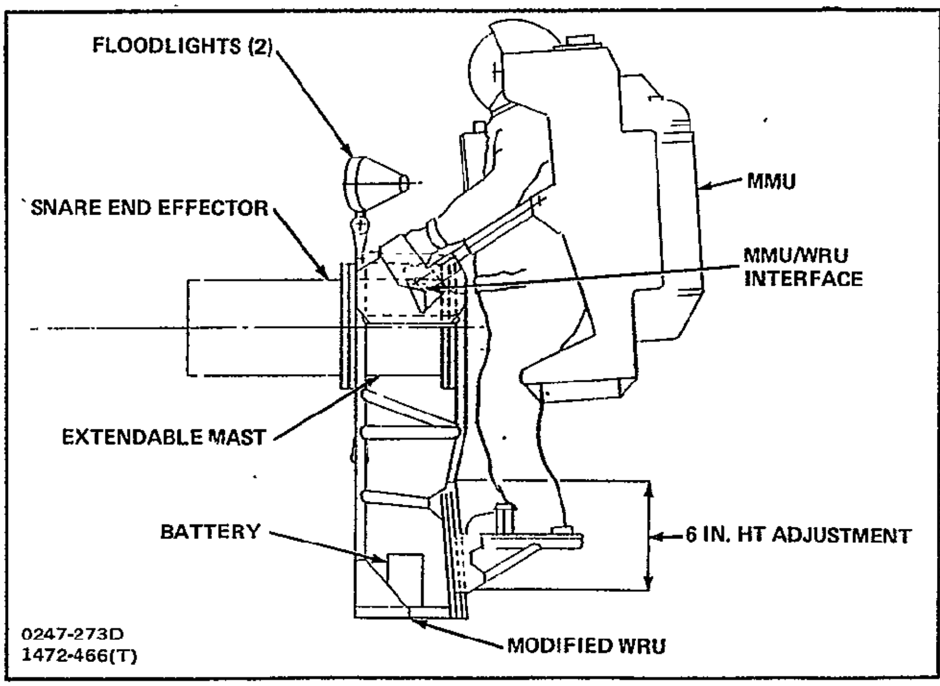


Fig. 5-4 MMU/WRU – End Effector Adaptation

The same adaptation of the WRU (with stabilizer) could also serve as a backup for hangups of spacecraft appendages that might occur during deployment of satellites by the RMS. The WRU, adapted with a stabilizer, would enable the astronaut to intercede in a mechanical hangup situation. For example, with the stabilizer attached to a "hard point" on a satellite, the astronaut could manually release a solar array mechanism.

The WRU stabilizer adaptation, therefore, is applicable for both RMS operative and inoperative situations.

With appropriate adaptations of the WRU, a revisit service mission could also be performed with the RMS inoperative. A WRU adapted with an RMS snare end effector could retrieve payloads within the local vicinity of the Orbiter and position the payloads on a Tilt Table, or on an HPA for on-orbit servicing. Furthermore, a payload handling adaptation of the WRU could transport replacement equipment/modules from the payload bay to the work platform at the service site. Figure 5-3 shows an astronaut using the MMU/WRU to transport an equipment module to a second astronaut who is servicing a satellite mounted on the HPA.

The three illustrated adaptations of the WRU (RMS snare end effector, payload handling, and stabilizer) are implemented in terms of "kits" that are adaptable to a single "core WRU" carried on the service mission.

C-2

6 — Delivery/Retrieval of High Energy Payloads

6 - DELIVERY/RETRIEVAL OF HIGH ENERGY PAYLOADS (LEO/PROPULSION CLASS)

Satellite service equipment associated with the delivery and retrieval of LEO/Propulsion class payloads includes:

- Versatile Service Stage (VSS)
  - Delivery, rendezvous, docking, and retrieval capability
  - End effector kit for noncooperative satellite stabilization
- Aft Flight Deck Controls and Displays (AFD C&D).

6.1 VERSATILE SERVICE STAGE - SATELLITE PLACEMENT & RETRIEVAL

A Versatile Service Stage (VSS) is used to transport and retrieve satellites from higher energy LEO orbits that are not directly accessible by the Orbiter (see Fig. 6-1).

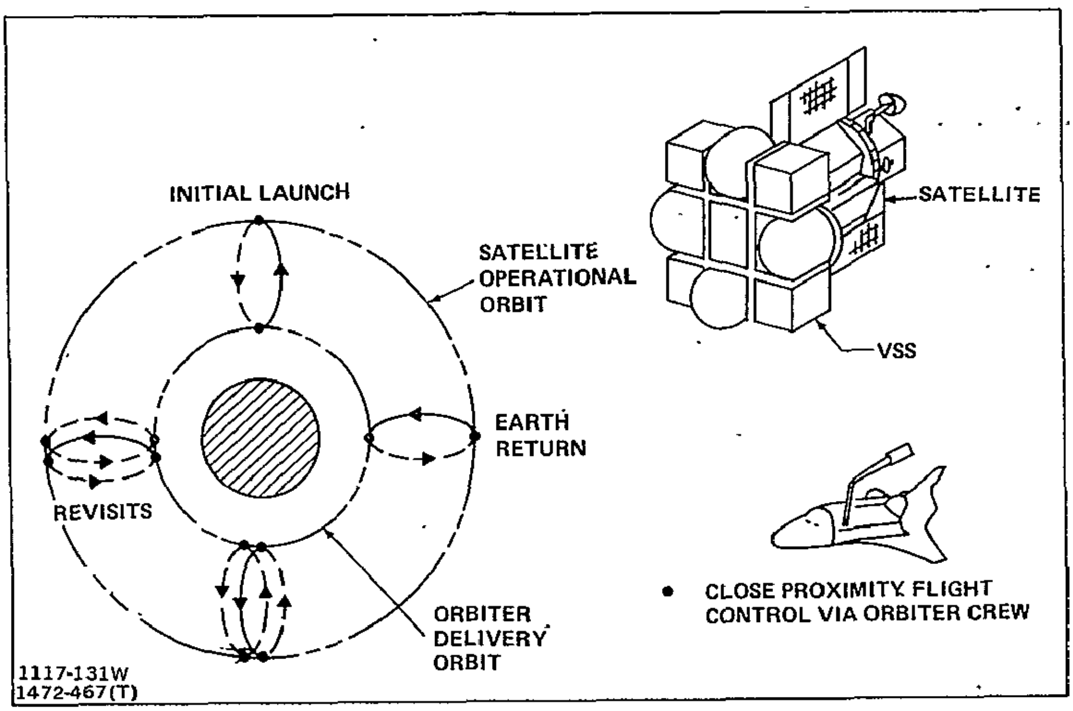


Fig. 6-1 Versatile Service Stage (VSS) — Satellite Placement and Retrieval

The VSS features:

- Reusable propulsion stage for delivering/retrieving payloads to/from Orbiter, to/from higher energy LEO orbits

- High performance main propulsion system for large ΔV maneuvers
- Non-contaminating propulsion system for satellite/Orbiter close proximity operations
- On-orbit refueling capability
- Docking/berthing to cooperative satellites
- Stabilizing and berthing to large uncooperative satellites/debris
- Controlled re-entry of satellites/debris
- Remote inspection of satellites
- Execution of automatic and manual remote commands.

The VSS is equipped with a high performance propulsion system to perform large ΔV maneuvers and a clean-firing, cold gas propulsion system for close-in satellite retrieval and Orbiter proximity operations. The VSS contains a television system for satellite examination and to support remote control of the VSS-to-satellite docking/capture operation.

For initial launch applications, the VSS deploys from the Orbiter at the standard Orbiter altitude, mates with the satellite to be delivered to higher LEO Orbit, and boosts the satellite to its operational altitude. Transfer maneuvers include Hohman-type transfer trajectories and small plane changes. At completion of payload delivery, the VSS returns to the Orbiter for subsequent reuse or earth return for ground refurbishment and reuse.

For use with revisit or earth return missions, the VSS is deployed by the Orbiter to transfer and rendezvous with a payload in a higher energy LEO Orbit. Upon successfully berthing or docking to the payload, the VSS/satellite returns to the Orbiter and achieves rendezvous within about 1000 ft. Close proximity flight control of the VSS/satellite is remotely controlled by the Orbiter crew. The crew "flies" the VSS/satellite to within reach distance of the RMS arm where it is grappled with the Orbiter RMS and placed onto the HPA for servicing, or in the Orbiter cargo bay for earth return. Servicing of the satellite takes place on the Orbiter. Following servicing, the VSS/satellite is deployed from the Orbiter. The VSS then delivers the satellite to its operational orbit and returns again to the Orbiter.

To satisfy a wide assortment of mission needs, the VSS is designed to operate with several front end attachments. The VSS is shown in Fig. 6-2 "snaring" a satellite that is

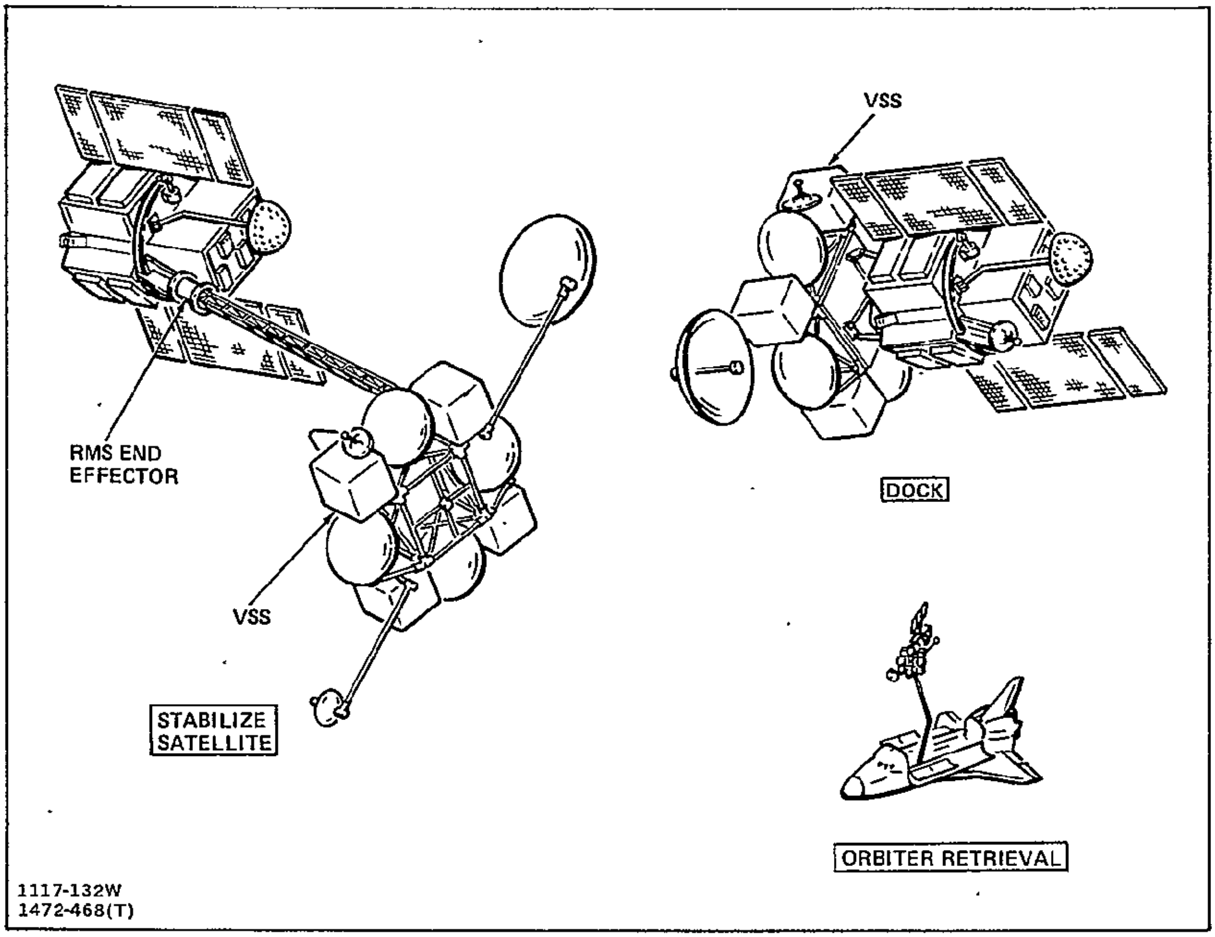


Fig. 6-2 Versatile Service Stage (VSS) — Non-Cooperative Satellite Retrieval

known to be oscillating at rates higher than acceptable for direct docking. A special front-end "kit" provided on the VSS, consists of an extensible mast and RMS snare end effector. The VSS would synchronize its motion with the satellite, extend the end effector to capture the satellite's RMS-compatible grapple fitting, and stabilize it for docking. The operation is remotely controlled via a TV link to the Orbiter (or the ground).

7 — Earth Return Equipment

ORIGINAL PAGE IS
OF POOR QUALITY

7 - EARTH RETURN EQUIPMENT

Satellite service equipment associated with earth return operations includes:

- Special retention structures
- Equipment storage
- Versatile Service Stage (VSS)
  - Debris capture kit
    - o Debris retrieval/return to Orbiter
    - o Debris deorbit
- Aft Flight Deck Controls and Displays (AFD C&D)

7.1 SPECIAL RETENTION STRUCTURES

Figure 7-1 illustrates the specialized type of retention structure required for Orbiter return of satellites (such as OAO-1) that were launched by an unmanned launch vehicle. The satellite is attached to a cradle structure by a clamp ring identical to that used for interfacing OAO with the Atlas/Centaur (it's original launch vehicle) interstage assembly. An equipment stowage rack is also included for storing solar arrays and other satellite appendages removed prior to satellite placement in the payload bay.

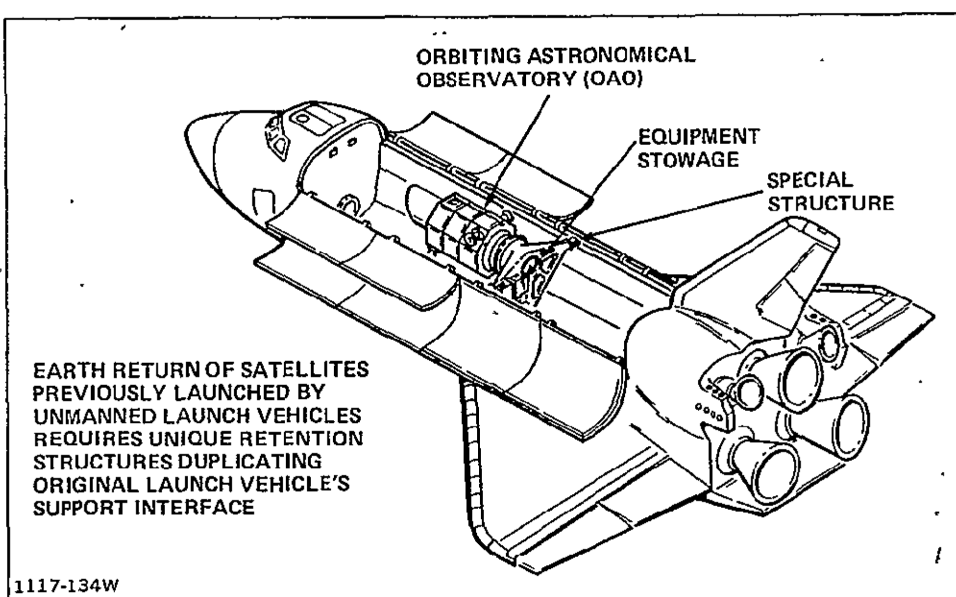


Fig. 7-1 "Special" Retention Structure

ORIGINAL PAGE IS
OF POOR QUALITY

Because of the various attachment fittings and satellite configurations used prior to Shuttle-launched satellites, the prospect of standardizing a generic retention system that is compatible with a number of satellites appears poor. Unique retention systems designed specifically for each debris satellite appear necessary.

7.2 VERSATILE SERVICE STAGE - DEBRIS CAPTURE KIT

Figure 7-2 shows the Versatile Service Stage (VSS) adapted with a special front-end "kit" to capture space debris for deorbit or return to the Orbiter. The "kit" consists of dexterous manipulator arms mounted to a rotating platform.

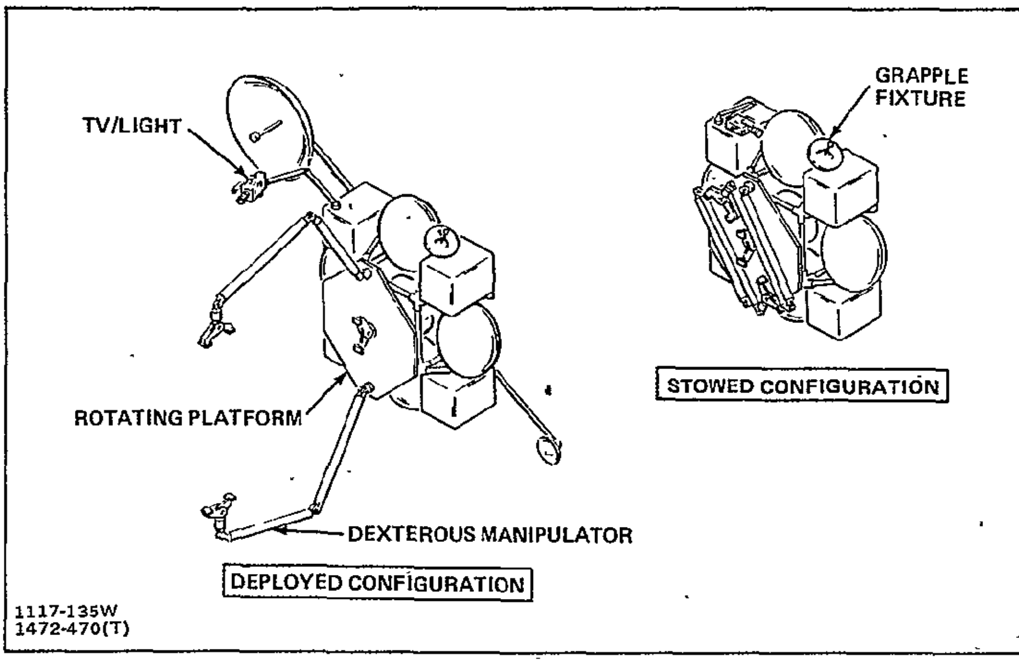


Fig. 7-2 Versatile Service Stage (VSS) – Debris Retrieval

Capture operations are remotely controlled via a TV link to the Orbiter (or the ground). After rendezvous with the debris element, the VSS TV monitors its tumbling motion and is maneuvered to a position where the plane of the VSS rotating platform parallels the tumbling motion. The platform is then spun-up to synchronize with the debris tumbling rate. Manipulators engage the satellite and gradually de-spin it via a clutch mechanism in the rotating platform. The debris satellite is then "cinched-up" against bumper stops and held for propulsion maneuvering. Figure 7-3 shows the VSS engaging a tumbling OAO-1. Note the manipulator reach which is capable of engaging the satellite at its structural hard points.

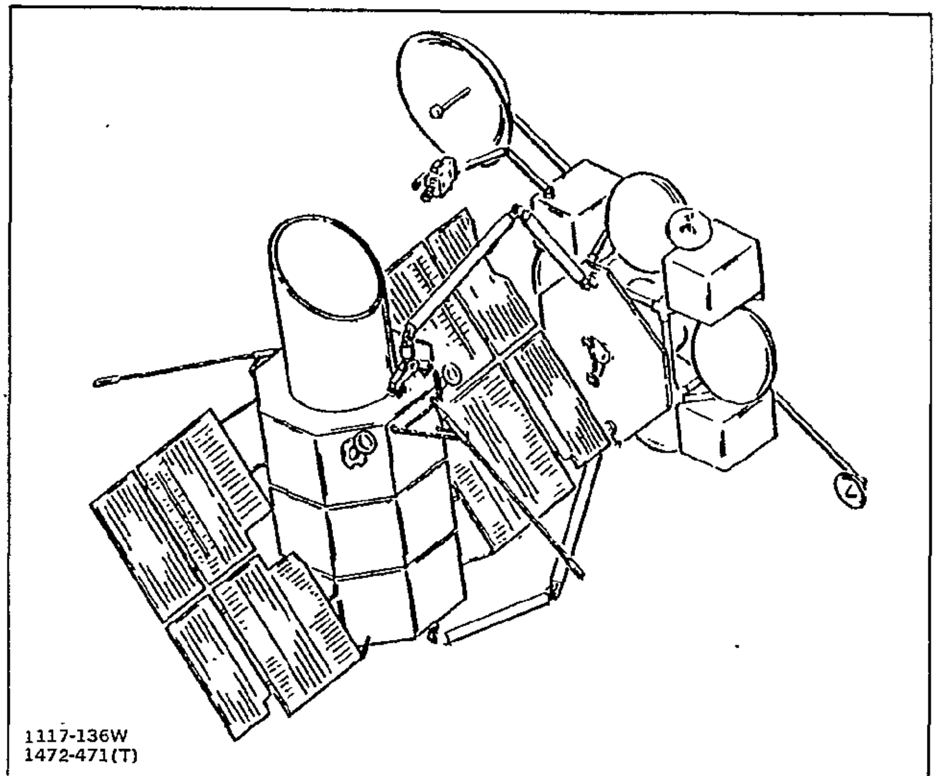


Fig. 7-3 Versatile Service Stage (VSS) – OAO Retrieval

The VSS could return to the Orbiter or perform a propulsion maneuver to place the debris element in a desired reentry trajectory, then release the debris to deorbit while the VSS returns to the Orbiter. Figure 7-4 shows the VSS engaged to an element of large orbital debris in preparation for a controlled-reentry propulsion maneuver. At completion of the maneuver, the VSS separates from the debris and returns to the Orbiter.

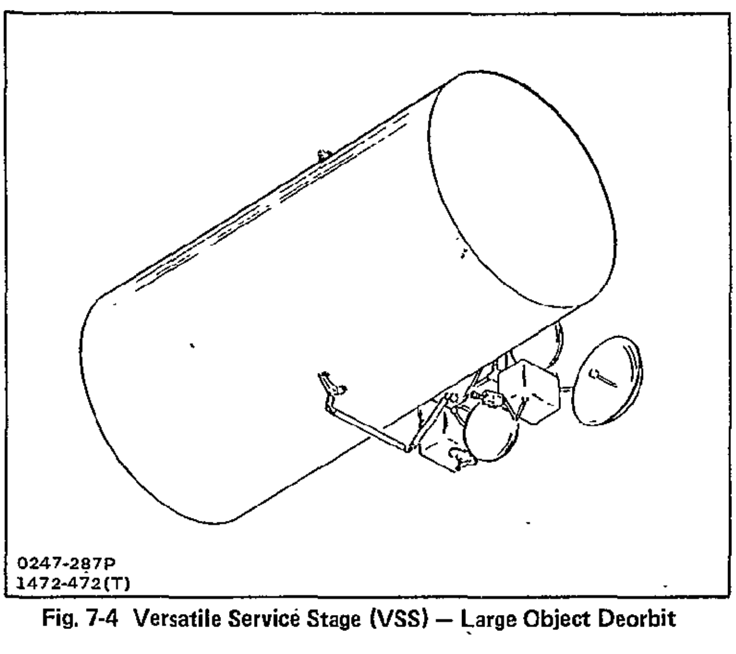


Fig. 7-4 Versatile Service Stage (VSS) – Large Object Deorbit

8 — Aft Flight Deck Servicing Controls & Displays

8 — Aft Flight Deck Servicing Controls & Displays

8 - AFT FLIGHT DECK - SERVICING CONTROLS & DISPLAYS

Controls and displays will be provided in the Aft Flight Deck (AFD) to support several man-in-the-loop servicing operations that will be performed or monitored from the AFD stations. Included are:

- RMS control (existing)
- Standardized satellite checkout
- Close proximity flight operations
  - Maneuverable Television (MTV) system control
  - Unmanned Proximity Operations Module (POM) control
  - Manned proximity operations flight monitoring
  - Versatile Service Stage (VSS) control.

Figure 8-1 shows where the controls and displays could be located for each of the service functions discussed. RMS control panels exist and are arranged as shown in Fig. 8-2. They consist of displays and controls mounted on a panel immediately below the port side, aft-looking window. This panel, A8, contains switches to activate monitoring and checking of the RMS. Two hand controllers are provided for RMS translation and rotation. They are positioned on each side of, and immediately adjacent to, the window to provide a direct, out-the-window view of the cargo bay while the crewman operates the hand controllers. Closed circuit TV monitors are also located nearby to help operate the RMS when a direct view is obscured.

A control console for standardized satellite check-out could be located on panel L12. It would consist of appropriate displays to support spacecraft activation/ checkout, and the controls and displays needed to deploy spacecraft from the Orbiter.

As illustrated in Fig. 8-1, panel L11 could be used to monitor and control all close proximity flight operations. Displays to fly the MTV, the unmanned POM, and the VSS (when in close proximity to the Orbiter) are also shown. These spacecraft would be

ORIGINAL PAGE IS
OF POOR QUALITY

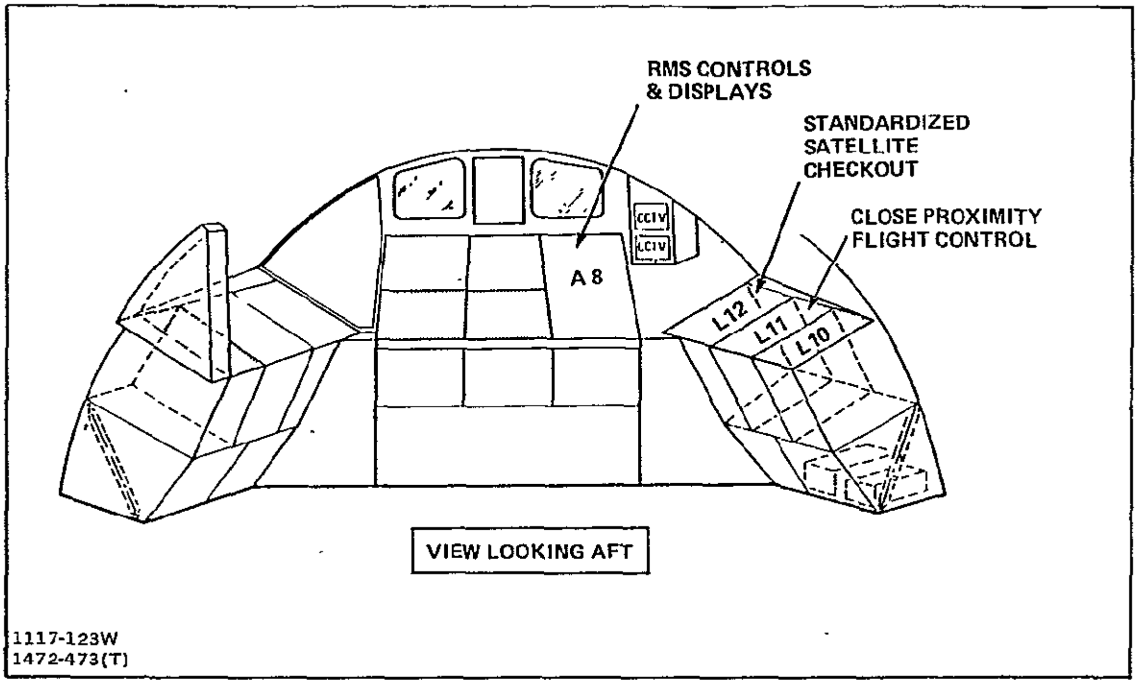


Fig. 8-1 Aft Flight Deck — Servicing Controls & Displays

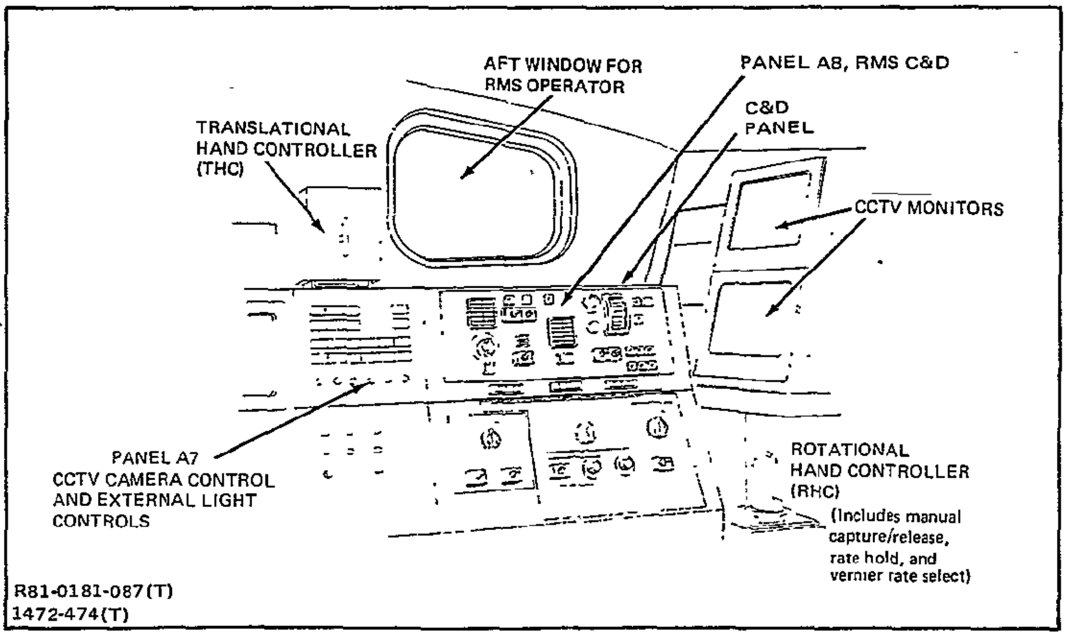


Fig. 8-2 RMS Operator Station

flown by the crew to within reach distance of the RMS for retrieval by the Orbiter. Although controlled by the crewman flying the system, the manned POM is directly dependent upon monitoring and voice link commands that are initiated from the Aft Flight Deck.

9 — Optional Service Equipment

9 - OPTIONAL SERVICE EQUIPMENT

Satellite service equipment that is associated with optional on-orbit service operations and that can be provided at the discretion of the satellite user includes:

- Sun Shield
- Orbital Storage
- Attitude Transfer Package
- Lighting Enhancement.

9.1 SUN SHIELD

This optional item of service equipment provides solar impingement protection to a satellite when the Orbiter's payload bay doors are open. Figure 9-1 illustrates the concept in which the sun shield is in retracted position during launch and with the payload bay doors closed on-orbit. As the payload bay doors open, the shield automatically closes to envelope the payload. This concept has the following features:

- Protects sun sensitive payloads with payload bay doors open without constraining Orbiter attitude requirements
- Stowed during launch - deploys when payload bay doors open and minimizes system weight to accommodate launch loads
- Shield is comprised of multilayer, thin-film insulation
- Provides solar shield over top, front, and back
- Design is adaptable to varying length payloads.

As presently conceived, the large-area surface of the sun shield would be composed of thin-film insulation and could be modularly adaptable to accommodate varying length satellite payloads. The deploy-on-orbit approach was selected to minimize the system's weight by eliminating the need for the shield to accommodate structural/vibration loadings during launch.

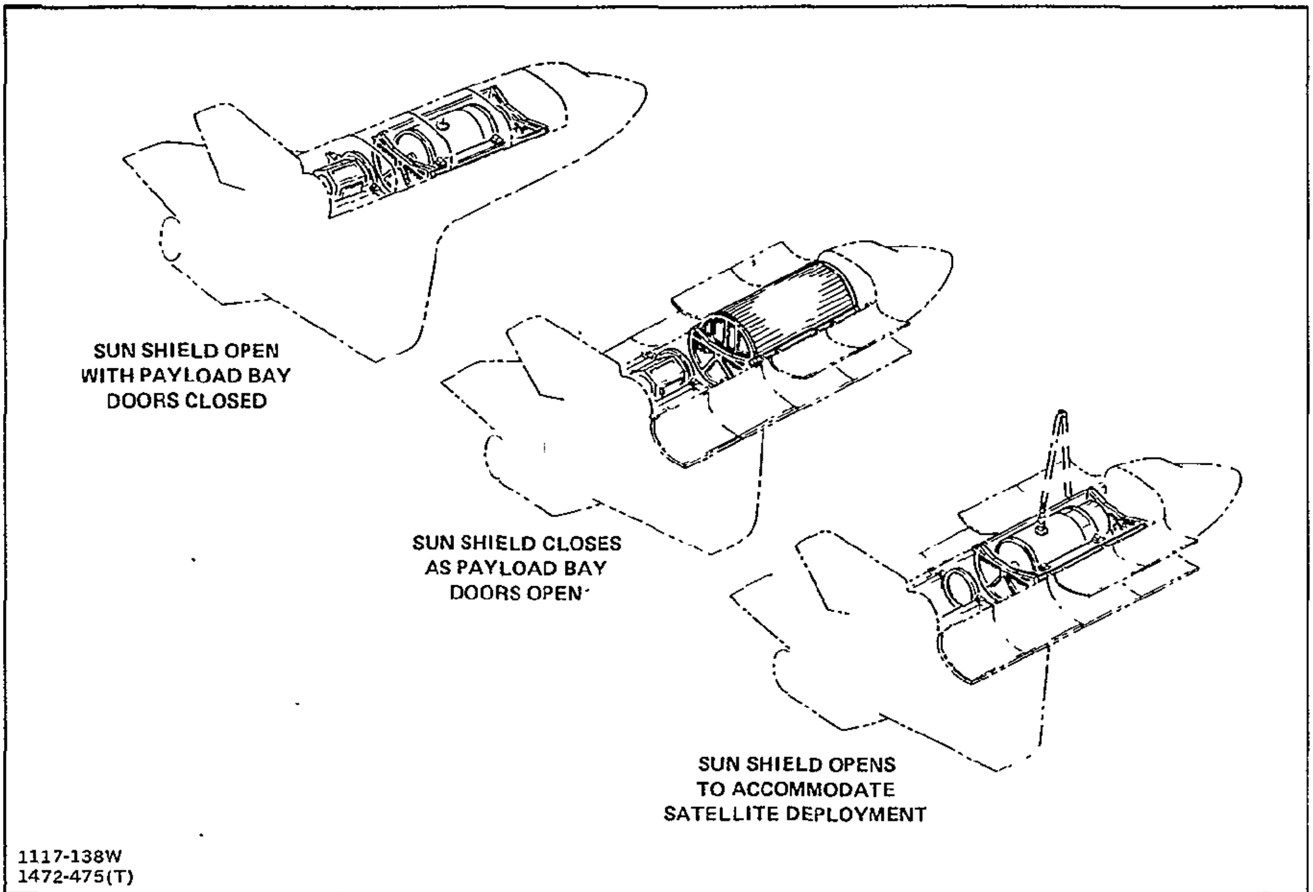


Fig. 9-1 Sun Shield

Figure 9-2 shows a layout drawing of the sun shield; its estimated weight is about 700 lb to enclose a satellite of about 28 ft in length.

9.2 ORBITAL STORAGE

The Orbital Storage mode provides the satellite user with the option to leave the spacecraft on-orbit for subsequent revisit/repair if a malfunction is detected (prior to deployment) that would categorize the satellite as non-operational. Orbital storage eliminates the need to carry backup spares, etc, and to return a satellite to earth for repair and subsequent relaunch. Both would incur additional user charges.

The Orbital Storage enclosure concept is illustrated in Fig. 9-3. Outside the enclosure, an RMS-compatible grapple fixture enables transport from the payload bay to the satellite mounted on the HPA. Inside the enclosure, an RMS snare end effector captures the satellite's grapple fixture and provides the enclosure's hard-point attachment to the satellite. The next step involves the release of the satellite from the HPA and raising it above the HPA platform to allow the storage enclosure to close. From this

ORIGINAL PAGE IS
OF POOR QUALITY

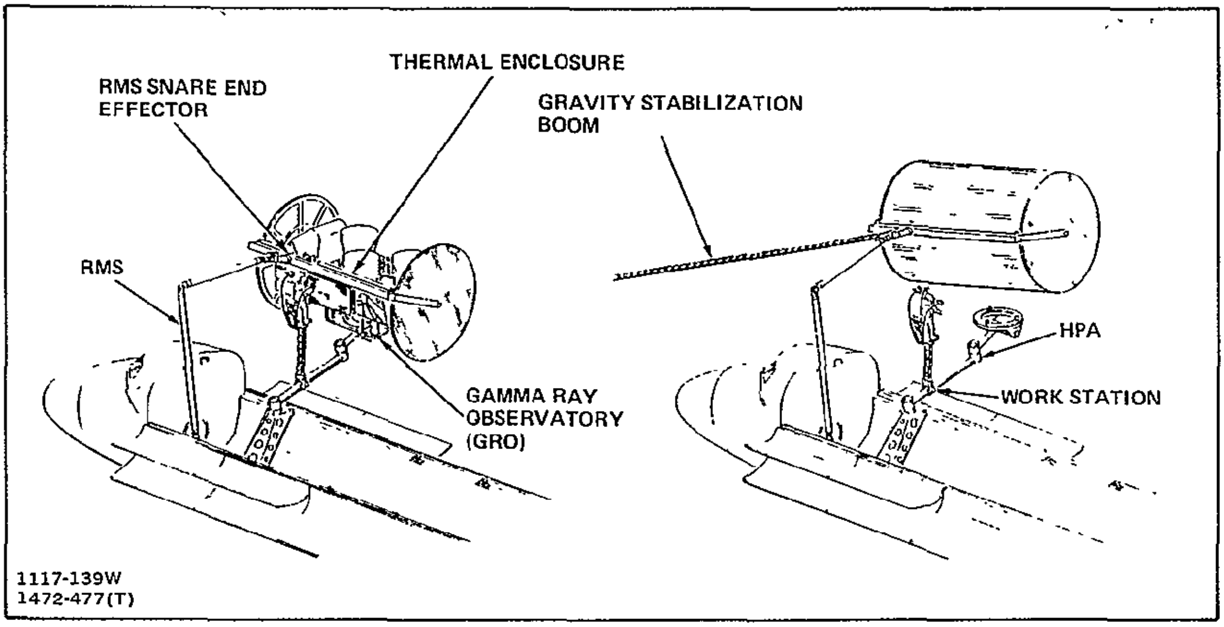


Fig. 9-3 Orbital Storage

position, a gravity stabilization boom is activated to provide sufficient on-orbit stability to enable subsequent retrieval of the satellite for repair/refurbishment. Following this sequence, the satellite is deployed by the RMS in the Orbital Storage mode.

Features of the Orbital Storage concept are:

- Avoids unnecessary satellite earth return
  - Saves user relaunch costs
  - Eliminates relaunch scheduling delays
- Provides gravity gradient stabilization during orbital storage period
  - Stabilized for retrieval
  - Predictable thermal environment
- Provides spacecraft with controlled thermal environment
  - Thin film enclosure designed for standard α / ϵ
  - Adjusted with aluminized tape coatings
  - Passive heat pipes can be added for finer temperature control
- System is stowed in a small volume container for Orbiter integration.

The thermal enclosure concept employs thin-film insulation with the end bulkheads and the enclosure shell being activated by inflation. This concept can also be modularly adaptable to accommodate varying length satellite payloads.

Preliminary studies indicate that the Sun Shield function and the Orbital Storage mode might be accommodated by a single service equipment design.

9.3 ATTITUDE TRANSFER PACKAGE

Before deploying from the Orbiter, some satellites may need an attitude reference update which could be transferred from the Orbiter's navigation base. Two attitude transfer approaches have been investigated:

- HPA mounted
- Payload Bay mounted.

Figure 9-4 illustrates an optical Attitude Transfer system concept utilizing the HPA to transfer accurate attitude reference data to satellites, or experiment packages that require accurate alignment prior to deployment. This approach will compensate for variations in orientation within the Orbiter payload bay due to temporal changes. The electro-optical system uses a combined projector-receiver to transmit and receive beams of collimated light. Transmitted beams are reflected from passive reflectors mounted on the HPA berthing platform. As adapted to the HPA, the concept standardizes reference alignment of payloads at a fixed location relative to the Orbiter navigation base.

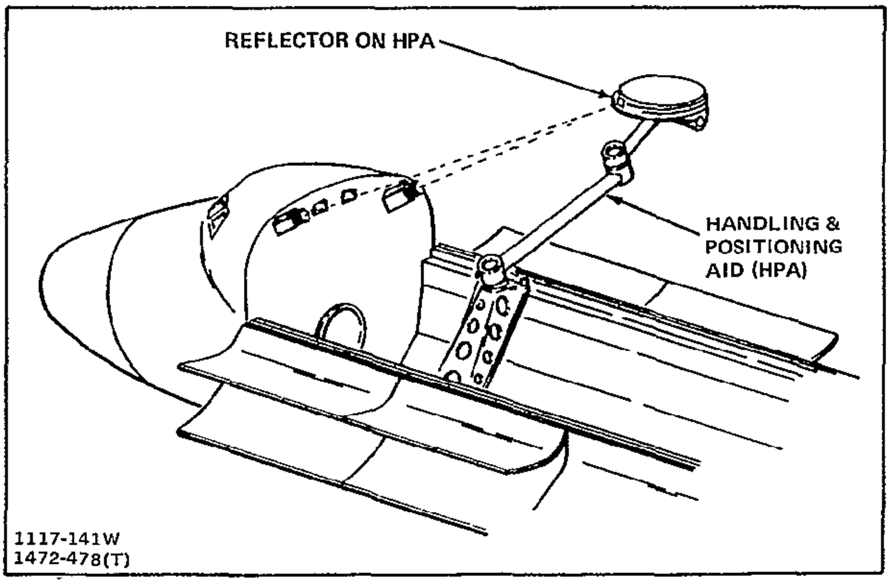


Fig. 9-4 Optical Attitude Transfer System — HPA Mounted

ORIGINAL PAGE IS
OF POOR QUALITY

Another adaptation of an optical Attitude Transfer system is shown in Fig. 9-5. In this application, passive reflectors are mounted at various stations along the payload bay to measure corresponding misalignments along the length of the payload bay. This Attitude Transfer approach could be applied to support pallet mounted instruments during Orbiter sortie missions.

Features of the respective Attitude Transfer concepts are:

- Provides 3-axis measure of misalignment between Orbiter navigation base and certain positions in or outside of payload bay
  - Optical head (IR source and detector)
  - Retro-reflectors
- Payload bay misalignment measurement by sill mounted reflectors and bulkhead mounted optical heads
  - Direct pitch and yaw measures
  - Differential roll measure

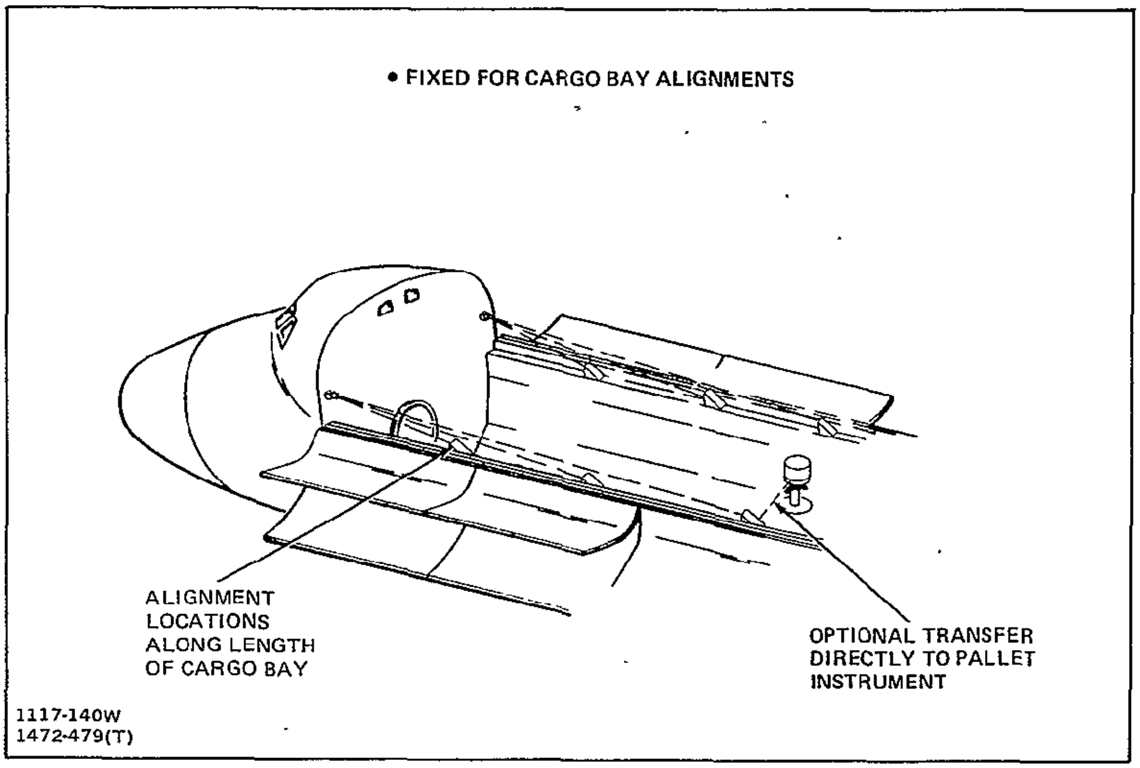


Fig. 9-5 Optical Attitude Transfer System – Payload Bay Mounted

- HPA - Transfer alignment
  - Provides single location for attitude transfer to all payloads
  - Retro-reflectors on HPA-Payload mount
  - Closed loop HPA control.

9.4 LIGHTING ENHANCEMENT

Wide variations in the intensity of natural lighting sources (sun, moon, and albedo) inside and above the cargo bay make additional lighting sources necessary. The lighting range varies from orbit night to direct sunlight which causes severe shadowing and high contrast ratios. Standard payload bay lights and auxiliary lights provide additional lighting in and about the cargo bay. Additionally, lights are added to other payload support equipment (e.g., the RMS, Open Cherry Picker), and the astronaut's helmet as illustrated in Fig. 9-6.

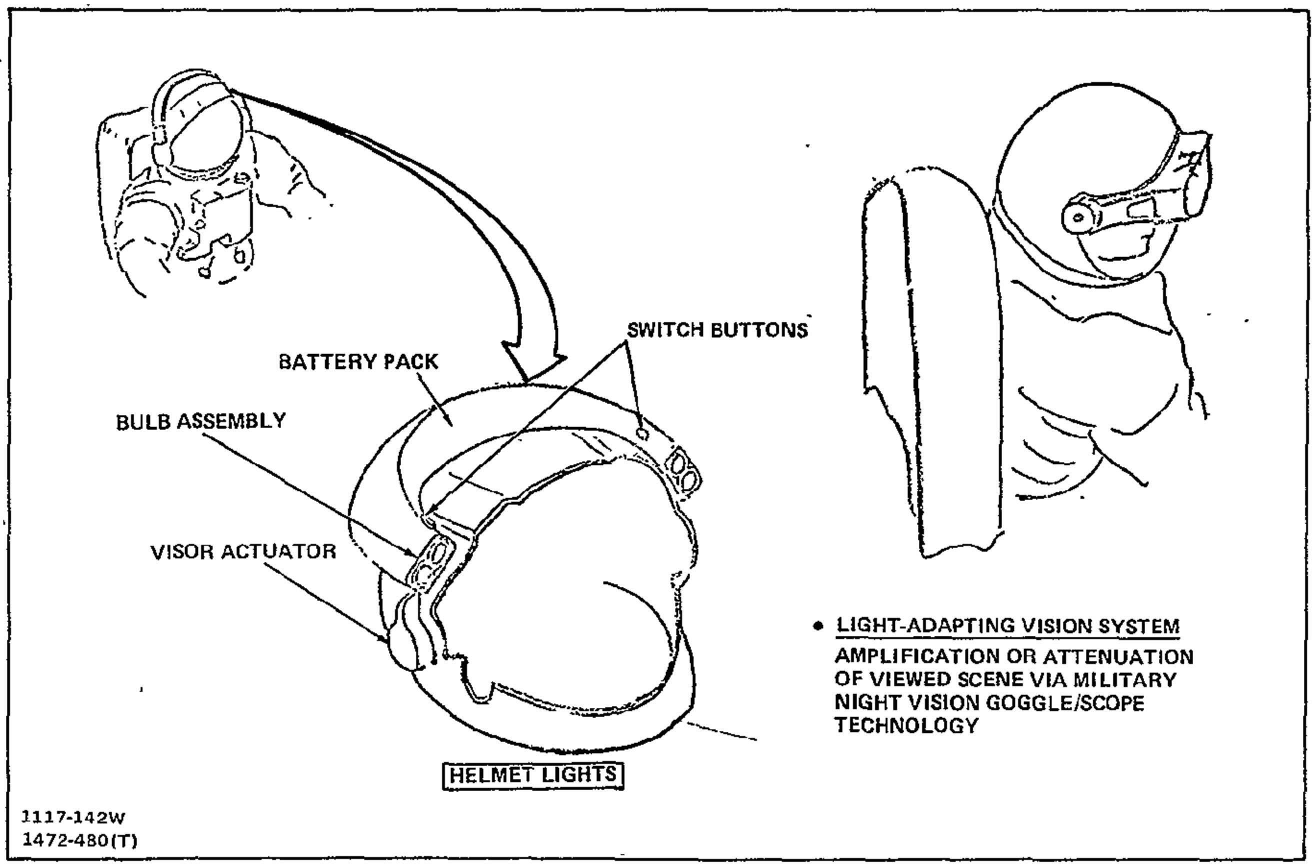


Fig. 9-6 Lighting Enhancement for EVA Operations

ORIGINAL PAGE IS
OF POOR QUALITY

Also illustrated is a new device for the EVA astronaut: the Light Adapting Vision System which is an adaptation of military night vision/goggle technology. This system is suggested to greatly reduce the requirements for artificial lighting during satellite servicing operations.

The Light Adapting Vision System (see Fig. 9-7) is a helmet-mounted electro-optical device that automatically amplifies (or alternates) the light intensity of the scene viewed by the astronaut. As a result, the scene appears to be uniformly lighted despite changing external lighting conditions. The need for additional artificial lighting during orbit night, or in shadows, is greatly reduced. Also, Orbiter attitude restrictions to provide natural lighting are eliminated.

This system permits EVA operations under any lighting conditions and increases productivity when performing satellite servicing functions. Features of this approach are:

- Provides ability to discern objects in the dark
- Nearly uniform lighting of objects throughout orbital daylight/darkness cycle
- Minimizes need for artificial lighting above the payload bay
- Provides full field of view, including peripheral "see-around" vision
- Expands timeline scheduling for planned or emergency EVA.

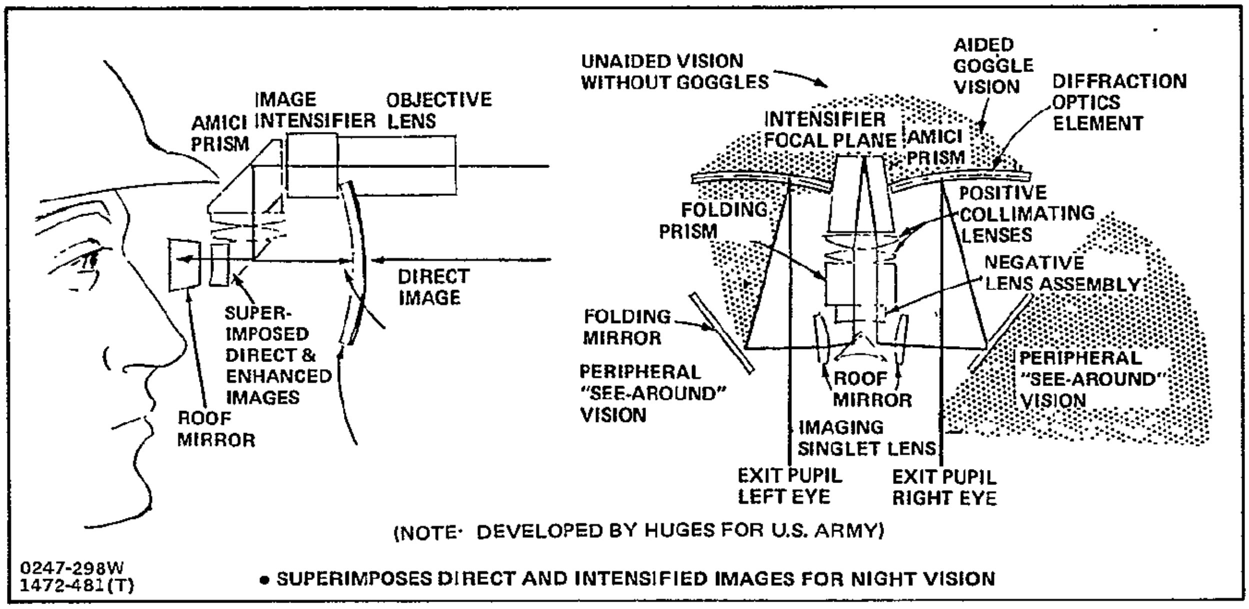


Fig. 9-7 Lighting Enhancement — System Description

10 — Advanced Capabilities Equipment

ORIGINAL PAGE IS
OF POOR QUALITY

10 - ADVANCED CAPABILITIES EQUIPMENT

Satellite service equipment with the potential to come on-line within the next decade, and which relates to on-orbit servicing involves:

- Dexterous Manipulators
  - With the Remote Manipulator System (RMS)
  - With the Handling and Positioning Aid (HPA)

10.1 DEXTEROUS MANIPULATORS

Dexterous manipulators for remote servicing operations can be expected as soon as the technology has been suitably developed.

Figure 10-1 shows two dexterous manipulators, mounted on the end of the RMS arm, operated, and controlled by a master unit on the Aft Flight Deck. Dexterous manipulators can duplicate the motions of a human arm and shoulder, including sensing forces, and feed them back to the master. This concept enables remote, hazardous operations within the payload bay, as well as servicing tasks.

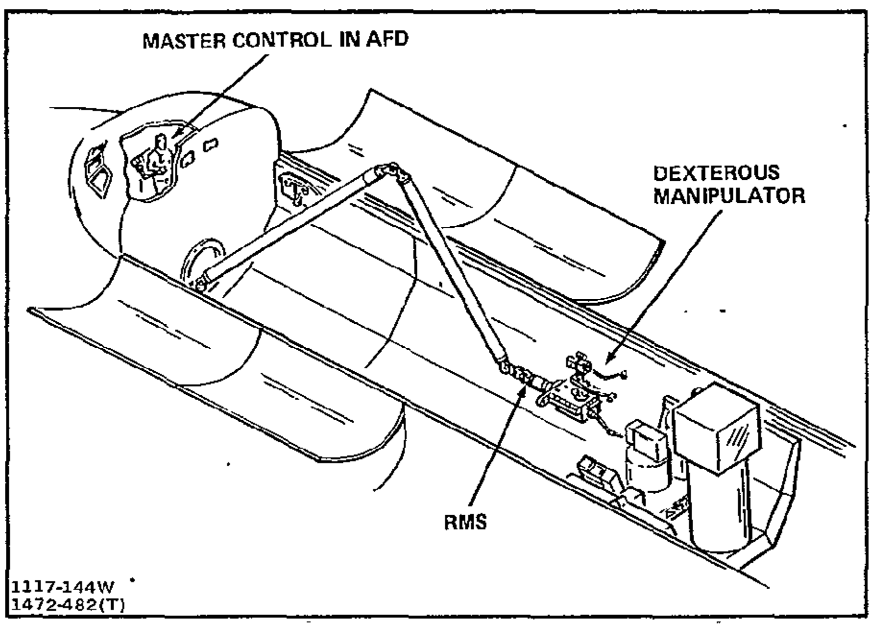


Fig. 10-1 Dexterous Manipulator

Figure 10-2 summarizes the overall features of the dexterous manipulator system including the master unit in the aft flight deck, and the slave unit on the RMS.

ORIGINAL PAGE IS
OF POOR QUALITY

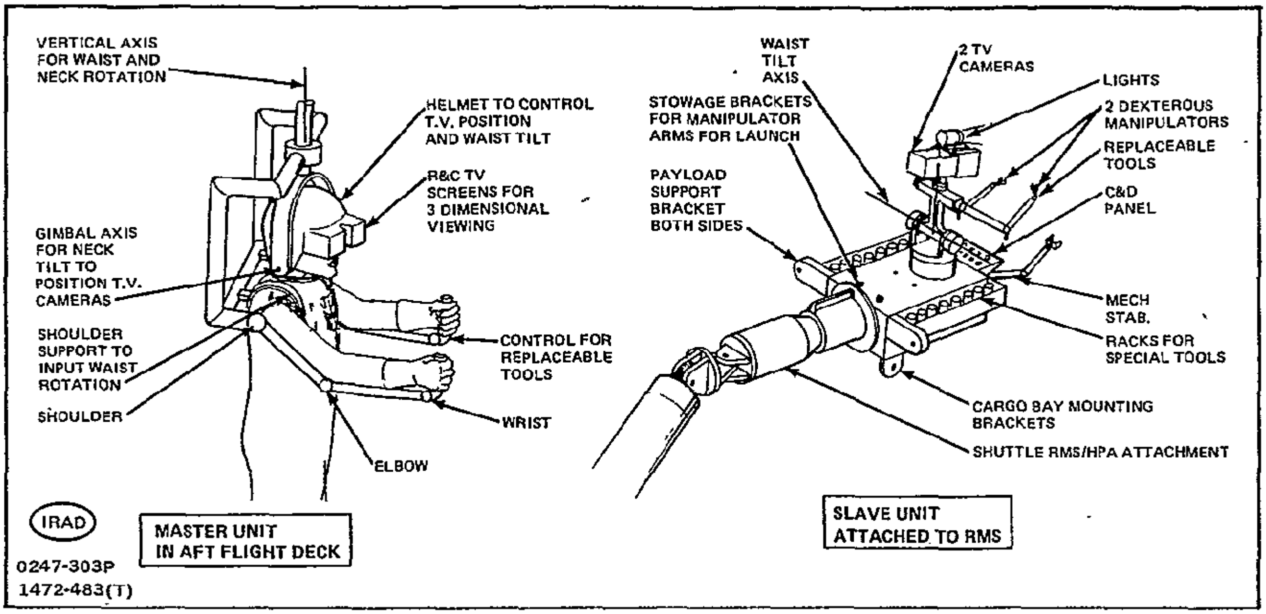


Fig. 10-2 Special Purpose End Effector Simulates Human Capability from the Waist Up

Figure 10-3 depicts a dual adaptation of dexterous manipulators to service satellites. Remote servicing is performed with manipulators on the RMS and HPA work platform.

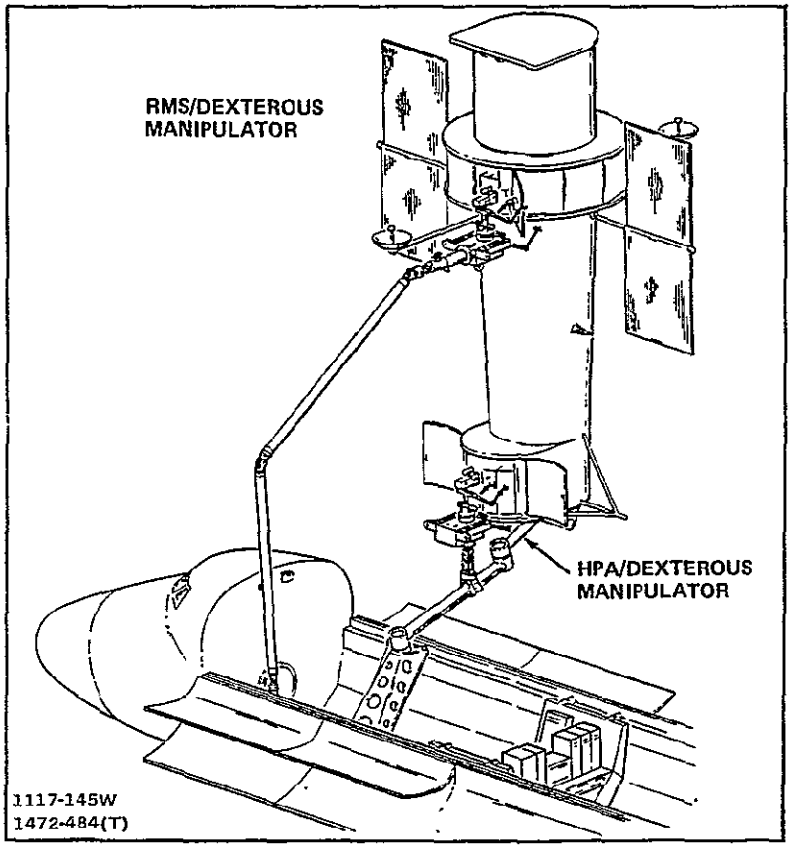


Fig. 10-3 Dexterous Manipulator – Adaptations to RMS/HPA

11 — Service Equipment Summary

11 — Service Equipment Summary

11 - SERVICE EQUIPMENT SUMMARY

Service equipment hardware items that are considered as key generic elements in the Satellite Services System and needed early in the program to provide viable services to the user community are:

- Backup/Contingency Equipment
  - Manipulator Foot Restraint (MFR)
  - Work Restraint Unit (WRU) Adaptations
- Close Proximity Retrieval Equipment
  - Maneuverable Television (MTV)
  - MTV-Proximity Operations Module
  - WRU-Proximity Operations Module
- On-Orbit Servicing Equipment
  - Open Cherry Picker (OCP)
  - Flight Support System - OCP Work Platform
  - Handling and Positioning Aid (HPA).

As discussed in Volume 5 (Section 5-2) of this report, initial "core service equipment" elements could be brought on-line in a four or five year period within a nominal annual funding ceiling of approximately $50 million.

The generic "core service equipment" should be developed as soon as possible to enable satellite users to effectively plan for its use. Early flight demonstrations of the service equipment (and its operation) is recommended to provide proof-of-capability to the satellite user community.

Figure 11-1 repeats the equipment status presented previously (see Fig. 1-2) and summarizes the recommended actions that should be taken to amplify and develop service equipment. Our recommendations are presented in terms of the following actions:

- Continue development

ORIGINAL PAGE IS
OF POOR QUALITY

- A separate study is warranted to define equipment requirements/concepts more thoroughly
- Amplification of these equipment concepts could be undertaken in follow-on satellite services efforts.

	STATUS					RECOMMENDED ACTIONS		
	5	6	3	12	1			
SUPPORT STRUCTURE	EXISTS	UNDER DEV OR STUDY	MODIF	NEW	UNIQUE	CONTINUE DEVELOPMENT	SEPARATED STUDY WARRANTED	AMPLIFY IN SUBSEQ SAT SVCS EFFORTS
• RETENTION STRUCTURES	●							
• SPECIAL RETENTION STRUCTURE					●			
ON-ORBIT EQUIPMENT								
• REMOTE MANIPULATOR SYSTEM (RMS)	●							
• TILT TABLE (FSS, IUS, PAM-A)	●							
• OPEN CHERRY PICKER (OCP) — TILT TABLE WORK PLATFORM				●				●
• OPEN CHERRY PICKER (OCP) — OCP/RMS		●				●		
• MANIPULATOR FOOT RESTRAINT/RMS		●				●		
• PAYLOAD INSTALLATION/DEPLOYMENT AID (PIDA)		●				●		
• HANDLING & POSITIONING AID (HPA)		●						
• SPIN TABLE (PAM-A, PAM D)	●							
• EQUIPMENT STORAGE — ON-ORBIT SUPPORT				●			●	
• EQUIPMENT STORAGE — EARTH RETURN					●		●	
• FLUID TRANSFER SYSTEM				●			●	
• NON-CONTAMINATING ATT CONTR SYS				●			●	
• AFT FLT DECK CONTR/DISPL — W/RMS CONTROL	●							
• AFT FLT DECK CONTR/DISPL — W/STD SAT C/O			●				●	
• AFT FLT DECK CONTR/DISPL — W/CLOSE PROX CONTR				●			●	
FREE-FLIGHT SYSTEMS								
• MANEUVERABLE TELEVISION (MTV)		●				●		
• PROXIMITY OPS MODULE – MTV ADAPTATION				●				●
• PROXIMITY OPS MODULE – MANNED VERSION				●				
• MANNED MANEUV UNIT/ WORK RESTRAINT UNIT (MMU/WRU) — W/END EFFECTOR	● (MMU)		●					●
• MANNED MANEUV UNIT/ WORK RESTRAINT UNIT (MMU/WRU) — W/STABILIZER			●					●
• MANNED MANEUV UNIT/ WORK RESTRAINT UNIT (MMU/WRU) — W/PAYLOAD HNDLG			●					●
• MANNED MANEUV UNIT/ WORK RESTRAINT UNIT (MMU/WRU) — PROX OPS MODULE			●					●
• VERSATILE SERVICE STAGE (VSS) — W/DELIVERY, RETRIEVAL		●				●		
• VERSATILE SERVICE STAGE (VSS) — RENDEZ, DOCKING								
• VERSATILE SERVICE STAGE (VSS) — W/END EFFECTOR KIT		●					●	
• VERSATILE SERVICE STAGE (VSS) — W/DEBRIS CAPTURE KIT		●					●	
OPTIONAL EQUIPMENT								
• SUN SHIELD				●			●	
• ORBITAL STORAGE				●			●	
• ATTITUDE TRANSFER PKG				●			●	
• LIGHTING ENHANCEMENT				●		●		
ADVANCED CAPABILITIES								
• DEXTEROUS MANIPULATORS — W/RMS				●		●		
• DEXTEROUS MANIPULATORS — W/HPA				●		●		
TOOLS								
• HANDLING/EQUIPMENT REMOVAL		●				●		

1472-465(T) 1472-402(T)

Fig. 11-1 Service Equipment— Status/Recommended Actions

Appendix A — Existing & Planned Service Equipment

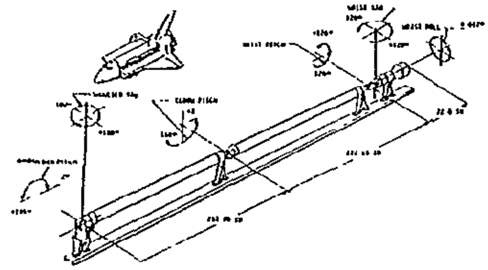
Appendix A

EXISTING & PLANNED

SERVICE EQUIPMENT

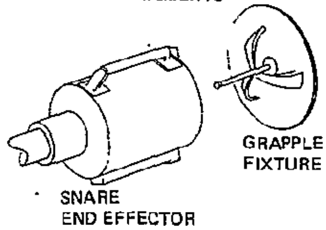
EQUIPMENT | **DESCRIPTION**

- REMOTE MANIPULATOR SYSTEM (RMS)



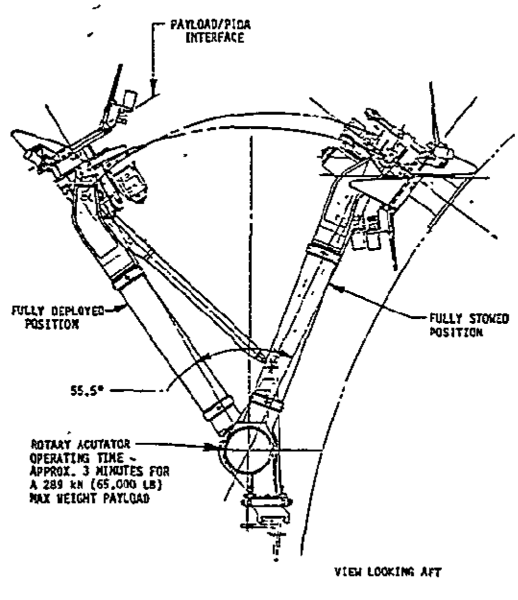
  - ARM
  - SNARE END EFFECTOR
  - GRAPPLE FIXTURE

STANDARD ELEMENTS



- SECOND RMS & INSTALLATION

- PAYLOAD INSTALLATION & DEPLOYMENT AID (PIDA)

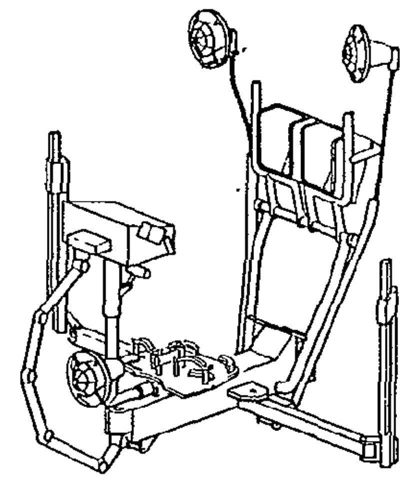
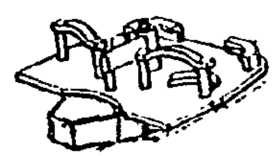
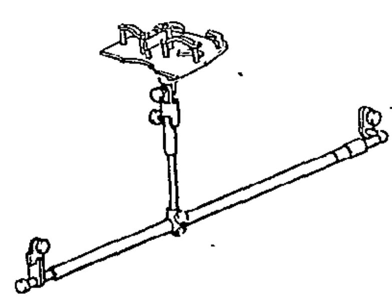
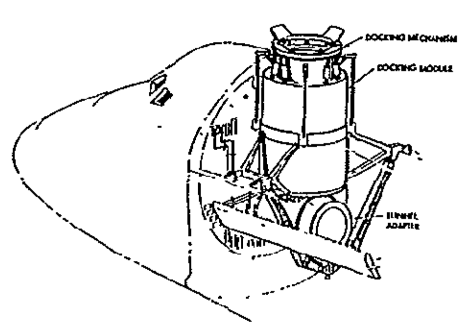


1472-486(1/8)(T)

FUNCTION	SIZE (IN.)
ORBITER CARGO BAY PAYLOAD TRANSFER	
PROVIDES 6 DEGREES-OF-FREEDOM	603L x 15DIA
PAYLOAD CAPTURE MECHANISM	21.5L x 13.6DIA
PAYLOAD MOUNTED	24.4L x 22.5W x 11.8H
——————	——————
MOVE PAYLOAD THROUGH A PRESCRIBED PATH BETWEEN CONFINED QUARTERS OF THE PAYLOAD BAY & A POSITION OUTSIDE THE CRITICAL MANEUVERING AREA OF THE ORBITER (RMS ASSIST)	

WT (LB)	STATUS
867	EXISTING
	EXISTING
15	
1171	
250	PLANNED

Fig. A-1 EXISTING/PLANNED EQUIPMENT

EQUIPMENT	DESCRIPTION
• OPEN CHERRY PICKER (OCP)	
• MANIPULATOR FOOT RESTRAINT (MFR)	
• PORTABLE FOOT RESTRAINT (PFR)	
• DOCKING MODULE	

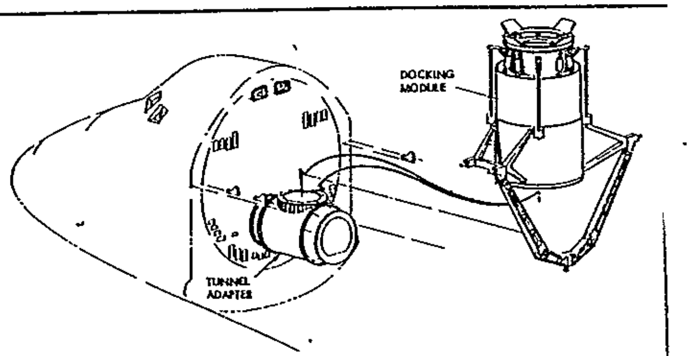
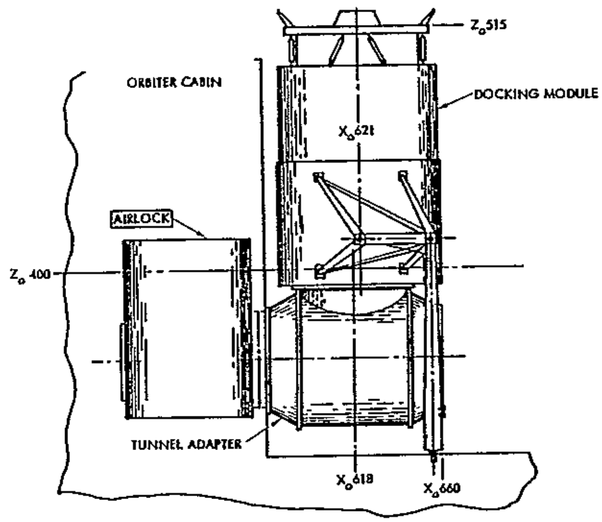
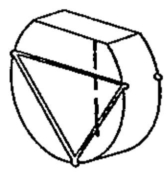
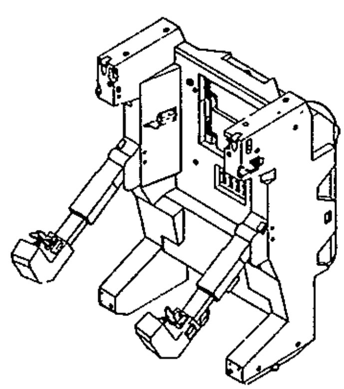
1472-486(2/8)(T)

FUNCTION	SIZE (IN.)
SUPPORT OF EVA ASTRONAUT AT WORK SITE FOR SATELLITE MAINTAINENCE, REPAIR, & SERVICE OPERATIONS. USED WITH RMS AS A SPECIAL END EFFECTOR CONTROLLED BY EVA ASTRONAUT	62L x 40W x 29H (STOWED CONFIGURATION)
SPECIAL END EFFECTOR FOR RMS. REMOTE WORK STATION FOR EVA ASTRONAUT CONTROLLED FROM AFT FLIGHT DECK	51L x 26W x 26H (STOWED CONFIGURATION)
WORK STATION FOR EVA ASTRONAUT IN & ABOUT CARGO BAY	70.5L x 10.1W x 22H (STOWED CONFIGURATION)
ALLOWS ORBITER TO DOCK TO ANOTHER ORBITAL ELEMENT. FOR TRANSFER OF CREW & EQPT, MAY BE USED AS AN AIRLOCK	84L x 66W x 150H

WT (LB)	STATUS
500	PLANNED
25	PLANNED
36	EXISTING
3900	PLANNED

ORIGINAL PAGE IS OF POOR QUALITY

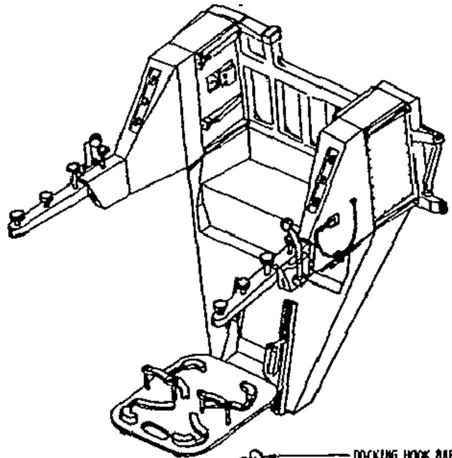
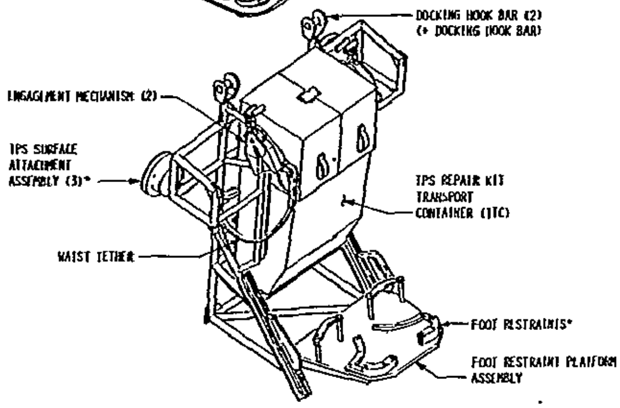
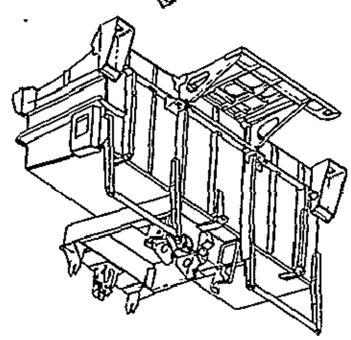
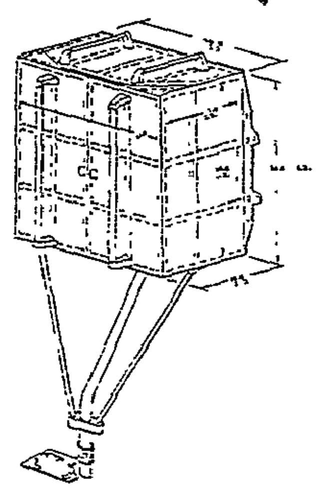
Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONTINUED)

EQUIPMENT	DESCRIPTION
• TUNNEL ADAPTER 	
• AIRLOCK	
• SPACE TELESCOPE (ST) FLIGHT SUPPORT EQUIPMENT – ENVIRONMENTAL PROTECTION ENCLOSURE	
– CLOTHESLINE	
• MANNED MANEUVERING UNIT (MMU)	

FUNCTION	SIZE (IN.)
PROVIDES SHIRT SLEEVE ACCESS BETWEEN ORBITER CABIN AND HABITABLE PAYLOAD IN CARGO BAY	84L x 63DIA
PROVIDES MEANS OF TRANSFER FROM SHIRT SLEEVE ENVIRONMENT OF ORBITER CABIN TO THE VACUUM ENVIRONMENT OF SPACE	83L x 63DIA
REPLACEMENT EQUIPMENT STORAGE	105L x 164W x 143H
EQUIPMENT TRANSFER FOR SERVICING	12.5L x 11W x 3.5H
ON ORBIT EVA PROPULSION FOR EMU SUITED ASTRONAUT – STOWED – ARM EXTENDED	 49.4L x 32.6W x 31.8H 49.4L x 32.6W x 47.6H

WT (LB)	STATUS
900	PLANNED
112	PLANNED
	PLANNED
2400	
TBD	
302	EXISTING

Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONTINUED)

EQUIPMENT	DESCRIPTION
• FLIGHT SUPPORT SYSTEM (FSS)	
• WORK RESTRAINT SYSTEM (WRS) – WORK RESTRAINT UNIT (WRU)	
– ANCILLARY EQUIPMENT STOWAGE ASSEMBLY (AESA)	
• CARGO BAY STORAGE ASSEMBLY (CBSA)	

1472-486(4/8)(T)

FUNCTION	SIZE (IN.)
FOR SUPPORT/STOWAGE OF MMU DURING LAUNCH, ENTRY, & ON-ORBIT	57.8L x 54.5W x 55.8H
WORK RESTRAINT FOR ON ORBIT EVA ASTRONAUT OPERATIONS WITH THE MMU	54L x 56W x 36H
FOR SUPPORT/STOWAGE OF WRU, TOOLS, & MATERIAL DURING LAUNCH, ON-ORBIT, & ENTRY	60L x 44W x 33H
PROVIDE PAYLOAD BAY STOWAGE OF GFE/CFE HARDWARE	40L x 36W x 22H

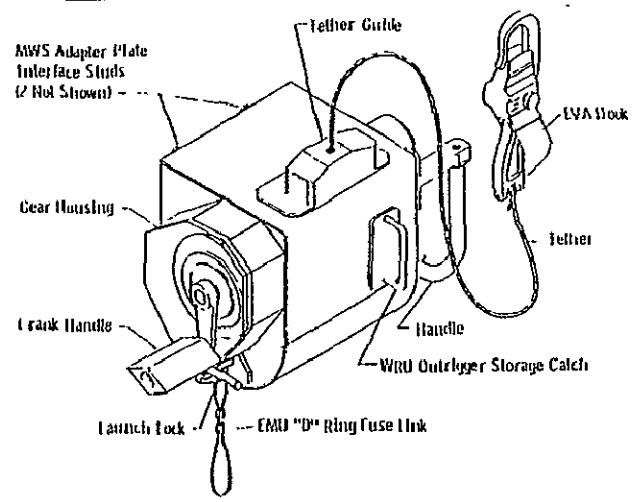
WT (LB)	STATUS
263	EXISTING
75	PLANNED
150	PLANNED
400†	EXISTING

† WEIGHT OF TOOLS INCLUDED

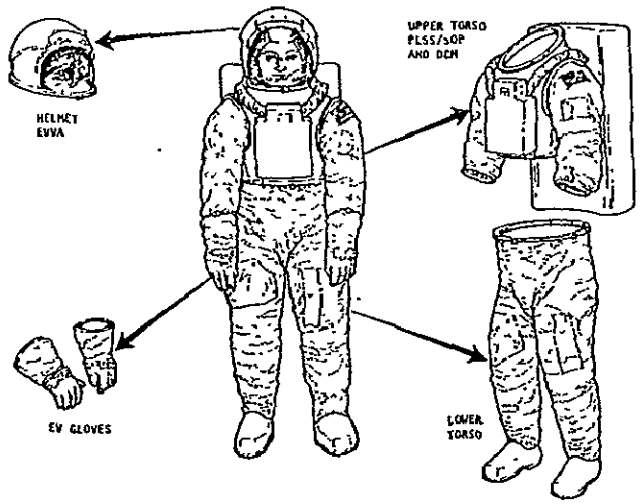
Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONTINUED)

EQUIPMENT	DESCRIPTION

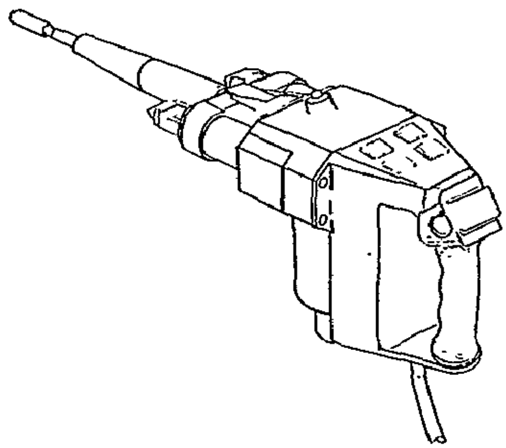
• RETURN LINE TETHER (RLT)



• EXTRA VEHICULAR MOBILITY UNIT (EMU)
  - HELMET
  - GLOVES
  - UPPER TORSO
  - LOWER TORSO
  - PLSS/SOP
  - DCM



• UNIVERSAL SERVICE TOOL (UST)



1472-486(5/8)(T)

FUNCTION	SIZE (IN.)
USED WITH MMU AS A BACK-UP MEANS FOR RETURN TO PAYLOAD BAY IF MMU MAL-FUNCTIONS	11L x 7.75W x 5.6H
PROVIDES UP TO 6 HRS OF PROTECTION & LIFE SUPPORT FOR CREWMAN PERFORM-ING TASKS IN FREE SPACE ENVIRONMENT	7L X 21 W X 24 H
INSTALLATION/REMOVAL TOOL FOR MMS SUBSYSTEM MODULES	26.5L X 7.15W X 10.2H

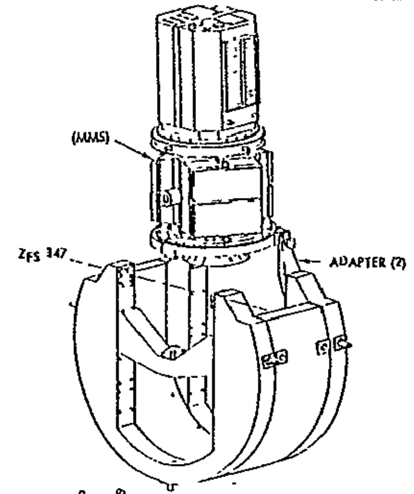
WT (LB)	STATUS
10.3	PLANNED
182	EXISTING
30	PLANNED

ORIGINAL PAGE IS OF POOR QUALITY

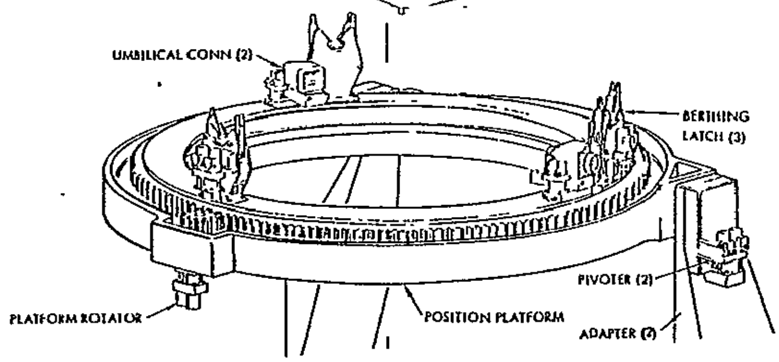
Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONTINUED)

EQUIPMENT	DESCRIPTION

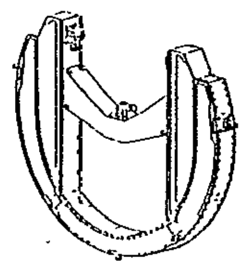
- MMS/FLIGHT SUPPORT SYSTEM (FSS)



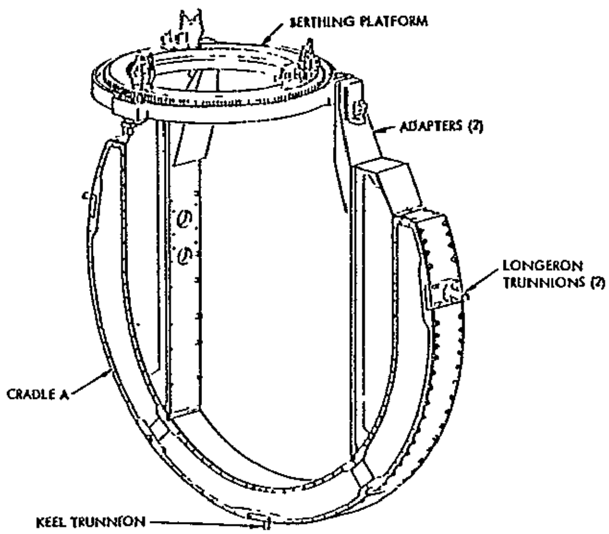
  - POSITION/BERTHING PLATFORM



  - CRADLE "A" (WITH LATCH BEAM & RETENTION LATCHES)



  - CRADLE "A" (WITH BERTHING &POSITIONING SYSTEM

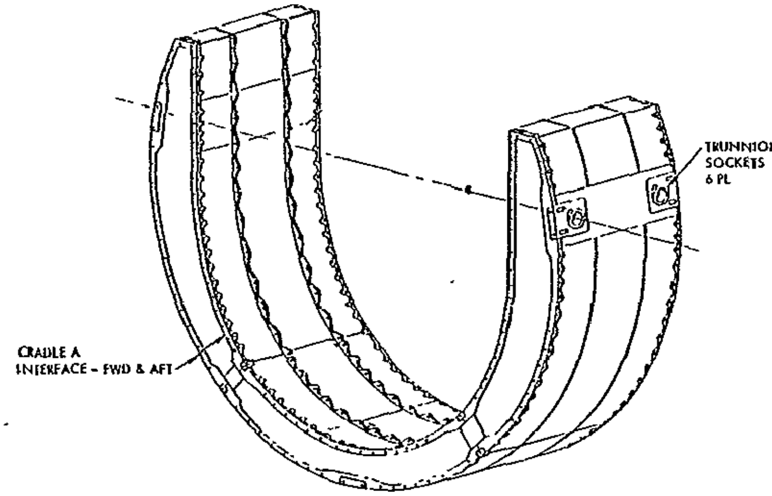
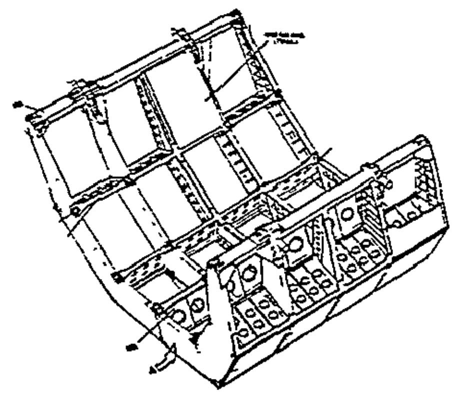
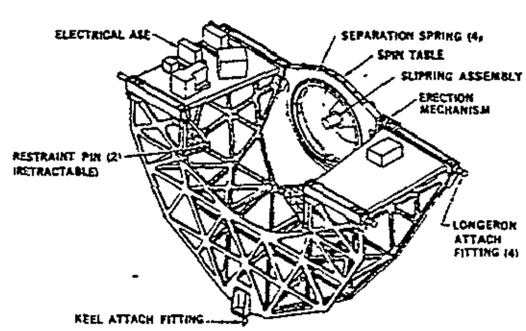


1472-486(6/8)(T)

FUNCTION	SIZE (IN.)
S/C LAUNCH RETENTION, ON-ORBIT, & RE-ENTRY	
S/C POSITIONING FOR LAUNCH	22H X 85DIA
S/C ON-ORBIT SUPPORT FOR SERVICING	16L X 178W X 150H
S/C SUPPORT FOR DEPLOY/RETURN	TBD

WT (LB)	STATUS
	EXISTING
600	EXISTING
2300	EXISTING
2500	EXISTING

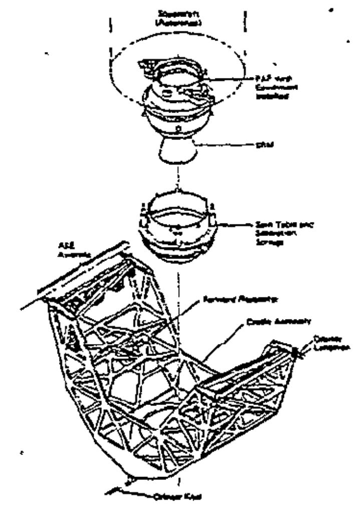
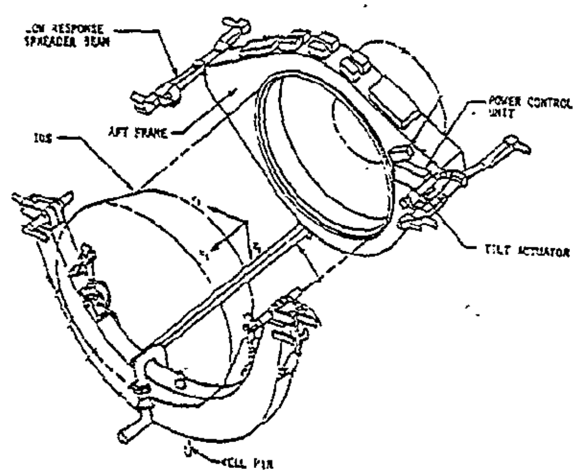
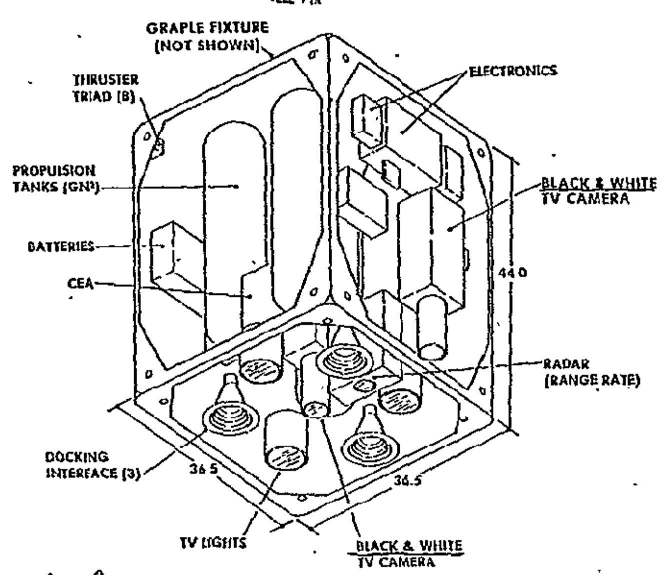
Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONTINUED)

EQUIPMENT	DESCRIPTION
– CRADLE "B"	
– ELECTRONIC CABLES & MISCELLANEOUS	
• SPACELAB PALLET	
• SPINNING SOLID UPPER STAGE (SSUS) – SSUS "A" – CRADLE ASSY – SPIN TABLE	

FUNCTION	SIZE (IN.)
S/C RETENTION, ON-ORBIT, RE-ENTRY	54L X 178W X 150H
SUPPORTS EXPERIMENT EQUIPMENT FOR DIRECT EXPOSURE TO SPACE	113L X 172W X 103H
CAPABLE OF LAUNCHING S/C WEIGHING UP TO 2750 LB INTO 27° GEO TRANSFER ORBIT FROM THE SHUTTLE ORBIT SSUS 'A' - 4400 LB S/C INTO GEO	TBD

WT (LB)	STATUS
3700	EXISTING
500	
1464	EXISTING
TBD	EXISTING

Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONTINUED)

EQUIPMENT	DESCRIPTION
– SSUS "D" – CRADLE ASSY – SPIN TABLE	
• INERTIAL UPPER STAGE (IUS) – FORWARD FRAME – AFT FRAME	
• MANEUVERING TELEVISION SYSTEM (MTS) – MANEUVERABLE TELE-VISION (MTV) – FSS	

FUNCTION	SIZE (IN.)
USED FOR LARGER SPACECRAFT: PAY-LOAD BAY INSTALLATION IS HORIZONTAL UP TO 45° ATTITUDE FOR DEPLOYMENT SPIN TABLE 45-66 RPM. SEPARATION VELOCITY = 1.5 FPS	80L X 180W X 106H
ASE PAYLOAD SUPPORT FOR STS LAUNCH, POSITIONS & DEPLOYS PAYLOAD	TBD
	TBD
	TBD
ON-ORBIT REMOTE OBSERVATION OF ORBITER OR RELEASED PAYLOAD	44L X 36 5W X 36.5H
	TBD

ORIGINAL PAGE IS
OF POOR QUALITY

WT (LB)	STATUS
2340*	EXISTING
4042**	EXISTING
1780	
1780	
	PLANNED
650	
175	
	* INCLUDING AVIONICS WT ** WT FOR PLANETARY (3-STG) PL-09A & PIONEER (4-STG) PL-22A

Fig. A-1 EXISTING/PLANNED EQUIPMENT (CONCLUDED)

GRUMMAN

1472IV-81