STUDY OF EVA OPERATIONS ASSOCIATED WITH SATELLITE SERVICES

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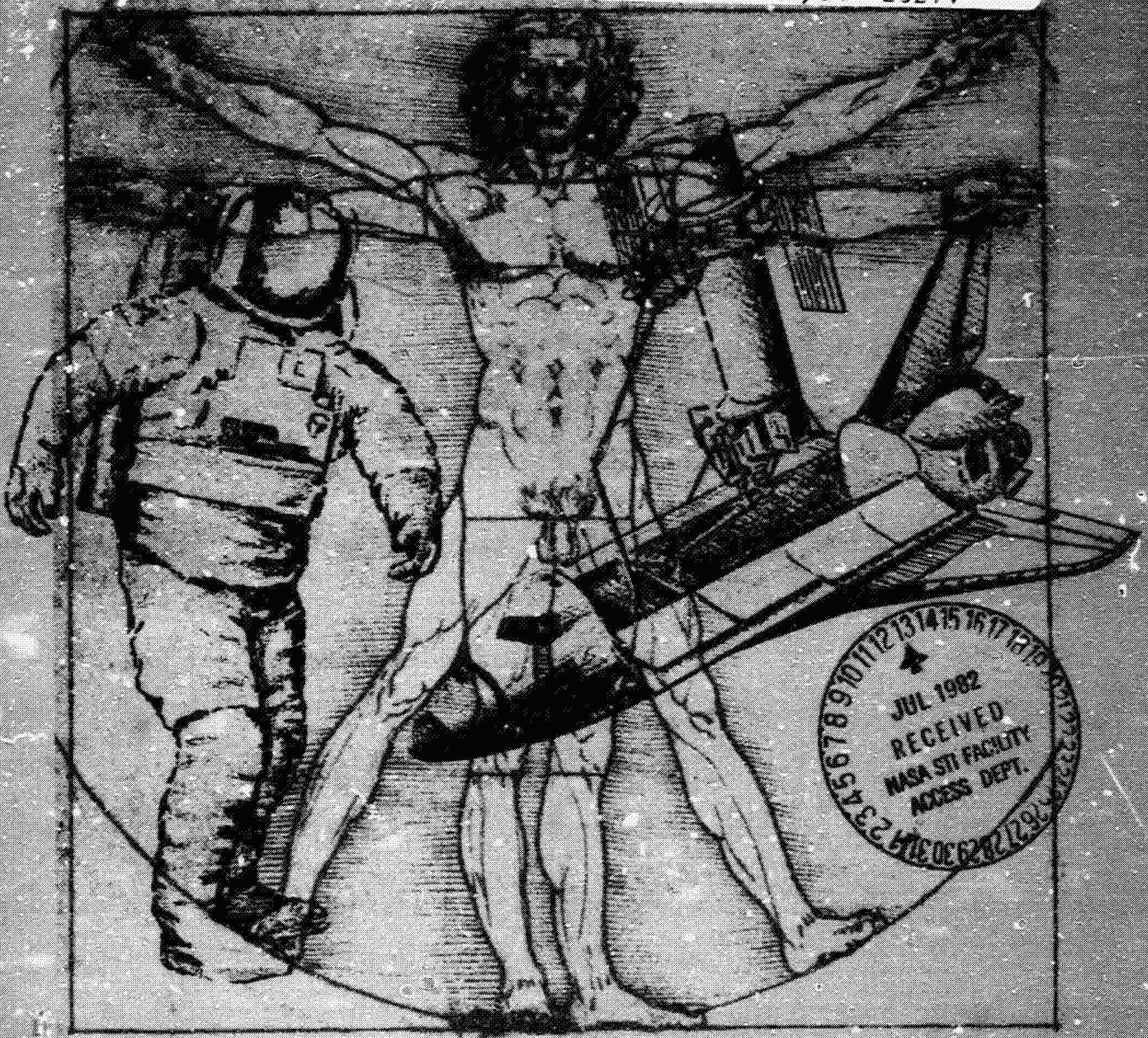

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APRIL 1982

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STUDY OF

EVA OPERATIONS ASSOCIATED WITH

SATELLITE SERVICES

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April 1982

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FOREWORD

This study has been performed for Grumman Aerospace Corporation, and in turn for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center under contract NAS 9-16120. This study has been performed over a period from August 1981 to January 1982.

This final report contains EVA capabilities and requirements for operations associated with satellite services. Appendices A and B contain detailed breakdown of time line data.

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ACRONYMS

AAP	-	Airlock Adapter Plate
ACS	-	Attitude Control System
AESA	-	Ancillary Equipment Stowage Assembly
AFD	-	Aft Flight Deck
ALSS	-	Airlock Support System
BITE	-	Built-in Test Equipment
BTU	-	British Thermal Unit
CCA	-	Communication Carrier Assembly
CCC	-	Contaminant Control Cartridge
CCTV	-	Closed Circuit Television
CMOS	-	Complementary Metal Oxide Semiconductor
CWS	-	Caution and Warning System
C&D	-	Control and Display
DCM	-	Displays and Control Module
EEH	-	EMU Electrical Harnesses
EMU	-	Extravehicular Mobility Unit
ETA	-	Environmental Test Article
EV	-	Extravehicular
EVA	-	Extravehicular Activity
EVC	-	Extravehicular Communicator
EVCS	-	Extravehicular Communication System
EVVA	-	Extravehicular Visor Assembly
FSS	-	Flight Support System
GAC	-	Grumman Aerospace Corporation
GFE	-	Government Furnished Equipment
GN_2	-	Gaseous Nitrogen
HC	-	Hand Controller
HPA	-	Handling Positioning Aid
HSD	-	Hamilton Standard
HUT	-	Hard Upper Torso
HX	-	Heat Exchanger

ACRONYMS (Continued)

IDB	-	Insuit Drink Bag
IR	-	Infrared
IV	-	Intravehicular
IVA	-	Intravehicular Activity
JSC	-	Johnson Space Center
LCVG	-	Liquid Cooling Ventilation Garment
LED	-	Light Emitting Diode
LSS	-	Life Support System
MESA	-	Modular Equipment Stowage Assembly
MFR	-	Manipulator Foot Restraint
MMC	-	Martin Marietta Corporation
MMU	-	Manned Maneuvering Unit
MTV	-	Maneuverable Television
NASA	-	National Aeronautics and Space Administration
OCP	-	Open Cherry Picker
OPA	-	Oxygen Purge Assembly
OWS	-	Orbital Workshop
PCM	-	Phase Change Materials
PIDA	-	Payload Installation and Deployment Aid
PLB	-	Payload Bay
PLSS	-	Primary Life Support System
POM	-	Proximity Operations Module
RHC	-	Rotational Hand Controller
RMS	-	Remote Manipulator System
ROM	-	Read Only Memory
SAA	-	Surface Attachment Assembly
SCU	-	Service and Cooling Umbilical
SOP	-	Secondary Oxygen Pack
SSA	-	Space Suit Assembly

ACRONYMS (Continued)

THC	-	Translational Hand Controller
TRK	-	Thermal Protection System Repair Kit
TTC	-	TRK Transport Container/Trash Container
UCD	-	Urine Collection Device
UV	-	Ultraviolet
VSS	-	Versatile Service Stage
WETF	-	Weightless Environment Training Facility
WIF	-	Water Immersion Facility
WRU	-	Work Restraint Unit
WSTF	-	White Sands Test Facility

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SECTION 1.0
SUMMARY

In this study Hamilton Standard identifies EMU factors associated with satellite servicing activities and outlines the EMU improvements necessary to enhance satellite servicing operations. Areas of EMU capabilities, equipment and structural interfaces, time lines, EMU modifications for satellite servicing, environmental hazards, and crew training are vital to manned EVA/satellite services and as such are detailed within this study. Using man for satellite servicing provides numerous benefits, especially in the performance of complex tasks. These benefits range from improving worksite access to utilizing man's adaptive ability to reprogram immediately in contingency and unplanned situations.

Evaluation of current EMU capabilities indicates that the EMU can be used in performing near-term, basic satellite servicing tasks; however, satellite servicing will be greatly enhanced by incorporating key modifications into the EMU. For instance, servicing missions involving contamination sensitive payload repair will require EMU modifications, as illustrated in Section 7.0.

EVA procedures and equipment can be standardized, reducing both crew training time and in-orbit operations time. By standardizing and coordinating procedures, mission cumulative time lines fall well within the EMU capability (See illustration on the following page).

EMU capabilities and modifications affect design of support equipment and satellite payload interfacing. For example, a non-contaminating thermal control subsystem will allow access to sensitive payloads. Also, joint and glove improvements will permit greater reach and range envelopes, consequently affecting support structure design. Development of an 8 psi EMU will eliminate conventional prebreathing, providing "quick reaction" and greater crewmember safety.

Identification of potential crew hazards indicates that hazards do not exceed current Shuttle program safety requirements. However, expansion of mission profiles into increased radiation orbits could require a reassessment of the suit protection system.

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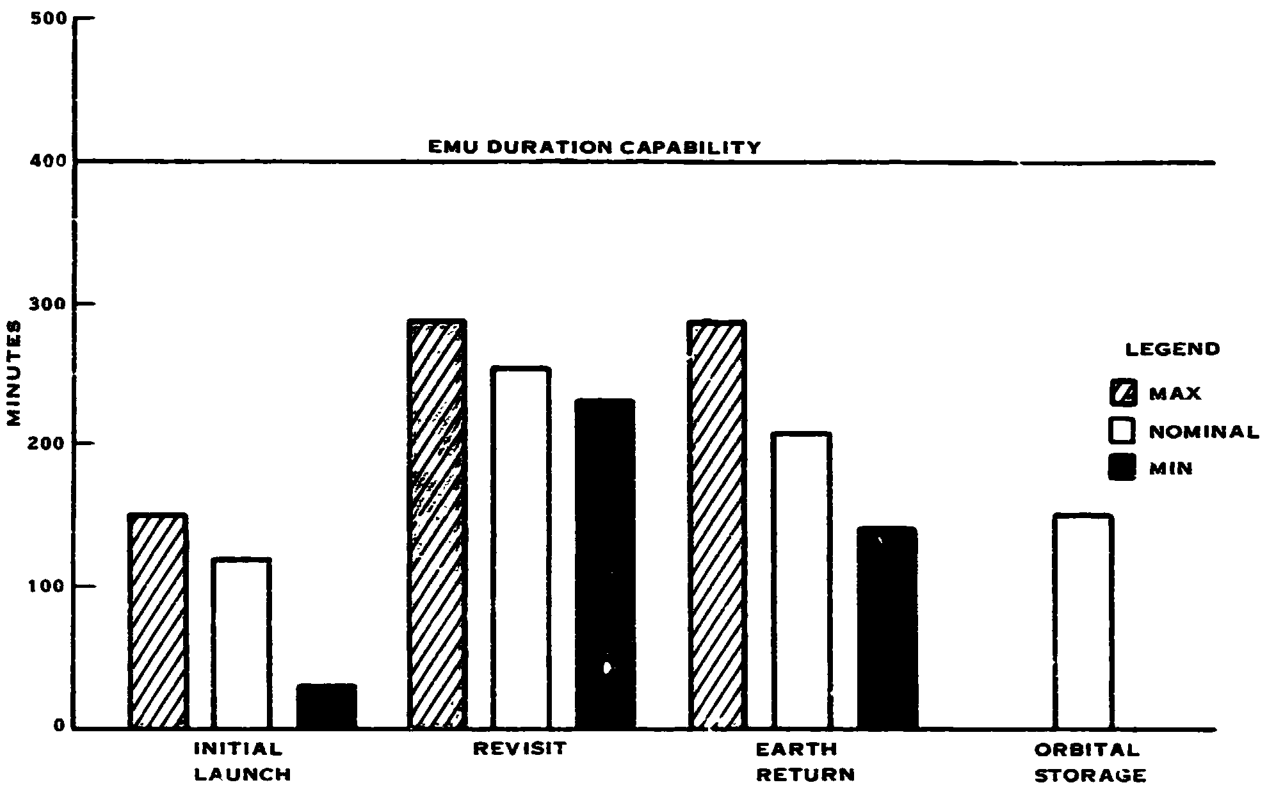

EVA MISSION TIME LINES WELL WITHIN EMU CAPABILITY

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SECTION 2.0
OBJECTIVES AND METHODOLOGY

The primary objectives of the "Study of EVA Operations Associated with Satellite Services" are to analyze and define Extravehicular Activity (EVA) operations associated with on-orbit satellite services. Of primary emphasis are the service activities foreseen for the 1983 to 1988 time frame, with a secondary emphasis on the 1988 to 1993 time period. This study provides a comprehensive and in-depth analysis of satellite services from the EVA operations perspective and identifies potential improvements in EVA-related equipment and operations which enhance the utility and safety of EVA servicing of satellites via the Space Shuttle. This study is consistent with basic approaches to satellite servicing contained in Grumman Aerospace Corporation document (SSSAS NAS 9-16120).

2.1 STATEMENT OF WORK

The Statement of Work defining the guidelines and tasks under which this study was developed are presented in the following paragraphs.

2.1.1 Study Guidelines

EVA servicing operations shall address three mission events; initial launch, revisits, and earth return. Service functions nominally associated with these mission events are: initial launch including checkout and deployment; revisits involving examination, retrieval, checkout, maintenance, resupply, reconfiguration and deployment; earth return involving examination, retrieval and earth return.

Servicing operations will occur near or in the general vicinity of the Orbiter vehicle, with near being defined as within 50 feet of the Shuttle.

On-orbit servicing of satellites will also be conducted while docked (berthed) to the Orbiter

2.1.2 Study Tasks

2.1.2.1 EMU Capabilities

The Contractor shall define dimensional and performance characteristics of the current Shuttle Extravehicular Mobility Unit. Any inconsistencies identified with projected satellite servicing tasks will be addressed.

2.1.2.2 Interfaces

The Contractor shall define the man/machine interfaces for EVA procedures to identify areas for special design/operations concerns in planning for satellite service operations. In addition, the Contractor shall provide transport interface and techniques concepts between Shuttle air-lock and worksite. The methods will be categorized in accordance with the distance from Shuttle. Three categories shall be covered; namely (1) within the Orbiter payload bay; (2) close-to-Orbiter (less than 50 feet); and (3) near-Orbiter (greater than 50 feet but less than 1000 ft). The transport options will include Manned Maneuvering Unit (MMU) considerations.

2.1.2.3 EVA Procedures

The Contractor shall assess EVA servicing operations associated with the three mission events; initial launch, revisits, and earth return. Each category may require unique operational procedures to accomplish EVA/Satellite servicing. Sufficient servicing scenarios shall be selected from Appendix B of the Grumman Service Equipment Requirements document to adequately reflect the extent of potential EVA activity, and shall be analyzed to identify the specific procedures required to accomplish EVA-based servicing.

2.1.2.4 Time Lines

The Contractor shall define time line elements for generic EVA routines expected to be used in satellite servicing. These shall cover both contingency and nominal EVA operations.

2.1.2.5 Support Equipment

The Contractor shall identify and analyze worksite EVA equipment requirements for support of satellite servicing. Equipment which may be used by the EVA crewmen shall be defined and concepted.

2.1.2.6 Extravehicular Mobility Unit (EMU) Improvements

The Contractor shall identify modifications and/or improvements required or desirable to the Shuttle EMU and MMU in order to optimize or improve satellite servicing activities.

2.1.2.7 Hazards Analysis

The Contractor shall identify and categorize safety hazards issues that are relevant to satellite servicing/EVA. Provide resolution or approaches for eliminating and/or preventing the occurrence of potential hazards.

2.1.2.8 Crew Training

The Contractor shall identify generic EVA servicing approaches that are applicable to the satellite scenarios, and which will lead to a reduction or a minimization in crew training requirements (e.g., approaches using electrical connectors, fasteners, and module changeout commonality features).

2.1.2.9 EVA Benefits Associated With The EMU

The contractor shall define benefits associated with EMU modifications and support equipment for use in Satellite Servicing.

2.1.2.10 Technology Plan

The contractor shall approximate development program schedules and eventual market entry dates for EMU modifications.

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SECTION 3.0
THE EXTRAVEHICULAR MOBILITY UNIT (EMU)

The Extravehicular Mobility Unit (EMU) performs two basic functions for the EVA astronaut. One is the life support function, that is, it provides a controlled pressurized environment, clean oxygen for breathing, temperature control and waste management. The second is that it provides a highly mobile enclosure, the space suit assembly (SSA), which permits tasks to be performed almost as easily as on earth.

The EMU combines the following life support functions:

- Pressure Retention
- Oxygen Regulation
- Atmosphere Revitalization (CO_2 and moisture removal)
- Temperature Control
- Thermal Hazards Protection
- Radiation Hazards Protection

into an end product which allows nearly 85% nude body mobility capability. The EMU consists of nineteen (19) end items, displayed in Figure 1. Each of the nineteen end items has been developed as a part of an integrated system, but are delivered, field-managed and maintained as individual items in order to provide flexibility and economy in field operations. Due to the use of standardized fittings, the EMU spacesuit arms, legs and boots of various sizes are interchangeable with various sizes of the fiberglass Hard Upper Torso (HUT) element. This modular feature permits assembly of EMU's for both male and female crewmembers, and eliminates the cost associated with custom sizing for a particular crewmember. Table I contains overall EMU performance characteristics and Figure 2 provides EMU dimensions.

3.1 EMU END ITEMS

Each of the EMU nineteen end items are described in the following paragraphs.

1. Primary Life Support System (PLSS) - The backpack, mounted on the rear of the Hard Upper Torso, contains the life support subsystem expendables and machinery.

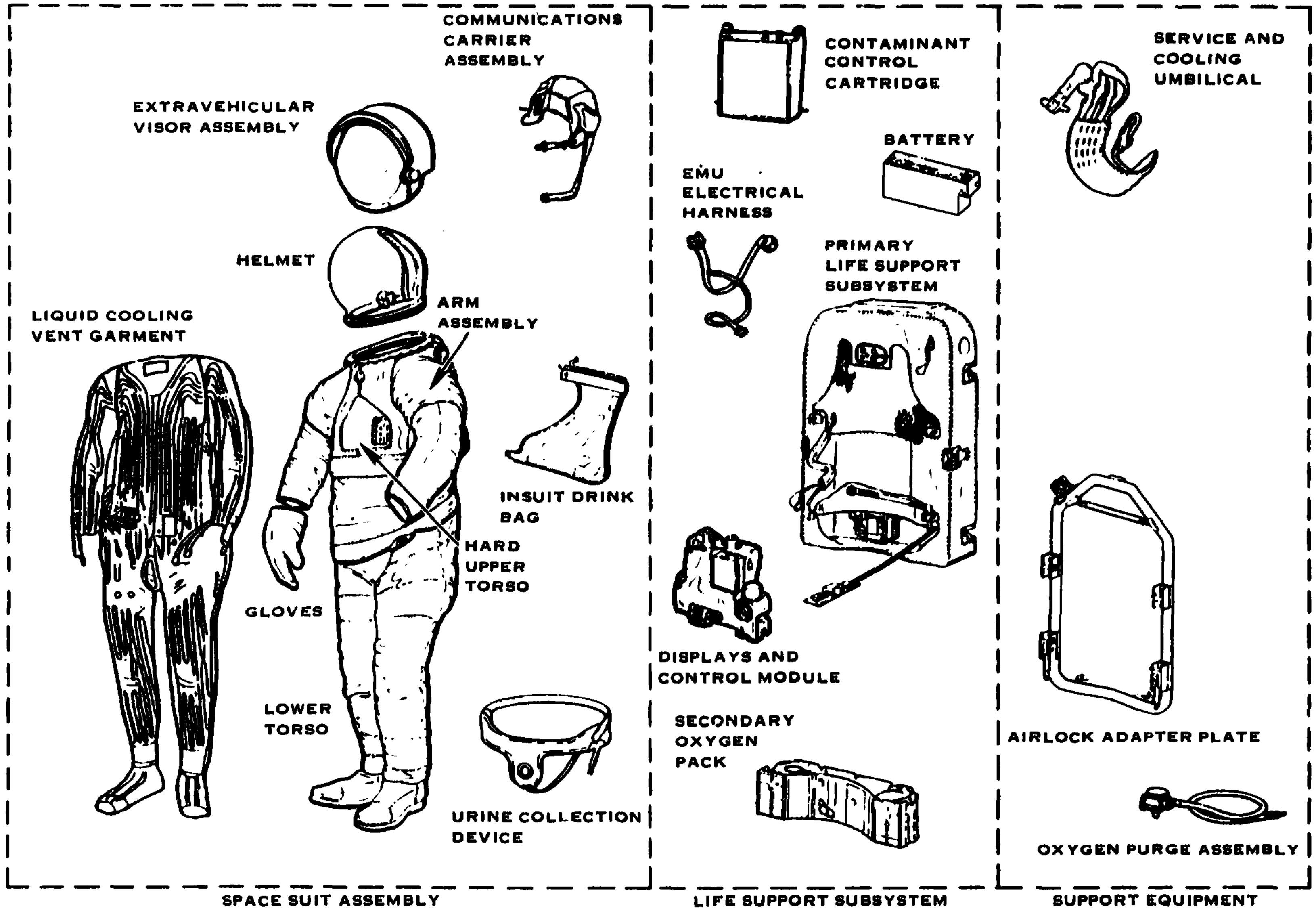

FIGURE 1. SPACE SHUTTLE EMU END ITEMS

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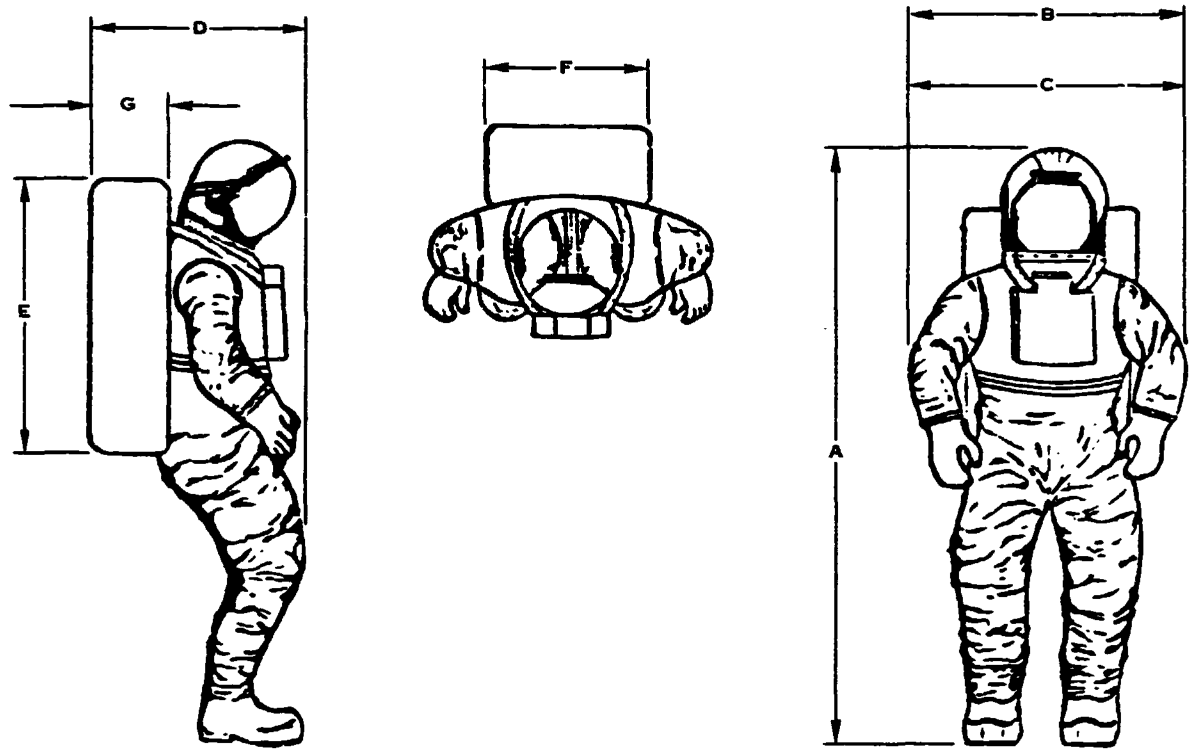
TABLE I. EMU PERFORMANCE CHARACTERISTICS

SYSTEM PROVISION	PARAMETER	PERFORMANCE REQUIREMENT
VENT SYSTEM	NORMAL PRESSURE	EVA 4.1±0.1 PSID IVA 0.4 TO 0.9 PSID
	EMERGENCY PRESSURE	0.06 TO 1.00 LBS/HR 3.33-3.7 PSID 1.01 TO 4.50 LBS/HR 3.33-3.7 PSID 4.51 TO 5.76 LBS/HR 3.33-3.55 PSID
	PRESSURE RELIEF	5.3 PSID MAXIMUM
	COLLAPSE PRESSURE	1.2 PSID MAXIMUM
	INTERNAL TEMPERATURE RANGE	40-90 DEG F
	DEWPOINT (SSA INLET)	65 DEG F MAXIMUM
	CO_2 PARTIAL PRESSURE	7.6 MMHG FOR METABOLIC RATES UP TO AND INCLUDING 1600 BTU/HR FOR ONE HOUR – 15 MMHG FOR METABOLIC RATES UP TO 2000 BTU/HR FOR 15 MINUTES

SYSTEM PROVISION	PARAMETER	PERFORMANCE REQUIREMENT
HEAT SINK CAPACITY		10,700 BTU'S
HEAT LOADS		
• METABOLIC		+1000 BTU/HR NOMINAL +1600 BTU/HR MAXIMUM
• ENVIRONMENTAL LEAKAGE		+330 BTU/HR MAXIMUM
• LIFE SUPPORT (CHEMICAL & ELECTRICAL)		+1450 BTU/HR MAXIMUM
• BODY HEAD STORAGE		±300 BTU MAXIMUM
• SKIN CONTACT TEMPERATURE		+110°F MAXIMUM 50°F MINIMUM
EVA DURATION	NORMAL INDEPENDENT	7 HOUR NOMINAL AT NOMINAL METABOLIC AND MAXIMUM DESIGN ENVIRONMENTAL.
	EMERGENCY	30 MINUTES MINIMUM AT NOMINAL METABOLIC.
LIFE	USEFUL	15 YEARS HARDWARE 6 YEARS OF SOFTGOODS
WEIGHT (CEI SPEC)	LSS, INCL O_2 & H_2O	136.84 LBS
	SSA	105.12
	EMU	241.96 LBS
	AAP	22.60 LBS
	SCU	12.05
	OPA	1.00
	TOTAL FLIGHT WEIGHT	277.61 LBS



DIMENSION	PERCENTILE MAN 5% CM	5% IN	95% CM	95% IN
A - HEIGHT	171.5	67.5	192.8	75.5
B - MAXIMUM BREADTH AT ELBOWS (ARMS RELAXED)	—	—	74.7	29.4
C - MAXIMUM BREADTH AT ELBOWS (ARMS AT SIDE)	—	—	67.1	26.4
D - MAXIMUM DEPTH WITH PRIMARY LIFE SUPPORT SYSTEM (PLSS) AND SECONDARY OXYGEN PACK (SOP)	66.0	26.0	72.1	28.4

	CM (MAX.)	IN (MAX.)
E - PLSS/SOP HEIGHT	78.7	31
F - PLSS AND SOP BREADTH	58.4	23
G - PLSS AND SOP DEPTH	17.8	7

FIGURE 2. EMU DIMENSIONS

3.1 (Continued)

2. Displays and Control Module (DCM) - The chest mounted displays and control module contains all external fluid and electrical interfaces, controls and displays required for one-man operation of the EMU. The DCM houses the fan switch, water pump switch, communications selector switch and audio volume control, oxygen quantity indicator, suit pressure gauge, cooling control valve, purge valve and status indicators. The location and size of the DCM is such that the crewmember can read displays and reach manual controls without undue compromise of work visibility and mobility. The individual DCM controls have been engineered to prevent inadvertent actuation by either the crewmember or external equipment contact.

3. EMU Electrical Harnesses (EEH) - This internal harness provides bioinstrumentation and communications connections to the DCM.

4. Secondary Oxygen Pack (SOP) - This pack is mounted to, and removable from the base of the PLSS. It contains a 30-minute emergency O_2 supply and a valve and regulator assembly.

5. Service and Cooling Umbilical (SCU) - This umbilical connects the Airlock Support System (ALSS) to the EMU for recharge and for Intravehicular Activity (IVA). The SCU contains power, recharge and communication lines, water and O_2 recharge lines and a water drain line. It has a multiple connector at one end and a permanent fitting at the other.

6. Battery - The battery provides electrical power used by the EMU during EVA. The battery is stored dry, and is filled, sealed and charged prior to flight. The battery is rechargeable.

7. Contaminant Control Cartridge (CCC) - This assembly integrates LiOH, charcoal and a filter into one assembly. It is replaced in flight without use of tools.

8. Hard Upper Torso (HUT) - This assembly is the structural mounting interface for most of the EMU - helmet, arms, lower torso, PLSS, DCM and electrical harnesses. It also includes the top half of the donning entry body seal closure.

3.1 (Continued)

9. Lower Torso - This assembly consists of the pants and boots, and contains the bottom half of the body seal closure, as well as the hip, knee and ankle joints.

10. Arms (Left and Right) - This assembly contains the shoulder joint and upper arm bearings that permit shoulder mobility, as well as the elbow joint and wrist bearing.

11. Helmet - The helmet consists of a clear, polycarbonate bubble, neck disconnect and ventilation pad.

12. Gloves (Left and Right) - Gloves contain the wrist disconnect, wrist joint, the fingers and thermal protection.

13. Liquid Cooling and Ventilation Garment (LCVG) - This garment, worn under the pressure garment, contains the liquid cooling tubes and gas ventilation manifolding.

14. Urine Collection Device (UCD) - This item consists of the adapter tubing, storage bag and disconnect hardware for emptying liquid.

15. Extravehicular Visor Assembly (EVVA) - This assembly attaches externally to the helmet and contains visors which are manually adjusted by the crewman to shield his eyes.

16. Insuit Drink Bag (IDB) - This assembly stores liquid in the HUT and has a tube projecting up into the helmet to permit the crewman to drink while suited.

17. Communication Carrier Assembly (CCA) - This assembly consists of a fabric head cover which mounts the headphones and microphone to the crewman.

18. Airlock Adapter Plate - This item is the mounting fixture for the EMU during stowage and is used as an aid in donning and doffing the EMU.

19. Oxygen Purge Adapter - The oxygen purge adapter permits the EMU to be purged of residual nitrogen prior to EVA.

These end items form a compact system capable of providing a seven-hour EVA. A system schematic is shown in Figure 3.

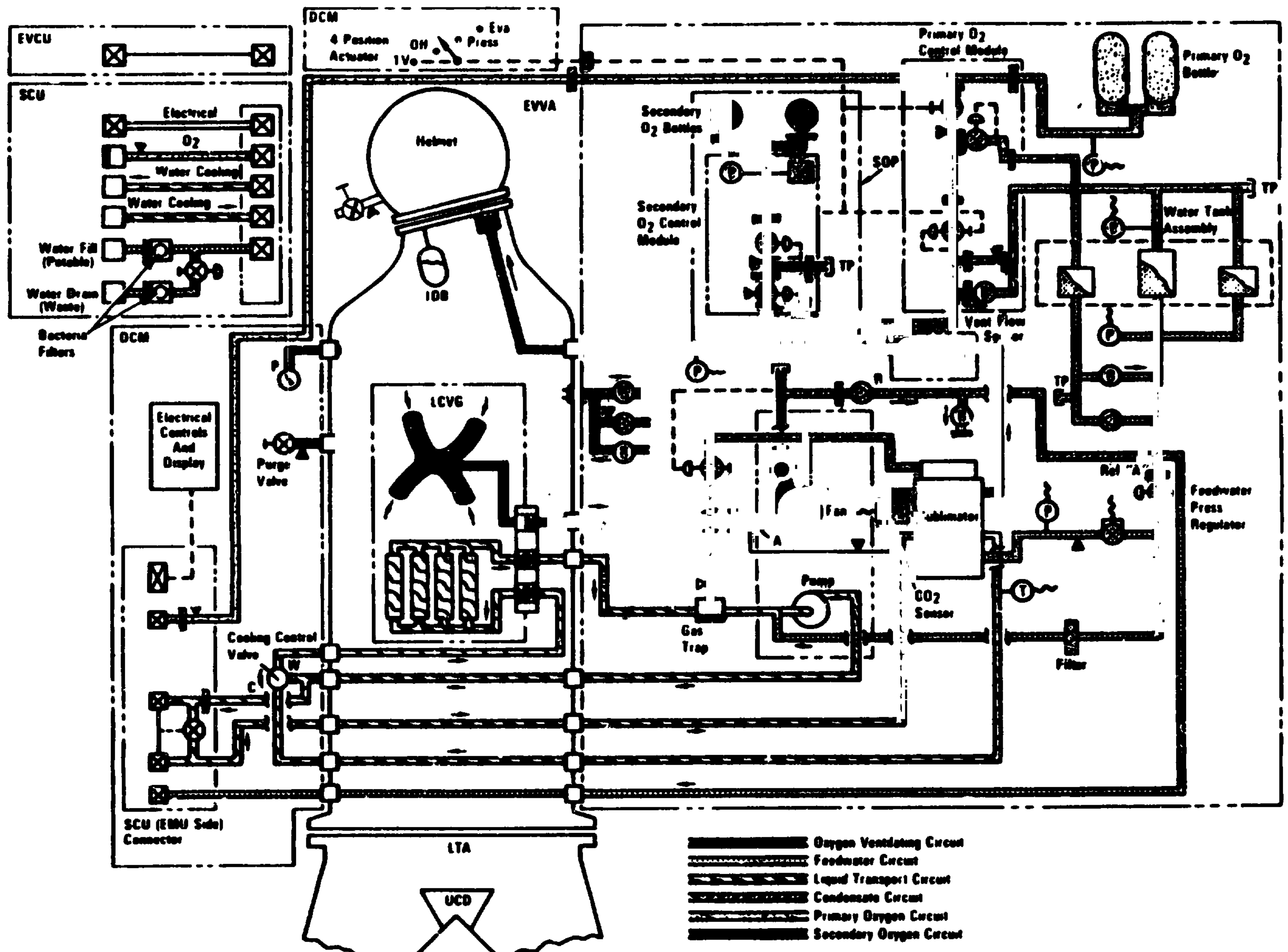


FIGURE 3. SPACE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT SCHEMATIC

3.2 EMU SUBSYSTEM DESCRIPTIONS

3.2.1 Primary Life Support System - The Primary Life Support System (PLSS) is a self-contained life support system that provides life support, voice communications and biomedical telemetry for an astronaut performing Space Shuttle extravehicular activity (EVA) tasks and for those intravehicular activity (IVA) tasks which require the use of a space suit. The PLSS is capable of supporting metabolic loads up to 2 X 10^6 J/hr and is designed to support a nominal EVA/IVA mission of seven hours.

Five major component groups perform the life support functions. These component groups are:

- Oxygen Ventilating Circuit
- Condensate Circuit
- Feedwater Circuit
- Liquid Transport Circuit
- Primary Oxygen Circuit

Each of these circuits are discussed in the following paragraphs.

3.2.1.1 Oxygen Ventilating Circuit

The Oxygen Ventilating Circuit shown in Figure 4 forms a closed loop with the space suit assembly within which oxygen for breathing and suit pressurization is circulated and purified. This oxygen picks up heat, humidity, CO_2 and other contaminants from the astronaut. These metabolic by-products are removed from the oxygen by the Oxygen Ventilating Circuit components.

The Oxygen Ventilating Circuit operates over a range of pressures controlled by the Primary Oxygen Subsystem or the Secondary Oxygen Pack (SOP) as follows:

Oxygen Ventilating Circuit Pressure Level	Pressure Source	Operating Mode
$23.77 \times 10^3\ N_m^{-2}$	SOP	EVA - purge
$28.26 \times 10^3\ N_m^{-2}$	Pri O_2	EVA - normal
$23.77 \times 10^3\ N_m^{-2}$	SOP	EVA - emergency make-up
$3.45 \times 10^3\ N_m^{-2}$	Pri O_2	IVA - normal
$28.76 \times 10^3\ N_m^{-2}$	Pri O_2	IVA - pressurized

3.2.1.1 (Continued)

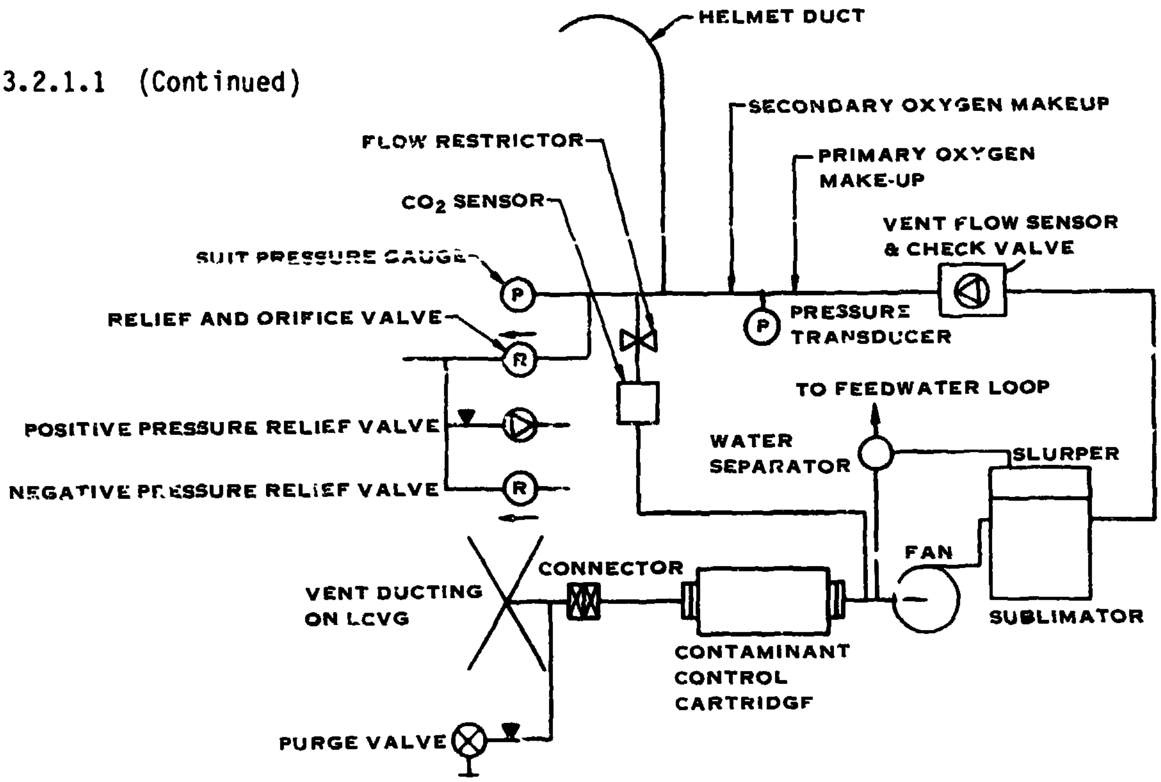


FIGURE 4. OXYGEN VENTILATING CIRCUIT

A centrifugal fan (integrated into a fan/separator/pump assembly) running at 14,000 to 20,000 rpm drives ventilation flow through the space suit. The gas flow picks up CO_2 and trace contaminants, humidity and sensible heat from the astronaut. CO_2 and trace contaminants are removed in the contaminant control cartridge. The gas stream continues through the sublimator, where it is cooled. Excess humidity is removed from the ventilation oxygen circuit and condensed in the sublimator.

The CO_2 level is measured in the Ventilating Circuit upstream of the sublimator by an electrochemical CO_2 sensor. A check valve/flow sensor is located downstream of the sublimator. The check valve assures that when the fan is unpowered, all purge flow is directed to the helmet. The flow sensor monitors flow level.

The ventilating circuit flow then passes to the HUT through hard-plumbed connections, and on to the helmet. Ventilating circuit ducting in the HUT superheats the inflow O_2 sufficiently to prevent visor fogging. Within the helmet the flow passes downward over the visor and head to provide CO_2 removal and

3.2.1.1 (Continued)

head cooling, then continues to the pressure garment. Ventilation flow is picked up at the extremities and returned to the Hard Upper Torso via a manifold that is part of the Liquid Cooling Ventilation Garment.

During emergency or other conditions requiring open loop operation the ventilating circuit can be operated in a purge mode. Purge, checkout and pressure relief are all accomplished with valves mounted in the DCM. The purge valve is manually activated and passes O_2 from the ventilating circuit. Positive pressure relief protection against failed open Secondary Oxygen Pack or Primary Oxygen Subsystem regulators is effected by a relief valve. A negative pressure relief valve permits suit internal pressure to rise at the same rate as the Orbiter airlock during an emergency repressurization.

3.2.1.2 Condensate Circuit

The Condensate Circuit shown in Figure 5 removes the condensate generated by the ventilating circuit and returns it to the feedwater circuit.

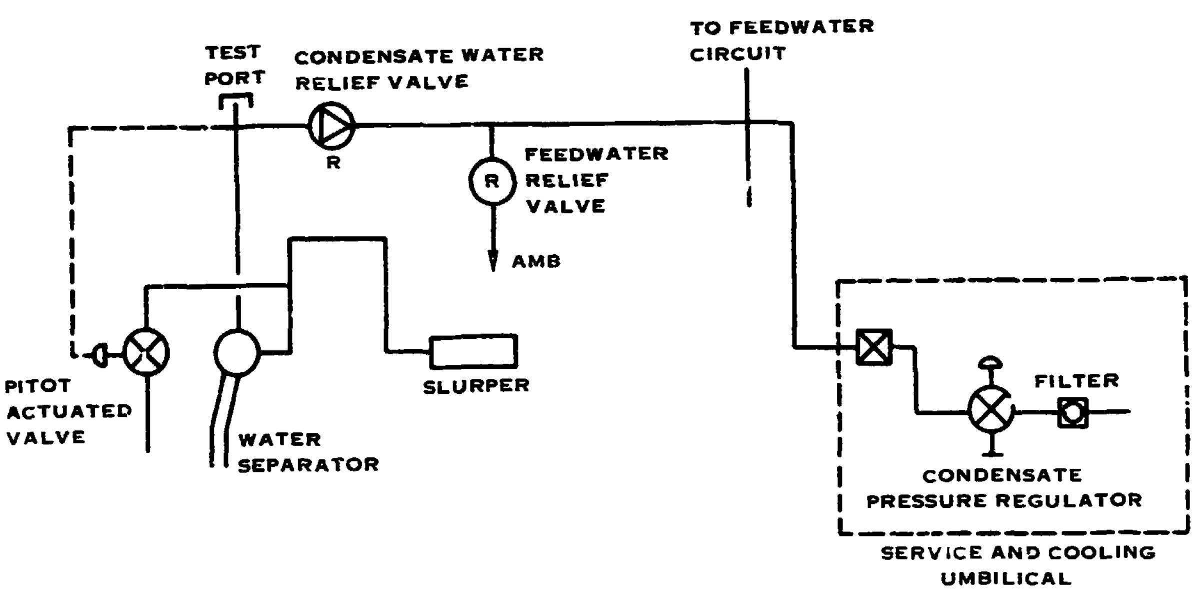


FIGURE 5. CONDENSATE CIRCUIT

3.2.1.2 (Continued)

Condensate collected by the slurper is passed to the water separator with a small amount of ventilation gas. A gas and water mixture also enters the water separator from the gas trap through the pilot actuated valve. The water separator separates the gas/water mixture, returns the gas to the ventilating circuit and pumps the water through a condensate water relief valve into the feedwater circuit.

3.2.1.3 Feedwater Circuit

The Feedwater Circuit as shown in Figure 6 stores and supplies feedwater for LCVG makeup, provides water for EMU cooling and condenses and delivers condensate to supplement the feedwater supply. Feedwater from the Orbiter potable water supply is stored in a water reservoir and pressurized by the Primary Oxygen Circuit. Potable water from Airlock Support System (ALSS) is added via the Service and Cooling Umbilical (SCU). Feedwater passes through a pressure regulator that reduces pressure to top off and pressurize the LCVG loop and to feed the sublimator. Feedwater passes into the sublimator, freezes in the stainless steel porous plate and sublimates to space, cooling the LCVG coolant water as it flows through the sublimator.

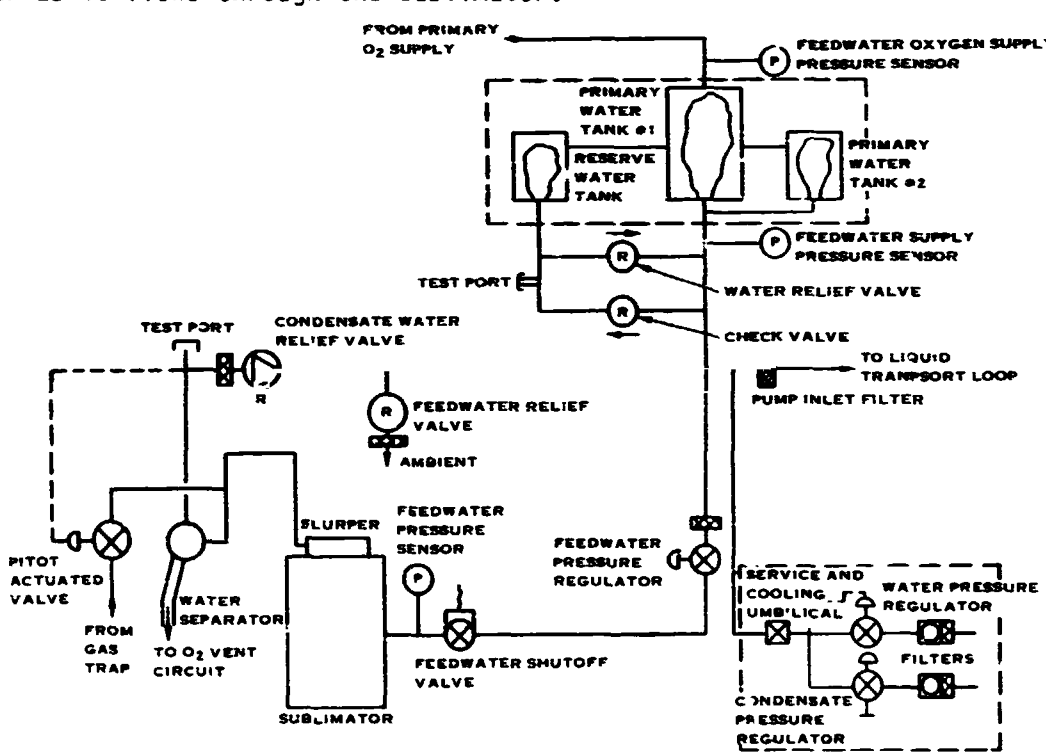


FIGURE 6. FEEDWATER CIRCUIT

3.2.1.4 Liquid Transport Circuit

The Liquid Transport Circuit as shown in Figure 7 circulates water through the LCVG and sublimator via a centrifugal pump, performing crewman temperature control. The LCVG pressure level is regulated by the Feedwater Circuit. A cooling control valve located on the DCM provides temperature control by permitting the astronaut to bypass a variable amount of water around the sublimator or ALSS heat sink back to the LCVG. During IVA operation, the pump circulates water not only through the EMU, but also through the ALSS through the SCU.

During IVA operation astronaut heat loads are picked up by a heat exchanger in the Orbiter ALSS control system. This is accomplished via the SCU which connects the Liquid Transport Circuit into the ALSS. The PLSS Ventilating Circuit heat loads are transferred to the Liquid Transport Circuit in the sublimator, which acts as a gas-to-liquid heat exchanger in this mode. The PLSS pump provides the water circulation through the Liquid Transport Circuit, SCU and ALSS heat exchanger in the IVA mode.

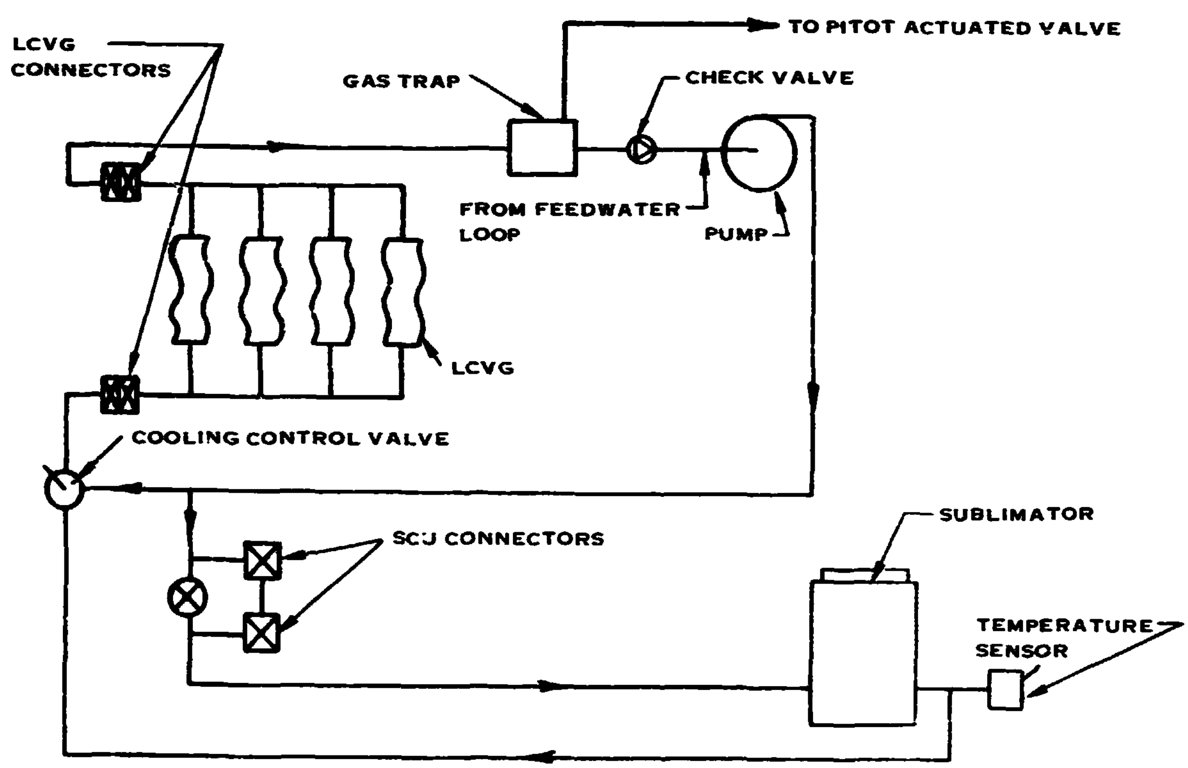


FIGURE 7. LIQUID TRANSPORT CIRCUIT

3.2.1.5 Primary Oxygen Circuit

A schematic diagram of the Primary Oxygen System is shown in Figure 8. Charging gas from the ALSS (via the SCU) fills the circuit through a disconnect on the DCM. Two oxygen tanks store the oxygen. The tanks are isolated from the Ventilating Circuit by a manual shutoff valve.

Two regulators provide oxygen at usable pressures. One regulator pressurizes the feedwater circuit, and the other regulator has two schedules, one to pressurize the Ventilating Circuit for IVA operation and one for EVA operations. Regulator valve settings are controlled by an O_2 actuator mounted on the DCM.

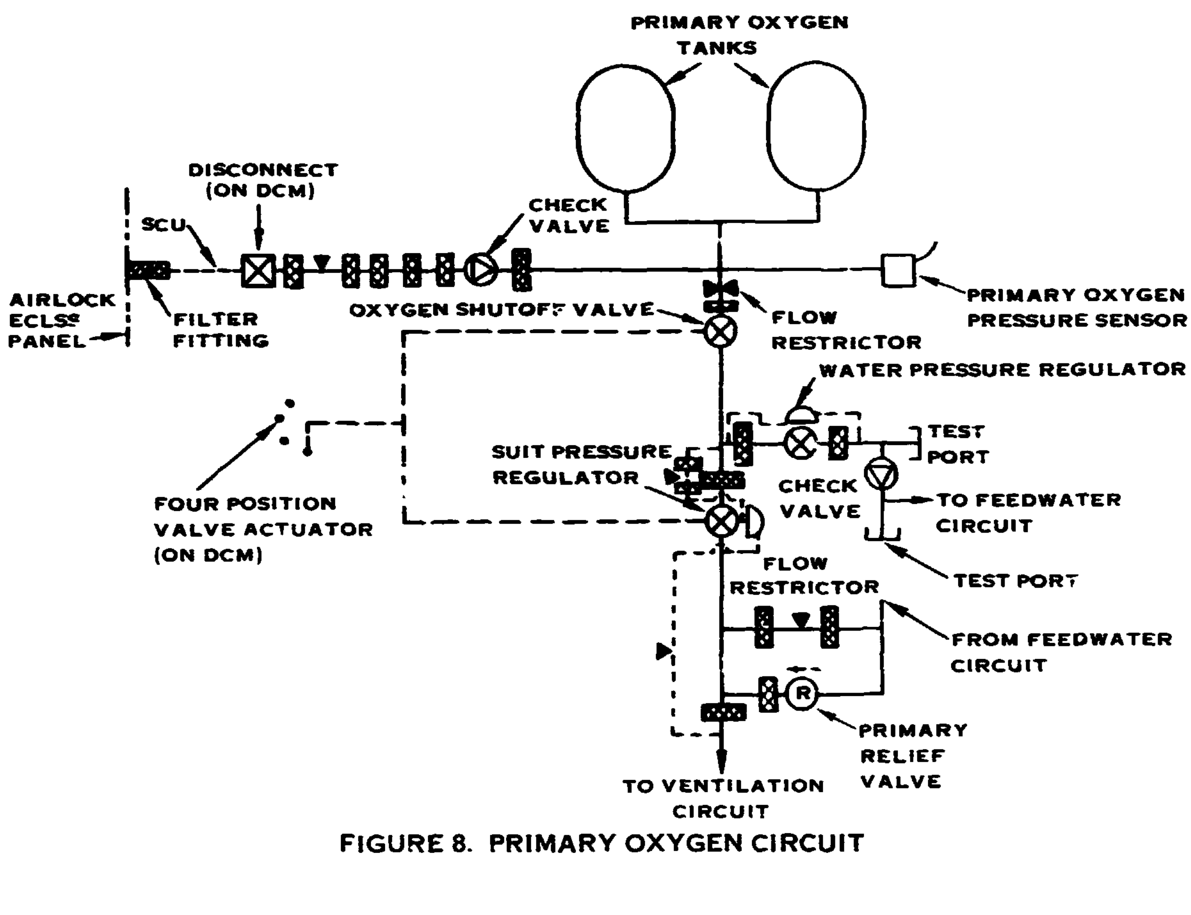


FIGURE 8. PRIMARY OXYGEN CIRCUIT

3.2.1.6 PLSS Packaging

An assembly diagram of the PLSS is shown in Figure 9. The PLSS has been designed to incorporate the following key features:

- Serviceability - Consumables are easily recharged in flight.
- Maintainability - PLSS is quickly returned to flight status.
- Compact Size - The suited astronaut has ar overall front-to-back (PLSS to DCM) dimension of less than 19.75 inches (50.8 cm), and a PLSS width of 23 inches (59 cm).
- Capability Modification - Capacity of expendables can be increased without redesign of moving parts or major rearrangement of the packaging.
- Modular Construction - Consists of separable, identifiable subsystems.

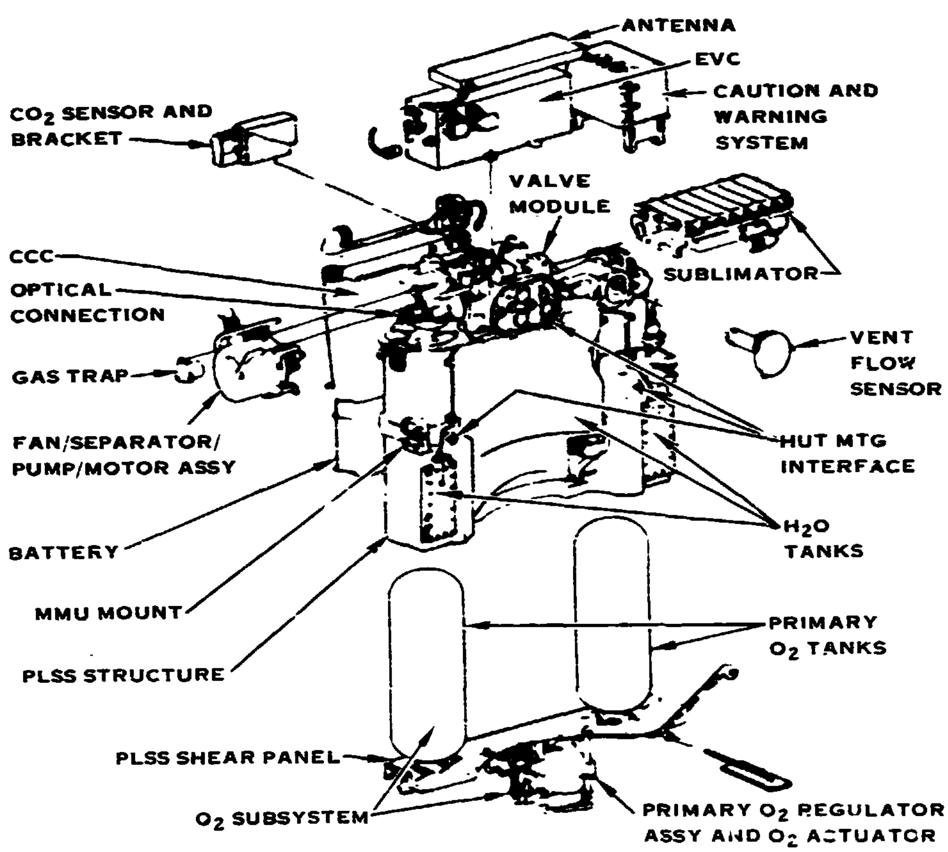


FIGURE 9. PLSS PACKAGE

3.2.2 EMU Electrical Subsystem

The EMU Electrical Subsystem as shown in the electrical schematic, Figure 10, consists of the DCM, Fan, Battery, Extravehicular Communication System and and instrumentation items to monitor EMU parameters as part of the Caution and Warning System.

The EMU Electrical Subsystem features maintainable electrical components and harnesses. Crimp type connectors are used for electrical terminations.

The Caution and Warning System (CWS) features a microprocessor which monitors EMU and Manned Maneuvering Unit (MMU) instrumentation. The visual display is a 12 character alphanumeric light-emitting diode type providing system parameter status, corrective actions instruction in the event of malfunctions and expendables monitoring.

The CWS utilizes software which is field interchangeable, low power CMOS electronics, and internal provisions for self-checking and failure diagnosis from the PLSS instruments. Information is transmitted to the crewman via an alphanumeric display located on the DCM. Audio tones aler the crewman to observe the display for instruction or information. In addition, the DCM provides the following information:

1. Startup, checkout, IVA, egress and ingress procedures to be executed by the crewman.
2. A quantitative status readout of system parameters (temperature, voltage, pressure, etc.) including oxygen, water and battery amp-hour expendables.
3. Notification of a failure or out-of-limit condition, the specific parametric value and the necessary corrective action to be taken.

The CWS contains built-in-test equipment (BITE) consisting of software routines which verify proper operation of the system. These routines are multiplexed with the normal monitoring routines to provide continuous monitoring of the health of the CWS as well as the EMU.

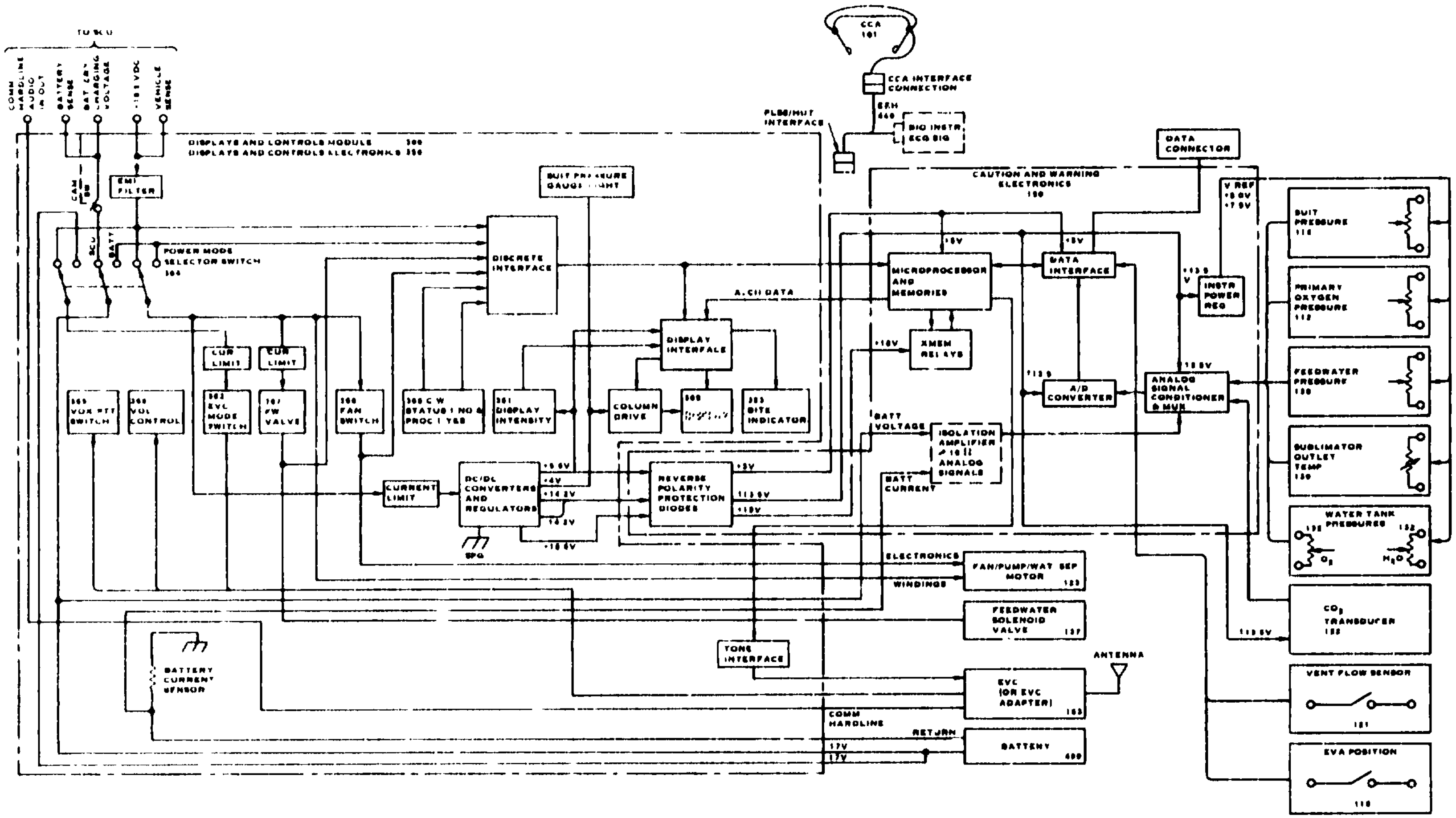


FIGURE 10. EMU ELECTRICAL SCHEMATIC

3.2.3 Secondary Oxygen Pack

The Secondary Oxygen Pack (SOP), shown schematically in Figure 11, provides space suit backup pressure regulation and emergency open loop purge capability. The SOP delivers oxygen at a sufficient rate to support a metabolic work load of 10^6 J/hr for 30 minutes in the open loop purge mode.

The SOP package contains two high pressure oxygen tanks, a regulator manifold assembly and a protective container/structure assembly. The two oxygen tanks contain a heating tube brazed to the internal wall of the tank to heat the effluent gas prior to entering the regulator manifold assembly. The SOP package is mounted to the bottom of the PLSS. The outside back contour of the SOP closely matches the inside radius of the airlock.

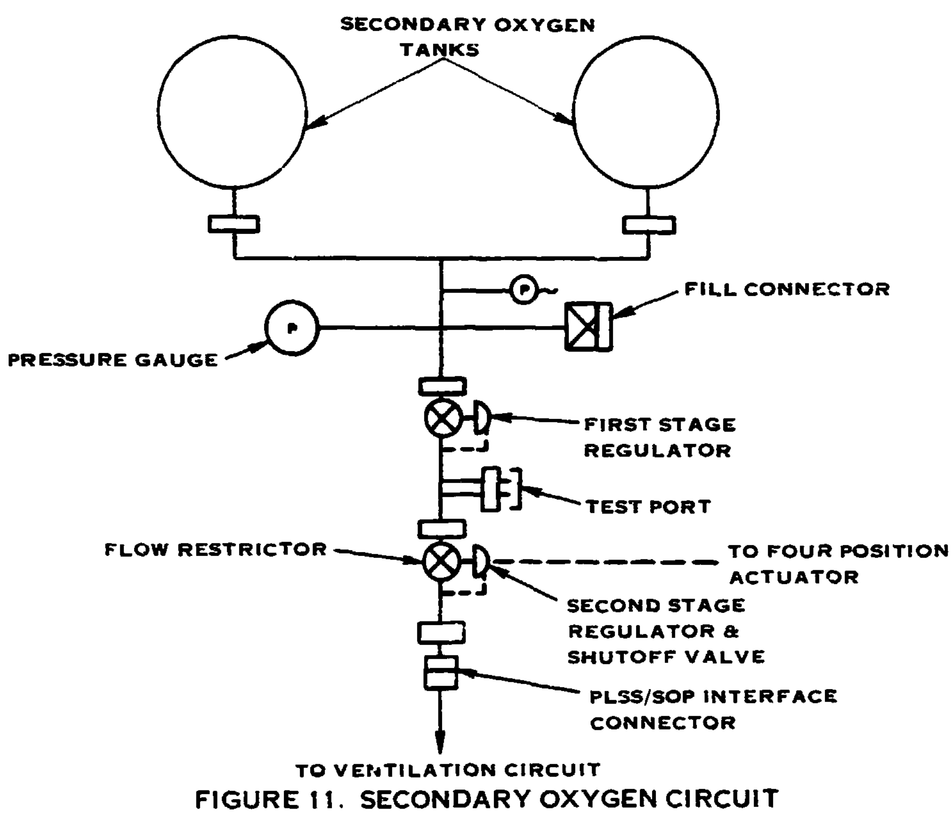


FIGURE 11. SECONDARY OXYGEN CIRCUIT

3.3 SPACE SUIT ASSEMBLY (SSA)

The SSA consists of eleven (11) end items forming an anthropormorphic pressure vessel which protects the extravehicular crewmen from extreme temperatures, micrometeroids, and space vacuum.

The eleven end items comprising the SSA are listed below:

Hard Upper Torso
Lower Torso Assembly Arm Assembly
Helmet
Extravehicular Visor Assembly
Gloves
Communications Carrier Assembly
Urine Collection Device
Insuit Drink Bag
Liquid Cooling and Ventilation Garment
Oxygen Purge Adapter

The key design features of the Space Suit Assembly are:

1. A hard upper torso that incorporates provisions for PLSS/SOP structural mounting and for interconnecting the DCM with the PLSS/SOP.
2. Tucked fabric and flat patterned joints. The wrist and finger joints are pleated tucked fabric joints. All other joints on the SSA, including the shoulder, elbow, waist, knee, hip and ankle, are single axis flat patterned joints. Sealed bearings at the scye, upper arm, wrist, and waist provide omni-directional capability.
3. Hard ring torso entry closure and sealed bearings for increased rotational mobility.
4. Removable bubble shaped helmet.
5. Removable Extravehicular Visor Assembly with replaceable visors.
6. Non-custom sizing with length adjustment provisions in arms and lower torso.
7. Combined LCVG water and vent connector that connects at the upper front torso.

3.3 (Continued)

8. Boot configuration to interface with Shuttle foot restraints.

3.4 EMU MOBILITY CAPABILITIES

The Shuttle EMU is capable of meeting all routine satellite servicing requirements. However, additional requirements will evolve from simple tasks and missions, such as work on contamination sensitive payloads, will require modification of the EMU, which will enhance satellite servicing and create a completely responsive satellite services system which, in turn, provides greater utilization of man in space. Specific projected EMU modifications are described in Section 7.0.

Important human factors engineering is evident in the EMU design. The use of new joint designs and bearings provides pressurized space suit mobility motions of nearly 85% nude range capability. Space suit joint torques are such that the EMU equipped crewmember can perform a wide range of activities. In addition, joints such as an elbow or knee, fully flexed, have no tendency to spring back to the extended position.

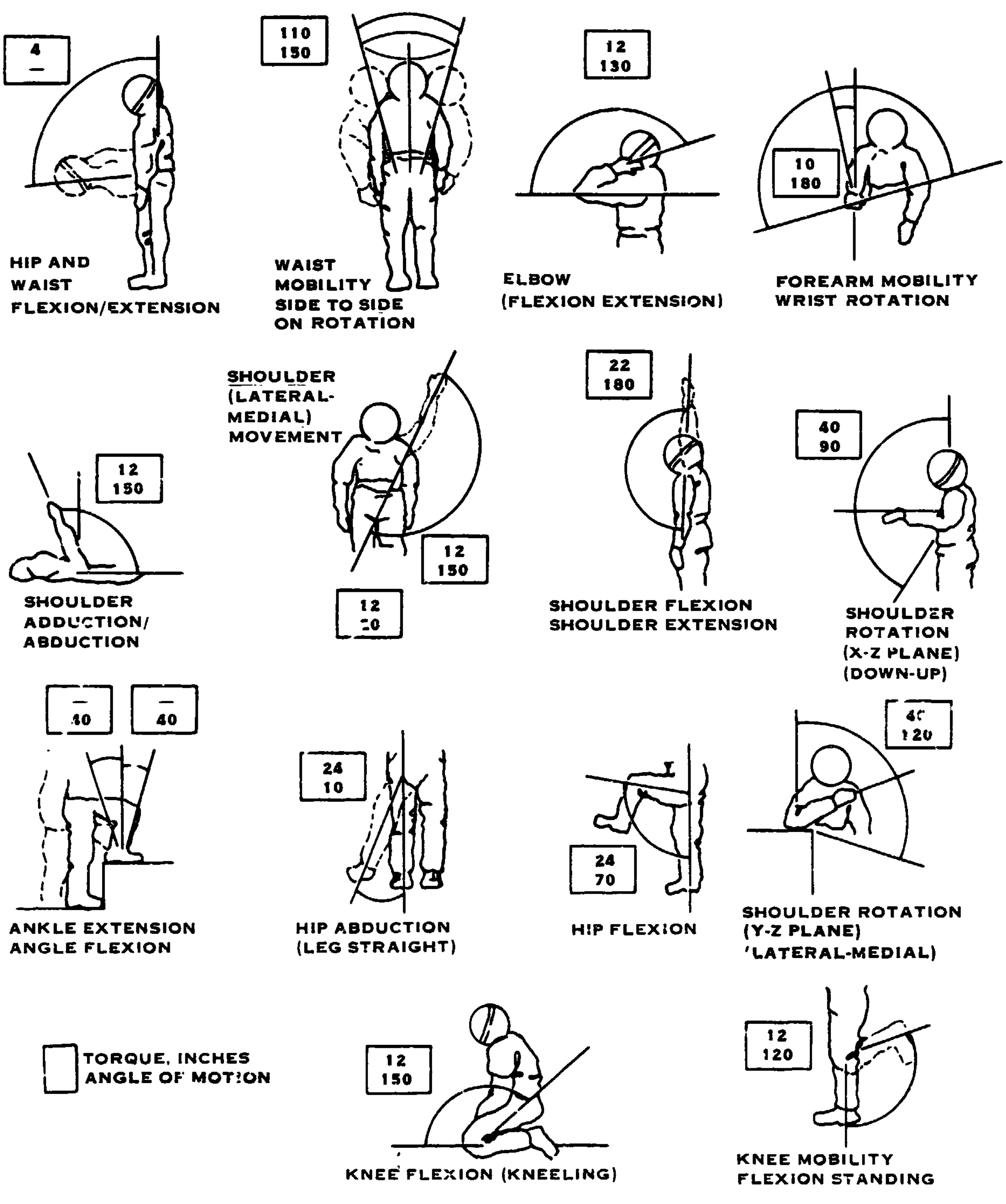
Specific mobility capability of the EMU is shown in Table II. Initial satellite servicing tasks demand no more than a few hours of EVA. However, as satellite servicing becomes more complex and mission time lines grow longer, crewmember fatigue will affect mission success. Providing greater nude range capability (i.e., >85% average) and reducing crewmember fatigue over long periods of time will directly enhance crewmember productivity.

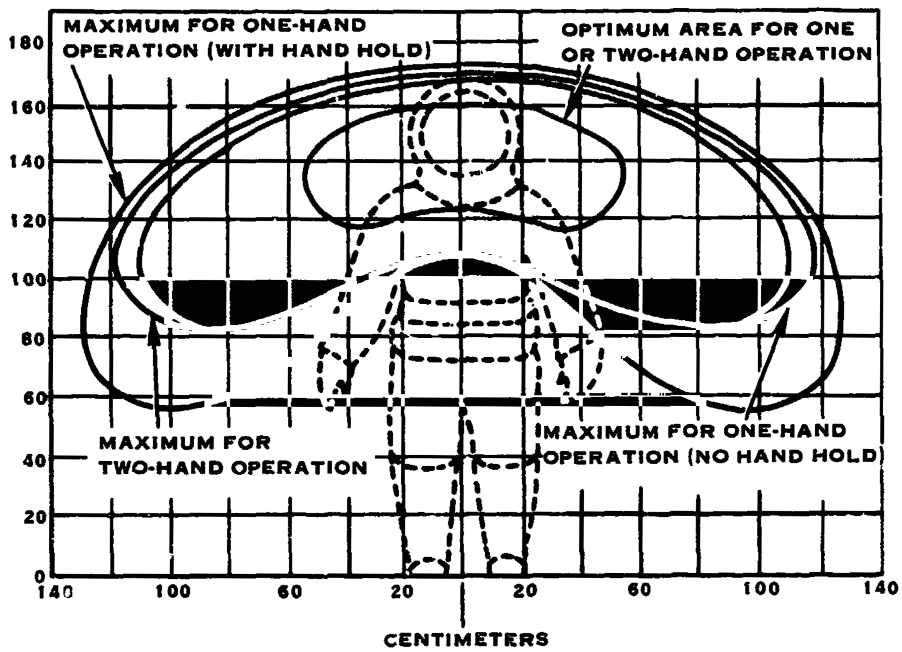
Mobility capabilities directly influence crewmember reach dimensions, which in turn aid in determining the design of both satellite servicing equipment and design of future satellite structures and compartmentalized payloads. Results of reach dimension analyses are presented in Figure 12.

TABLE II. MOBILITY REQUIREMENTS (AT 4.0 PSIG)

ITEM	RANGE	TORQUE (IN-LBS)
SHOULDER MOBILITY		
ADDUCTION/ABDUCTION	150°	12.0
LATERAL/MEDIAL	20°/150°	12.0
FLEXION/EXTENSION	180°	40.0
ROTATION (X-Z PLANE)	90°	30.0
ROTATION (Y-Z PLANE) (LATERAL-MEDIAL)	120°	30.0
ELBOW MOBILITY		
FLEXION/EXTENSION	130°	12.0
WRIST MOBILITY		
FLEXION/EXTENSION	90°	6.0
ADDUCTION/ABDUCTION	120°	6.0
WAIST MOBILITY		
FLEXION/EXTENSION (HIP & WAIST)	90°	48.0
ROTATION	150°	110.0
HIB MOBILITY		
FLEXION	70°	24.0
ABDUCTION	10°	24.0
KNEE MOBILITY		
FLEXION (STANDING)	120°	12.0
FLEXION (KNEELING)	150°	12.0
ANKLE MOBILITY		
FLEXION/EXTENSION	40°/40°	12.0
FOREARM MOBILITY		
WRIST ROTATION	180°	6.0
GLOVE MOBILITY		
FINGER FLEXION/EXTENSION	GRASPING FOR 5 MINUTES	—

TABLE II. MOBILITY REQUIREMENTS (AT 4.0 ± 0.20 PSIG) (CONTINUED)





EVA CREWMAN SIDE REACH ENVELOPE

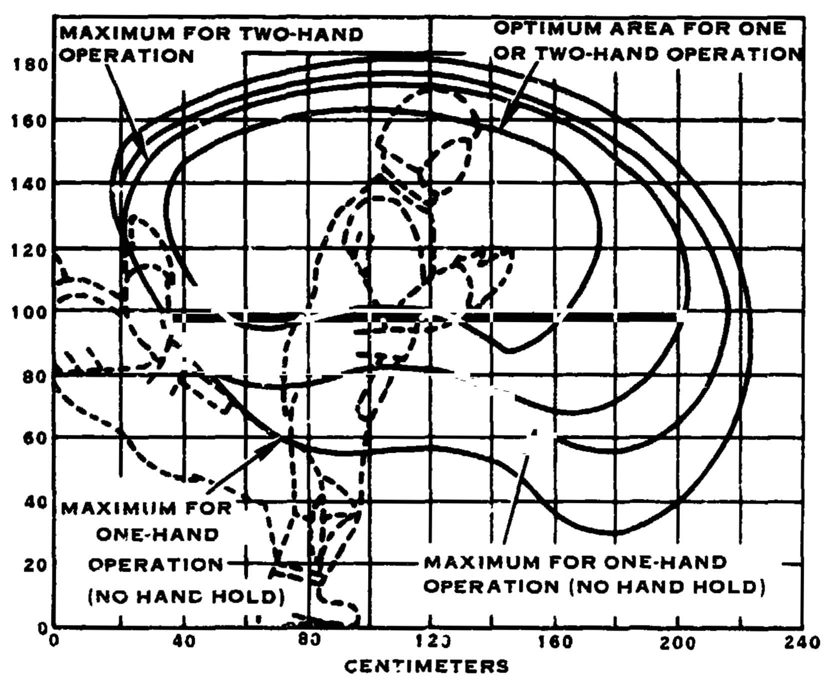


FIGURE 12. EVA CREWMAN FORE-AFT REACH ENVELOPE

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SECTION 4.0
EVA EQUIPMENT AND TRANSPORT INTERFACES

4.1 EVA SCENARIOS

Grumman Aerospace Corporation's Satellite Services System Analysis Study (SSSAS Document No. CSS/SSS/RP008 dated August 1981) has identified satellite services from an equipment systems/operations standpoint. This study utilizes Grumman Aerospace Corporation scenarios as a baseline from which to develop the manned interface within satellite servicing missions. A preliminary outline of currently defined satellite servicing tasks has been formed within the 184 scenarios defined by Grumman Aerospace Corporation. The missions are divided into four separate operational categories. This breakdown appears as follows:

TOTAL SCENARIOS	
Initial Launch	34
Revisit	48
Earth Return	98
Orbital Storage	4
TOTAL	184

From this set of 184 scenarios, Grumman Aerospace Corporation selected a subset of 43 representative scenarios as a basis for more detailed analysis. These 43 scenarios form the baseline from which Hamilton Standard conducted its detailed analysis. In respect to the subcategories, the scenarios are divided as follows:

SCENARIOS - DETAILED ANALYSIS	
Initial Launch	19
Revisit	8
Earth Return	12
Orbital Storage	4
TOTAL	43

By selectively analyzing 10 of the 43 scenarios, almost all aspects of satellite servicing procedures are covered, and utilization of both Grumman Aerospace Corporation equipment and specific worksite tools is addressed. The 43

4.1 (Continued)

scenarios were further subdivided into prime or backup EVA usage. This breakdown is presented below:

	EVA STATUS		
	Prime Usage	Backup	Total
Initial Launch	4	15	19
Revisit	8	0	8
Earth Return	5	7	12
Orbital Storage	4	0	4
TOTAL	21	22	43

Hamilton Standard selected prime usage EVA missions since all satellite service procedures and equipment are found within these and their related backup missions.

The scenarios are referenced accordingly: D = initial launch, R = revisit, ER = earth return, OS = orbital storage. The following scenarios were selected as being representative:

HAMILTON STANDARD DETAILED SCENARIOS

Initial Launch	D1, D2, D4, D6
Revisit	R2, R4
Earth Return	ER4, ER5, ER6, ER8

These scenarios provided the foundation from which a "building block" procedural interface and time line analysis was created. The "building block" approach allows for redundancy of operations among scenarios. Redundancy allows for standardization of procedures, thus minimizing the amount of time required to train astronauts for satellite service functions. In addition, standardized procedures increase the ease with which satellite servicing functions can be effected.

Scenarios D1 and D2 are discussed in detail in the report text. The remaining scenarios are presented in detail (along with the task data bank) in Appendix A.

The first stage of interface analysis involves defining human/equipment interfaces within three broad categories, namely: 1) within the orbiter payload bay, 2) close to the orbiter (less than 50 feet), and 3) near the orbiter (greater than 50 feet but less than 1000 feet). These interfaces were identified as follows:

4.1 (Continued)

Operational Subcategory	Scenario	Interface
Initial Launch	D1	Within Orbiter Payload Bay
(Analyses include		Close to Orbiter
Payload Deployment, Retention	D2	Within Orbiter Payload Bay
Latch Hangup and Appendage		Close to Orbiter
Hangup)	D4	Within Orbiter Payload Bay
		Close to Orbiter
	D6	Within Orbiter Payload Bay
		Close to Orbiter
Revisit	R2	Within Orbiter Payload Bay
(Analysis includes Payload		Close to Orbiter
Deployment/Retrieval,	R4	Within Orbiter Payload Bay
Retention Latch Hangup and		Close to Orbiter
Appendage Hangup)		
Earth Return	ER4	Within Orbiter Payload Bay
(Analyses includes Payload		Close to Orbiter
Retrieval, Retention Latch	ER5	Within Orbiter Payload Bay
Hangup and Appendage Hangup)		Close to Orbiter
		Near Orbiter
	ER6	Within Orbiter Payload Bay
		Close to Orbiter
		Near Orbiter
	ER8	Within Orbiter Payload Bay
		Close to Orbiter
		Near Orbiter

These operational procedure interfaces then were scrutinized in more detail by utilizing the ten detailed scenarios. The resultant procedures and associated timelines identified by this analysis can be combined to create almost any of the 184 scenarios identified by Grumman Aerospace Corporation. Several isolated tasks which were not addressed in the ten scenarious were analysed in order to provide complete coverage of the 184 scenarios. This information appears in Appendix B.

4.1 (Continued)

Equipment interfaces are covered first since they are considered a subset of procedural interfaces and timelines. The equipment interface analysis is initially conducted on an established specific level before progressing to more undefined general levels.

4.2 EQUIPMENT INTERFACE

The design of EVA equipment must take EMU operational capabilities into account. Design criteria for items such as handrails/handholds, switches, displays, surfaces, tools, modules, fasteners, and envelopes must be included into equipment design wherever manned EVA interface may occur.

The major EMU parameters affecting equipment and payload design are as follows:

- Mobility Requirements
- Dimensions
- Reach Envelope
- Environmental Conditions

4.2.1 Mobility Requirements

The Shuttle EMU provides 85% of nude range mobility, thereby establishing limits to which associated equipment must be designed. Mobility parameters for the key physical lines of motion have been presented in the EMU Capabilities Section (3.0). These mobility parameters must be taken into account when considering design of platform rotational envelopes, placement of controls and handholds, modular work kits and hand held tools. For example, current foot restraint structures can rotate a full 360° at 90° intervals. This will not create any reach problems, since the crewman's waist rotation capability exceeds 90°.

An important, most used interface is that of the EV glove and its surrounding environment. The level of EVA task complexity is directly related to EV glove tactility and protection capabilities. Due to the somewhat reduced tactile feedback inherent in any glove, mechanical feedback must be sufficient enough to override glove attenuation so that the crewman receives positive indication that the task is complete. This level of feedback can be obtained by utilizing devices such as toggle switches. Use of devices such as push buttons and rotary switches are discouraged due to uncertainty of verifying operational status. The mechanical feedback actuation forces should be detectable yet not exceed 15.8 kg (35 lbs).

4.2.2 EMU Dimensions

EMU dimensions affect the structural design of EVA equipment. The dimensions of the EMU have been shown in Figure 2. The EMU dimensional envelope will play an important role for any task requiring the crewmember to enter into an opening such as during a space construction task and the servicing of large satellites such as the Space Telescope. For example, a passageway or traverse point must provide at least a 39.4" (1.0 meter) breadth clearance due to human dimensions. Also, the design of handholds (see Figure 13) or work compartments should account for the glove dimensions (see Figure 14) and work envelope. A 7.9" (20 cm) clearance is required for any grip function. This, along with the 1.2" (3.0 cm) diameter clearance for individual glove fingers, provides design guides from which to construct instrumentation or equipment which requires the crewmember to grab it. Mobility tests indicate that handhold/handrail spacing, to be effective, should not exceed 18" (46 cm) above or below the shoulder or 21" (61 cm) to the left or right of the body centerline when working in a foot restrained position. However, extensions of this area are possible.

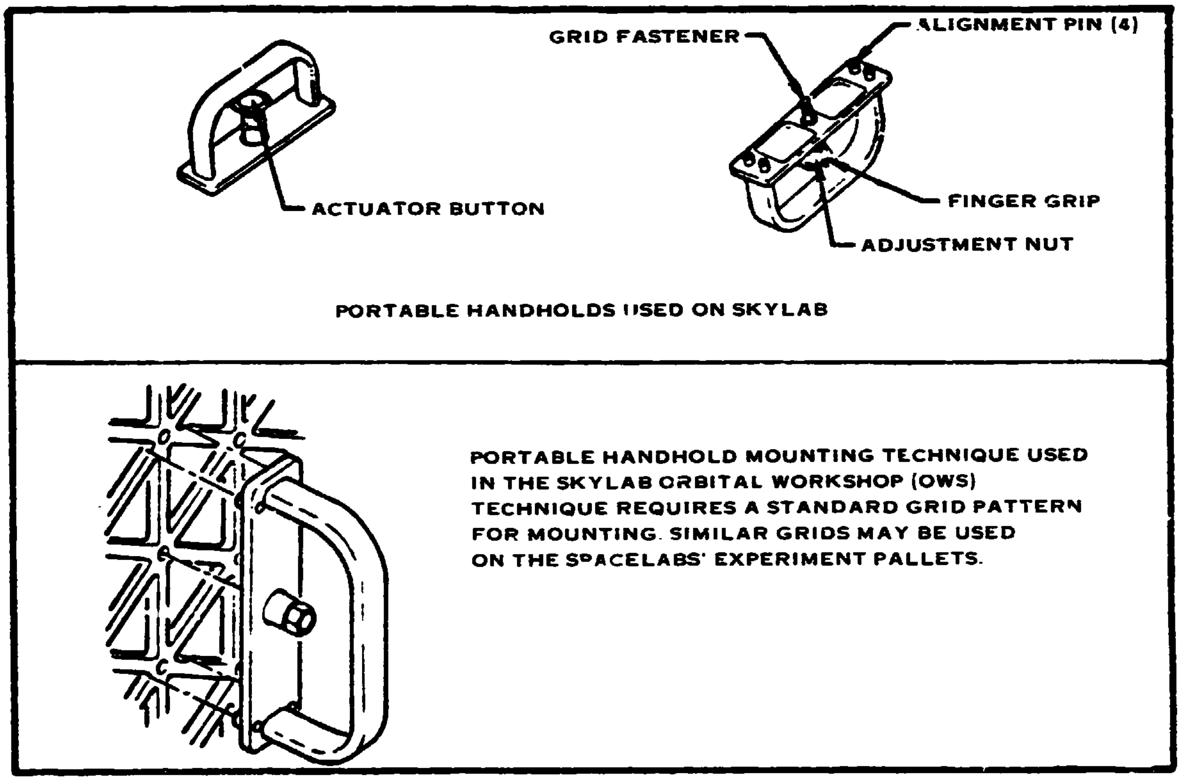

FIGURE 13. PORTABLE EVA/IVA HANDHOLD CONCEPT

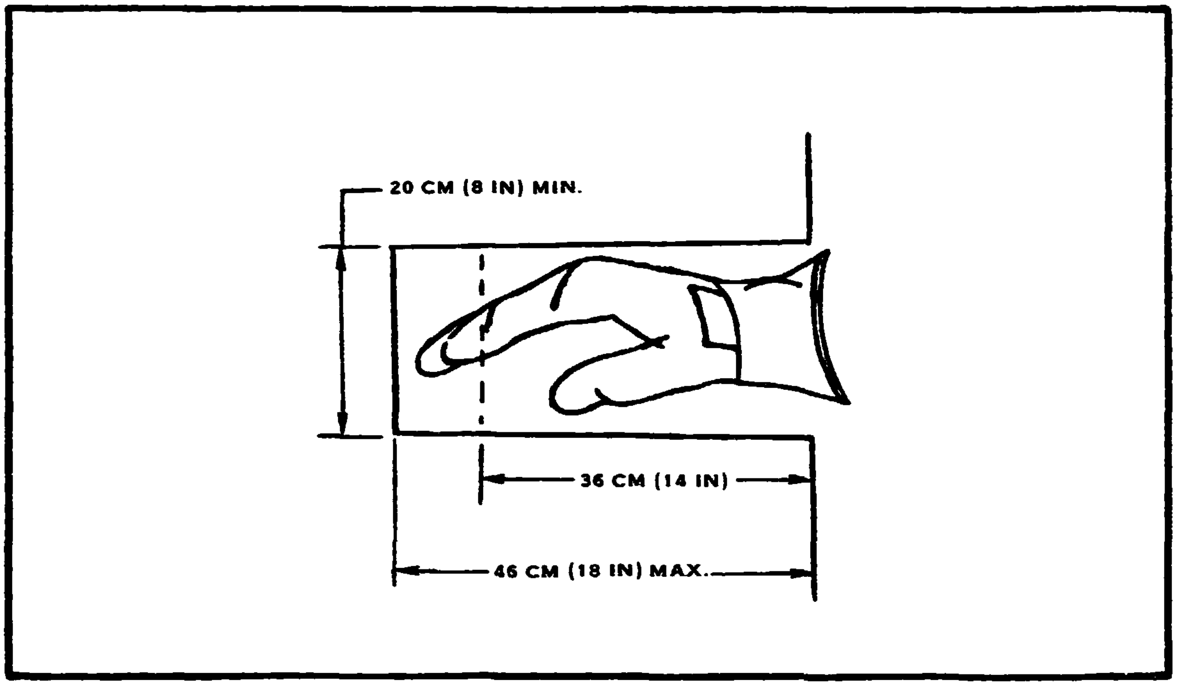

FIGURE 14. MINIMUM WORK ENVELOPE FOR GLOVED HAND

Figure 15 demonstrates the docking handle positioning of the Ancillary Equipment Stowage Area (AESA), which represents similar work platform structures.

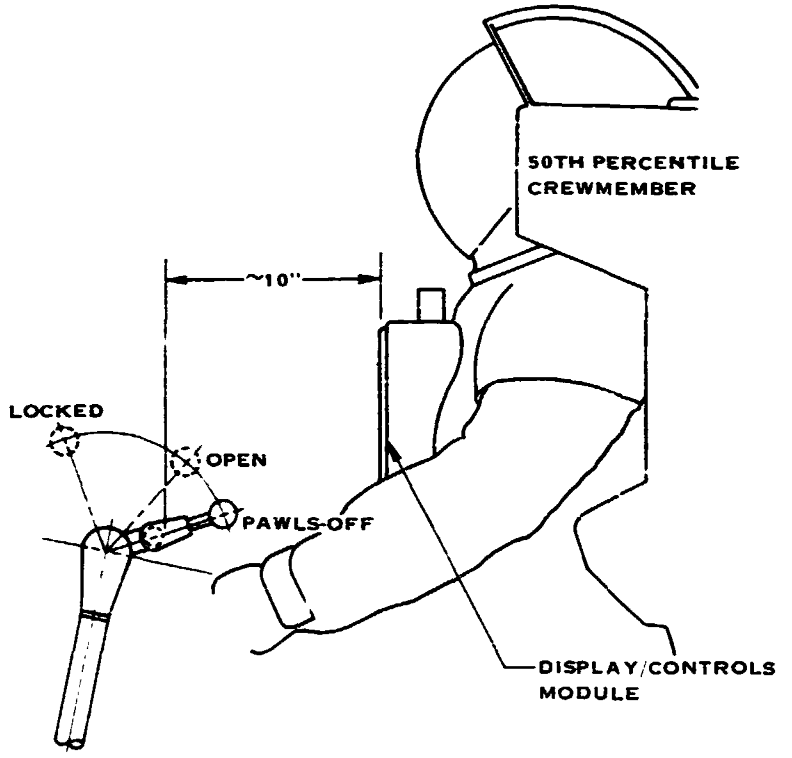

FIGURE 15. DOCKING HANDLE POSITIONS OF THE ANCILLARY EQUIPMENT STOWAGE ASSEMBLY

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4.2.3 Reach Envelopes

The EVA crewman must have access to most areas of the payload bay, berthed payloads, orbiter exterior surfaces, satellites and satellite servicing equipment. Figure 12 illustrated a Shuttle EVA crewman's side reach envelope and fore-aft reach envelope. This reach envelope guides the design of work platforms such as the Open Cherry Picker (OCP). More specifically, boom length and control design are considered so that crewman/satellite distances can be properly established. As an example, the astronaut's ability to reach into tight areas or work within a confined environment is a function of his ability to effectively coordinate his reach envelope and the work platform boom range.

The more effectively the crewmember positions himself for a task, the less effort he must expend to complete the task. By expending less energy, the crewmember reduces any fatigue effects along with utilizing a higher percentage of EVA work time.

For utilization of controls or equipment requiring visual alignment, controls should be located within 25° of the normal line-of-sight in the vertical plane and 50° in the horizontal plane. Visual range is identified as a function of both helmet design and environment illumination.

Table III illustrates the visual range requirement for the EV helmet. The helmet provides both IR and UV protection, as well as protection from bright light via the Extravehicular Visor Assembly.

The EV astrolight assembly, which is located on the helmet, provides sufficient illumination to conduct all close satellite servicing tasks. The astrolight assembly consists of two light ports (one on each side of helmet), each of which contains two lights. Tests conducted at Johnson Space Flight Center have provided insight into EVA lighting requirements; results for complete dark environment astrolight tests are as follows:

Distance (Ft:Meters)	No. Lights On	Ft-Candles	Comments*
2 : 0.6	1	3.37	a
	2	6.05	a
	4	12.73	a

4.2.3 (Continued)

Distance (Ft:Meters)	No. Lights On	Ft-Candles	Comments*
5 : 1.5	1	1.44	b
	2	3.54	a
	4	10.80	a
10 : 3	1	0.91	b
	2	1.62	b
	4	2.44	b
15 : 4.5	1	0.63	b
	2	1.26	b
	4	1.88	b
20 : 6	1	0.38	Same as 30'
	2	0.90	b
	4	1.25	b
30 : 9	4		Can distinguish shapes able to avoid bumping into objectives
50 : 15	4		

* Legend a - Can conduct any task
b - Can discern large nomenclature

As an example of visibility design implementation, Figure 16 shows a typical lamp assembly. This LED is recessed approximately 0.8 inch (2 cm) in a flat block cylindrical hole. Any illuminated display must ensure visibility of the lights in all lighting conditions.

4.2.4 Environmental Conditions

Environmental conditions play a vital role in providing for crewman safety and equipment utilization during EVA. Environments which exhibit extreme conditions of sharp edges, protrusions, thermal extremes, radiation, electrical, electromagnetics or pyrotechnics should either be avoided or neutralized for satellite servicing. Potentially dangerous equipment located within 30.5 cm (12.0") of the translation route or worksite will be identified in accordance with document No. SC-M-0003. Thermal surfaces shall be compatible with EMU limits, namely within -180°F to +200°F (-117.8°C to +93.3°C). If not, special thermal protection must be provided.

TABLE III. EVA HELMET VISUAL RANGE LIMITATIONS

SYSTEM PROVISION	PARAMETER	PERFORMANCE		
HELMET AND EVVA OPTICAL VISIBILITY	FIELD OF VISION	120 DEG. LEFT AND RIGHT IN THE HORIZONTAL PLANE. 105 DEG. DOWN AND 90 DEG. UP IN THE VERTICAL PLANE		
	CRITICAL AREA OF VISION	THERMAL 90 DEG SUPERIOR-TEMPERAL 62 DEG SUPERIOR 85 DEG INFERIOR-TEMPERAL 85 DEG INFERIOR 70 DEG		
OPTICAL DISTORTION		NO VISIBLE DISTORTION OR OPTICAL DEFECTS DETECTABLE BY THE UNAIDED EYE. (20/20 VISUAL ACUITY) AT THE TYPICAL "AS WORN" POSITION		
		UV	LUMINOUS	IR
TRANSMITTANCE	NANOMETERS	200–300	400–700	700+

THERMAL/COATING OPTICAL CHARACTERISTICS

CHARACTERISTICS	INNER PROTECTIVE VISOR	OUTER SUN VISOR
TRANSMITTANCE		
550 NM	70% MIN.	16 ± 4%
1100 NM	N/A	10% MAX.
*SOLAR REFLECTANCE		
550 NM	5% MAX.	40% MIN.
2400 NM	70% MIN.	N/A
700 NM	N/A	55% MIN.

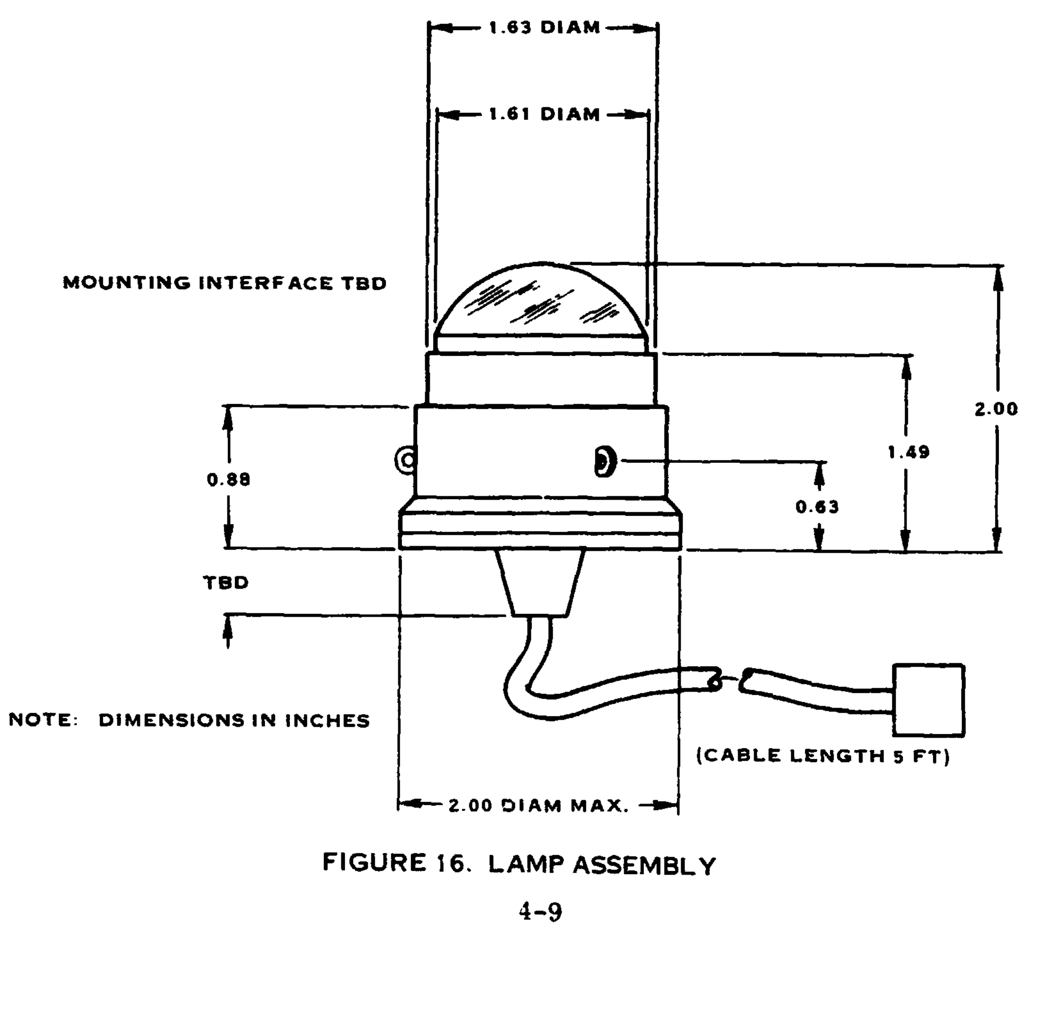


FIGURE 16. LAMP ASSEMBLY

4.2.4 (Continued)

Contamination from the environment or payloads could create adverse safety conditions. Whereas most forms of contamination will dissipate into the vacuum of space, certain fluid transfer missions may dictate that the astronaut don a protective overgarment while performing the mission. All such equipment must be designed so as to avoid contamination of the EMU by rupture of tanks, seals, or fluid lines.

The Manned Maneuvering Unit (MMU) will provide transportation from the payload bay to a work site. The primary interface between the Primary Life Support System (PLSS) and the MMU includes hard points and mechanical latches, a reserved electro-optical data interface, and man/machine interfaces related to use of the MMU by an extravehicular crewmember. The dimensions of the MMU are illustrated in Figure 17. Man/machine interfaces between the MMU and the crewmember are related to reach and visibility requirements for MMU switch actuation, hand controller, control-arm glove envelopes, and gage and cue readability. Two work station attachment points and two ancillary equipment attachment points provide on-orbit interface points. The interface points are shown in Figure 18.

Table IV lists the possible man/equipment interfaces which are identified in more detail in Section 5.0 of this report

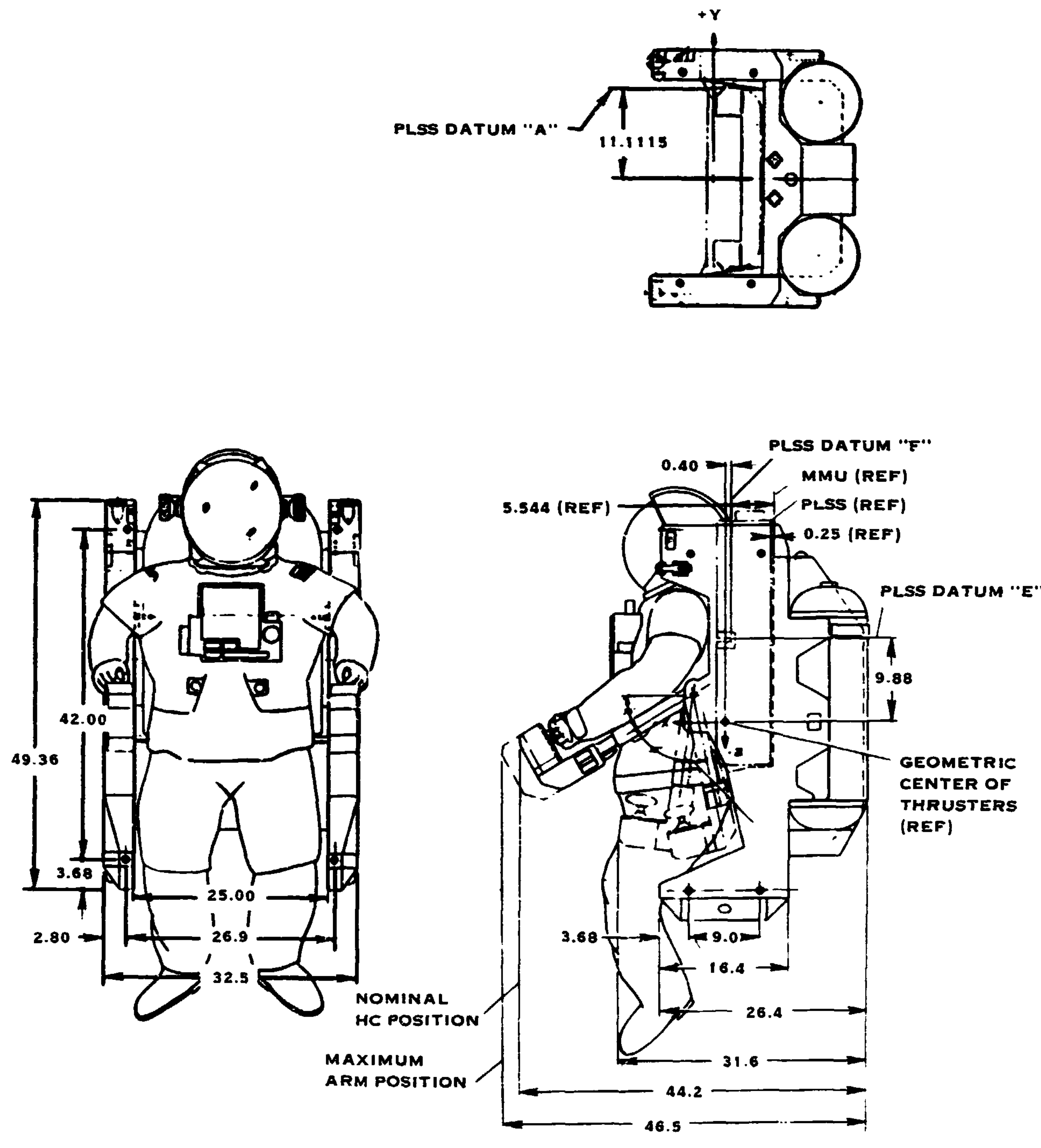
Whereas specific tasks will not be analyzed as a function of equipment for the time line task, they will be analyzed according to procedures.

Table IV provides a comprehensive list of Grumman Aerospace Corporation proposed equipment for satellite servicing. The triangles located at the far right of the table indicate that the designated equipment has been utilized in the timeline analysis.

The following summary takes each of the major pieces of equipment from Table IV and summarizes general crew interface characteristics.

RETENTION STRUCTURE - provides capability to store spacecraft in the orbiter bay.

- The payload bay must provide an adequate handrail structure for crewmember transfer from the airlock to the retention structure.



NOTE: DIMENSIONS IN INCHES

FIGURE 17. OUTBOARD PROFILE OF THE MMU

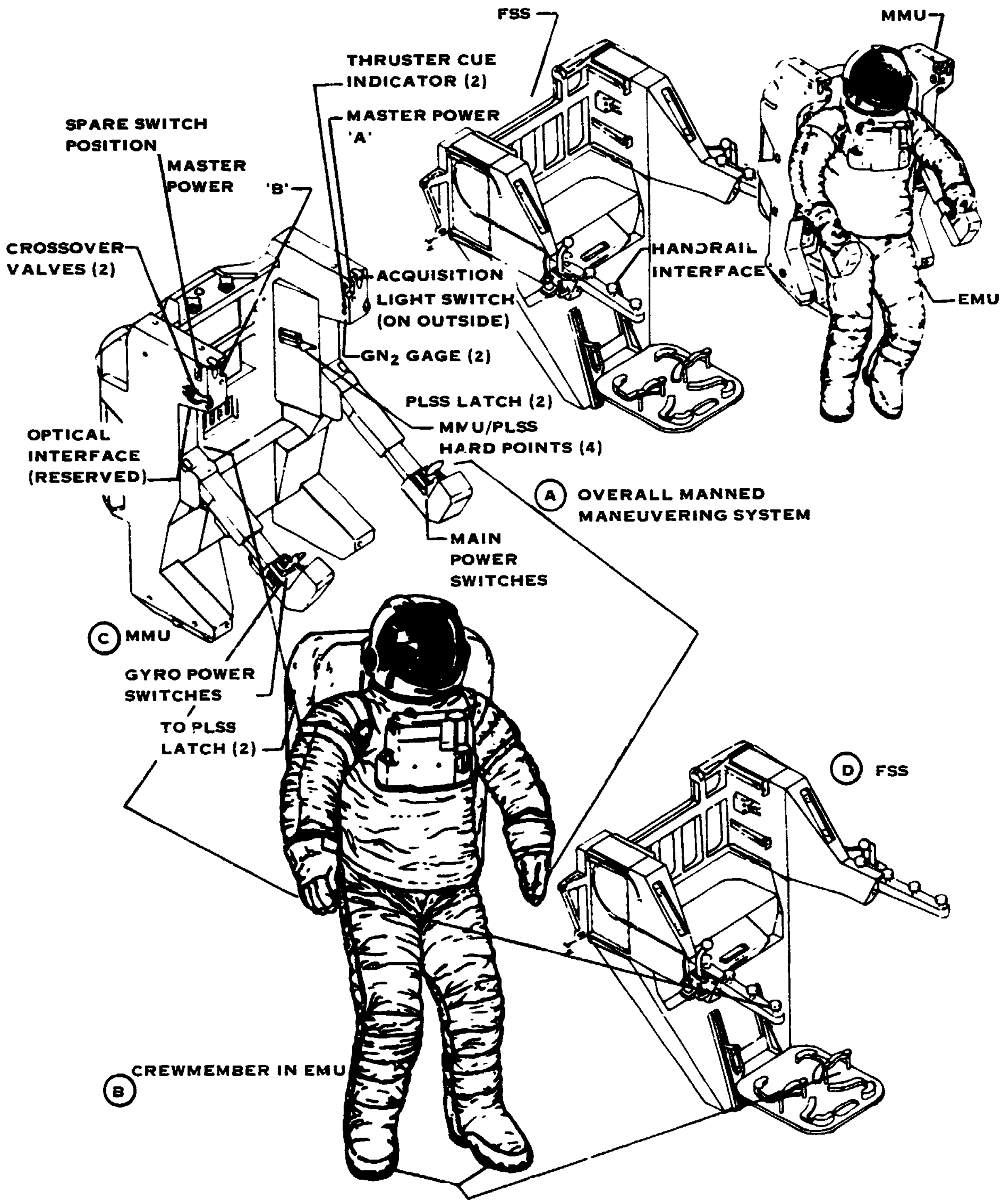


FIGURE 18. THE MMU/FSS-TO-EMU INTERFACE

TABLE IV. SATELLITE SERVICING SCENARIO SUMMARY

	EQUIPMENT	D-1	D-2	D-4	D-6	R-2	R-4	ER-4	ER-5	ER-6	ER-8	EQUIPMENT	
		DIRECT DELIVERY				DIRECT DELIVERY REVISIT		DIRECT DELIVERY RETURN					
		MULTIPLE PAYLOADS			F RGE OADS	NOMINAL (MMS) TYPE PAYLOAD		NOM (MMS-TYPE) PYLD COOP/NON-COOP		LARGE PYLD CO/NON-CO	CON SENS. CO/NON-CO.		
	NOMINAL											NOMINAL	
●	RETENTION STRUCTURE	●	●	●				●	●	●	●	RETENTION STRUCTURE	▲
●	SPECIAL' RETENTION STR											"SPECIAL" RETENTION STR	
●	EQUIPMENT STORAGE PROVISION					●	●	◎	◎	◎	◎	EQUIPMENT STORAGE PROVISION	▲
●	FLUID TRANSFER SYS					●	●					FLUID TRANSFER SYS	▲
●	TILT TABLE				●	●						TILT TABLE	▲
●	SPIN TABLE											SPIN TABLE	
●	PIDA									●		PIDA	▲
●	RMS	●							●	●		RMS	▲
●	OCP TILT TABLE WK PLAT					●						OCP-TILT TABLE WK PLAT	▲
	OCP/RMS											OCP/RMS	
●	MFR/RMS	○*								○*		MFR/RMS	○*
●	MMU/WRU											MMU/WRU	
	W/END EFFECT		●	●	●	●	●	●—○			●—○	W/END EFFECT	▲
	W/STABILIZER	○	○ 2	○*	○*	○ 2	○*	○ 2	○	○	○ 2	W/STABILIZER	○ 2
	W/PL'D HOLG					●	●					W/PL'D HOLG	▲
	PROX OPS MOD								●			PROX OPS MOD	▲
◎	PROX OPS MODULE - MANNED VERSION									●		PROX OPS MODULE - MANNED VERSION	▲
●	PROX OPS MODULE - MTV ADAP'N										●	PROX OPS MODULE - MTV ADAP'N	▲
●	HPA			●—○			●	●—○	●—○	●—○	●—○	HPA	▲
●	NON CONTAM ACS					●					●	NON-CONTAM ACS	▲
●	MTV						●					MTV	▲
●	VSS											VSS	
	W/DOCKING RENDEZ											W/DOCKING RENDEZ	
	W/END EFFECT											W/END EFFECT	
	W/DEBRIS CAPTURE											W/DEBRIS CAPTURE	
●	AFD C&B											AFD C&B	
	W/RMS	●							●	●		W/RMS	
	W/CHECKOUT	●	●	●	●	●	●	●	●	●	●	W/CHECKOUT	
	W/CL PROX CONT					●	●	●			●	W/CL PROX CONT	
	OPTIONAL											OPTIONAL	
●	SUN SHIELD	●	●	●	●							SUN SHIELD	▲
●	ORBITAL STORAGE	● ✓	● ✓✓	● ✓	● ✓	● ✓	● ✓					ORBITAL STORAGE	▲
●	ALT. TRANS PACKAGE	●	●		●							ALTITUDE TRANS PACKAGE	▲
●	LIGHTING ENHANCEMENT	○	●—○	●—○	●—○	●—○	●—○	●—○	●—○	●—○	●—○	LIGHTING ENHANCEMENT	▲
	RMS INOPERATIVE		●	●		●	●	●			●	RMS INOPERATIVE	

CODE
● PRIME USAGE
○ BACKUP
◎ OPTIONAL
○² SECOND MMU/WRU REQ'D
○—○ / ●—○ } ONE UNIT
✓ MMU/WRU REQ'D
✓✓ SECOND MMU/WRU REQ'D
✱ EVA VIA HANDRAILS OPTIONAL
✱ APPENDIX SCENARIO
▲ HS REPORT COVERAGE

4.2.4 (Continued)

- The crewmember must be capable of stabilization and possible two-handed work ability.
- In case of malfunction, the manual release of the retention latches must be safe, i.e., if the latches are spring loaded the force exerted upon the astronaut may be up to 35 lbs.
- Provide either a jettison mode or crewmember manual retractual mode for contingency.
- The manual retention release mechanism must be able to accommodate the EMU glove (must extend beyond the plane of the retention structure by at least 5.0" (12.8 cm)).
- The retention structure must not exceed temperature limits of the EMU.

RMS - deploys spacecraft from cargo bay and retrieve free flying structures. Conditions same above.

- Must allow for routine mating of EVA manned structures such as the OCP.

OPEN CHERRY PICKER/RMS - transport EVA astronaut and equipment.

- S/C equipment and tools shall be EVA compatible.
- Controls and displays shall be EVA compatible.
- OCP designed for crewmember comfort.
- The manual retention release mechanism must be able to accommodate the EMU glove (must extend beyond the plane of the retention structure by at least 5.0" (12.8 cm).
- The retention structure must not exceed temperature limits of the EMU.

4.2.4 (Continued)

MANIPULATOR FOOT RESTRAINT/RMS - stable work platform.

- Same as OCP/RMS.
- Satellite or debris return operations must provide for extra care in dealing with sharp edges, damaged appendages, radiation or contamination.

SPECIAL RETENTION STRUCTURE - provide storage for inactive satellites and space debris. Same conditions as retention structure.

EQUIPMENT STOWAGE PROVISION - orbiter cargo bay stowage of any type of OR EQUIPMENT.

- The operation of stowage actuators shall conform to crewmember grasp envelope.
- Access must be provided for astronaut to return to the airlock from the rear of orbiter while a large payload is positioned in the retention structure.

SPIN TABLE - spins spacecraft to impact a separation ΔV. Same conditions as retention structure.

PIDA - move larger payloads in and out of payload bay.

FLUID TRANSFER SYSTEM - provide replenishment of S/C propellant.

- Crewmember must be able to perform backup operations.
- Contamination Control.
- Provide accurate indication of the refuel level and pressurization level.

TILT TABLE - rotates payload out of bay.

- Manual override of tilt table arms - includes all conditions associated with the retention structure.

SECTION 5.0

SATELLITE SERVICING PROCEDURE TIMELINE ANALYSIS

In this portion of the satellite servicing study, the logic employed in developing the procedures and timeline analyses for the eight (8) detailed scenarios is presented. Two (2) simple example scenarios (D1 and D2) are detailed in order to explain the methodology employed in analyzing all 12 of the scenarios. (See Figures 19a and 19b for graphic illustrations).

5.1 SATELLITE SERVICING SCENARIO D1 - INITIAL LAUNCH

Satellite servicing scenario D1 is an initial launch scenario in which EVA is required in a contingency mode. The contingency modes for this scenario consist of backup for either retention latch or appendage malfunction. Each of these backup modes is analyzed in the following paragraphs.

5.1.1 Retention Latch Malfunction

The analysis of this scenario assume that a problem exists with a retention latch, in that the mechanism has failed to unlatch, preventing removal and deployment of the satellite from the payload bay (via the RMS). The astronaut must disengage the faulty mechanism in order to correct the situation and ensure mission success. The timeline analysis of this and all other scenarios assuumes that the astronaut has completed prebreathe activities, has donned the suit, has verified the operational health/status of the EMU, and is in the airlock ready to begin the EVA. Also, post EVA activity is not included in timeline analysis. Timelines for all satellite servicing scenarios initiate when the astronaut opens the airlock hatch, and conclude when the astronaut has re-entered the airlock and closed the airlock hatch.

Table V lists the EVA activities the astronaut must perform in order to implement the mission. The task times associated with each of the operational steps have been estimated based upon data obtained from WIF (Water Immersion Facil- ity) tank testing which involves the use of the EMU for satellite servicing on such structures as the space telescope (handling of replacement modules). In addition, timeline data from Apollo and Skylab missions, and simulators are considered. Factors incorporated in determining the timeline estimates include complexity of the task involved and the translational distances which must be traversed within the payload bay, close to the orbiter, and near the orbiter.

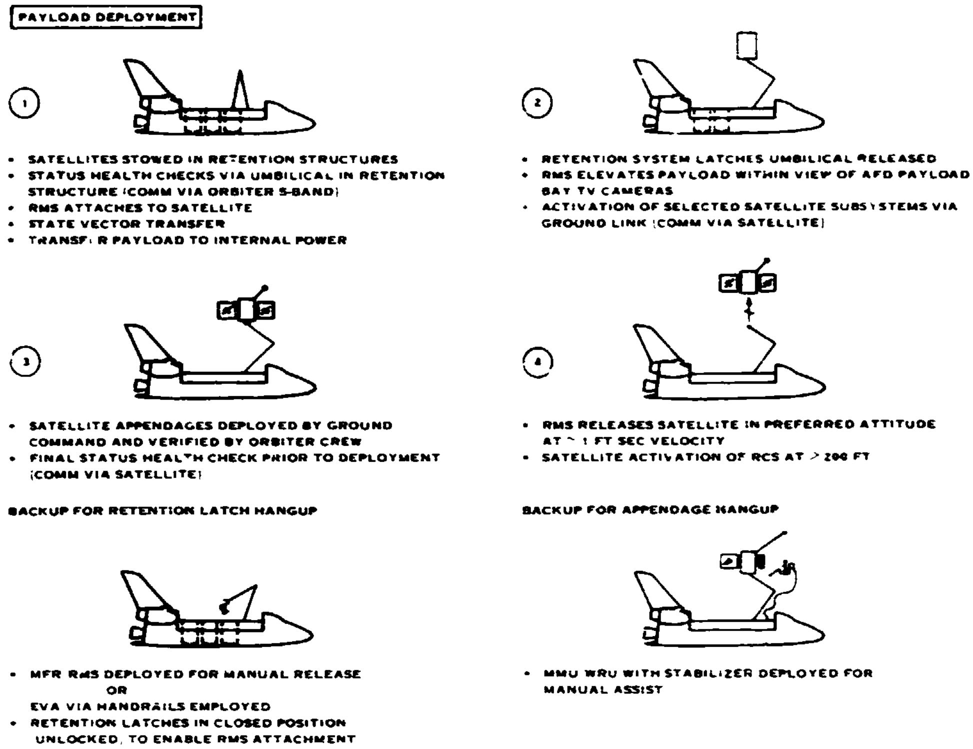


FIGURE 19A. D1 NOMINAL DEPLOYMENT SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - MULTIPLE PAYLOADS - RMS USAGE

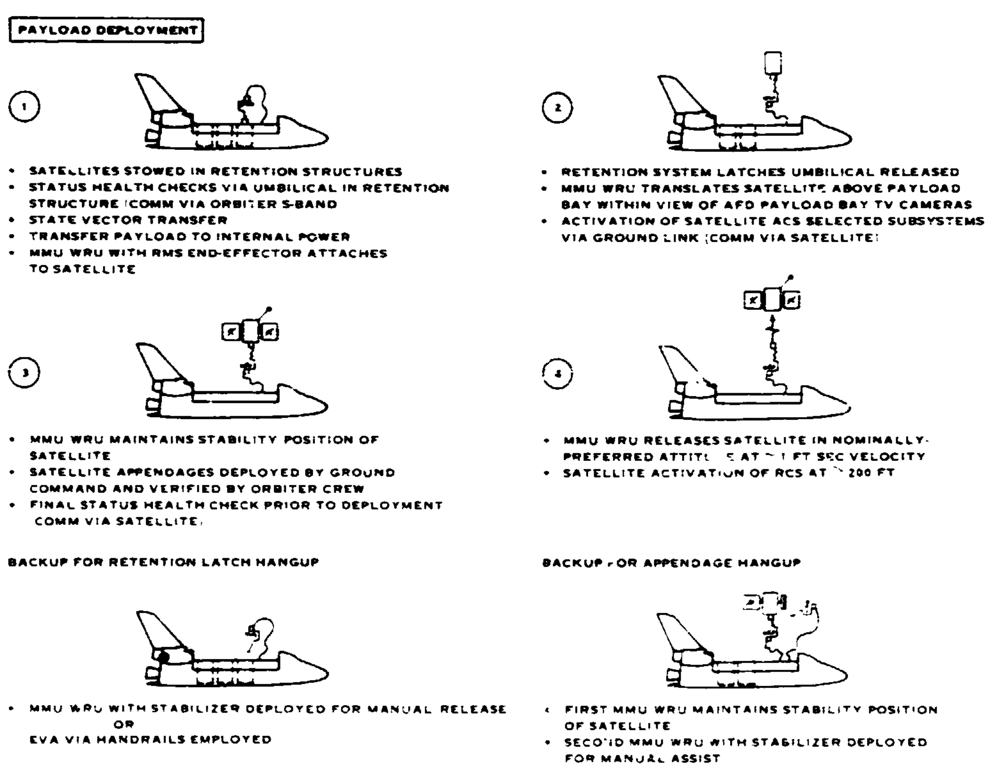


FIGURE 19B. D2 RMS INOPERATIVE DEPLOYMENT SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - MULTIPLE PAYLOADS

5.1.1 (Continued)

TABLE V

Initial Launch

D1 Nominal Deployment Sequence

Backup For Retention Latch Hangup

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MFR/RMS	1	8
5.	Attach MFR Into RMS End Effector	.5	8.5
6.	Lock Into MFR	.5	9
7.	Translate RMS To Retention Latch	1.5*	10.5
8.	Manually Release Retention Latch	10	20.5
9.	Translate RMS To Storage Position	1.5*	22
10.	Unlock From MFR	.5	22.5
11.	Detach MFR From RMS End Effector	.5	23
12.	Translate To Tool Storage	1	24
13.	Return Equipment	5	29
14.	Translate To Air Lock	1	30
15.	Enter Air Lock	1	31

* With Computer Control Of RMS

Step No. 1

In scenario D1 the first activity the astronaut must perform is to leave the airlock. This involves the opening of the airlock hatch, stepping through the hatch into the payload bay, and then closing the airlock hatch. The air- lock hatch is shown in Figures 20 and 21. Based upon the relative routine- ness of activating the actuator handle, opening the hatch, stepping through the hatch into the payload bay, closing the hatch and latching the hatch, it has been estimated that a time of 1.0 minutes is required to perform all of the above listed activities. (Figure 22 presents the view of the airlock hatch within the Shuttle bay). Also depicted within the figure are handrails which the astronaut can use for support, stabilization, and translational activities while operating within the payload bay.

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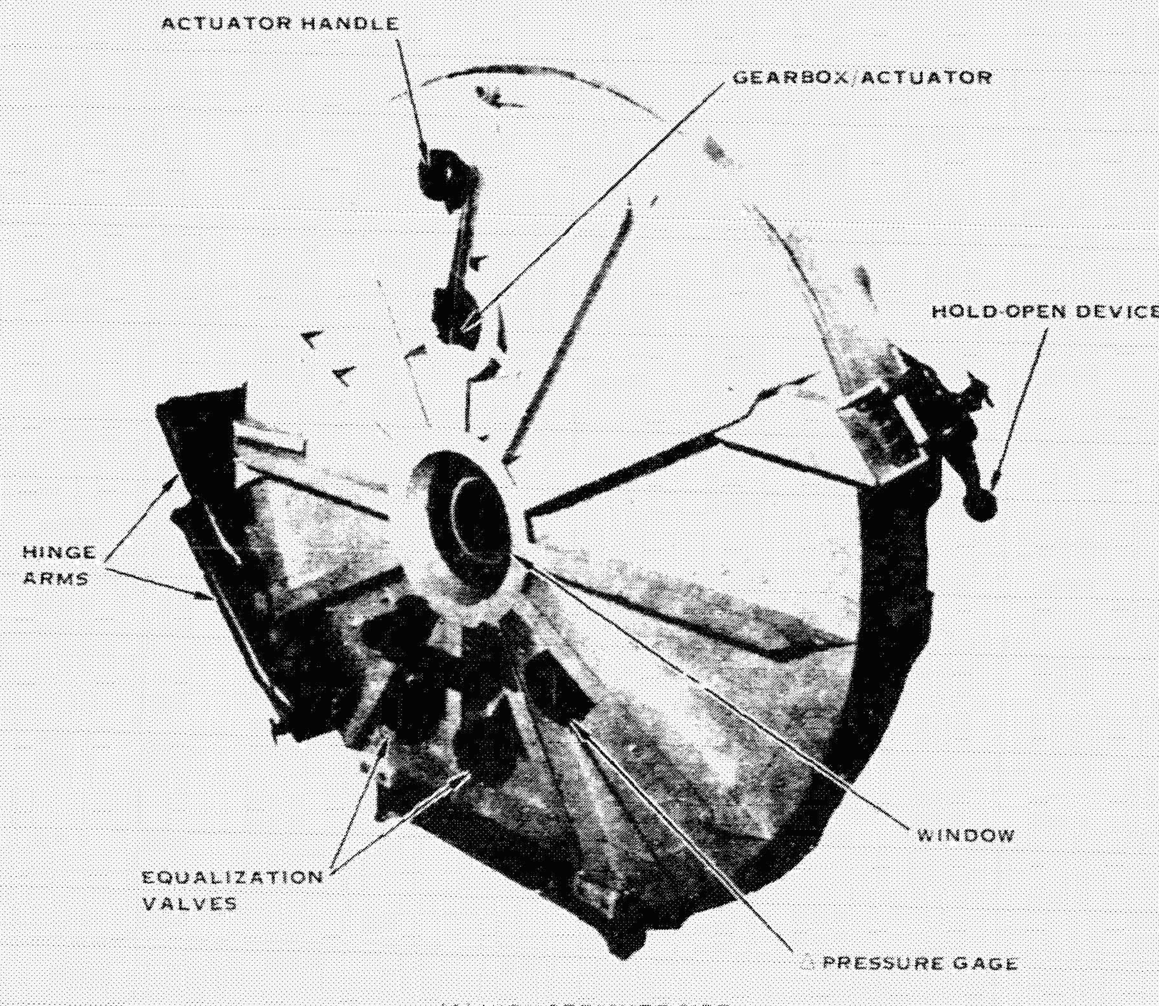
BLACK AND WHITE PHOTOGRAPH



(A) HIGH-PRESSURE SIDE

FIGURE 20. TYPICAL AIRLOCK HATCH

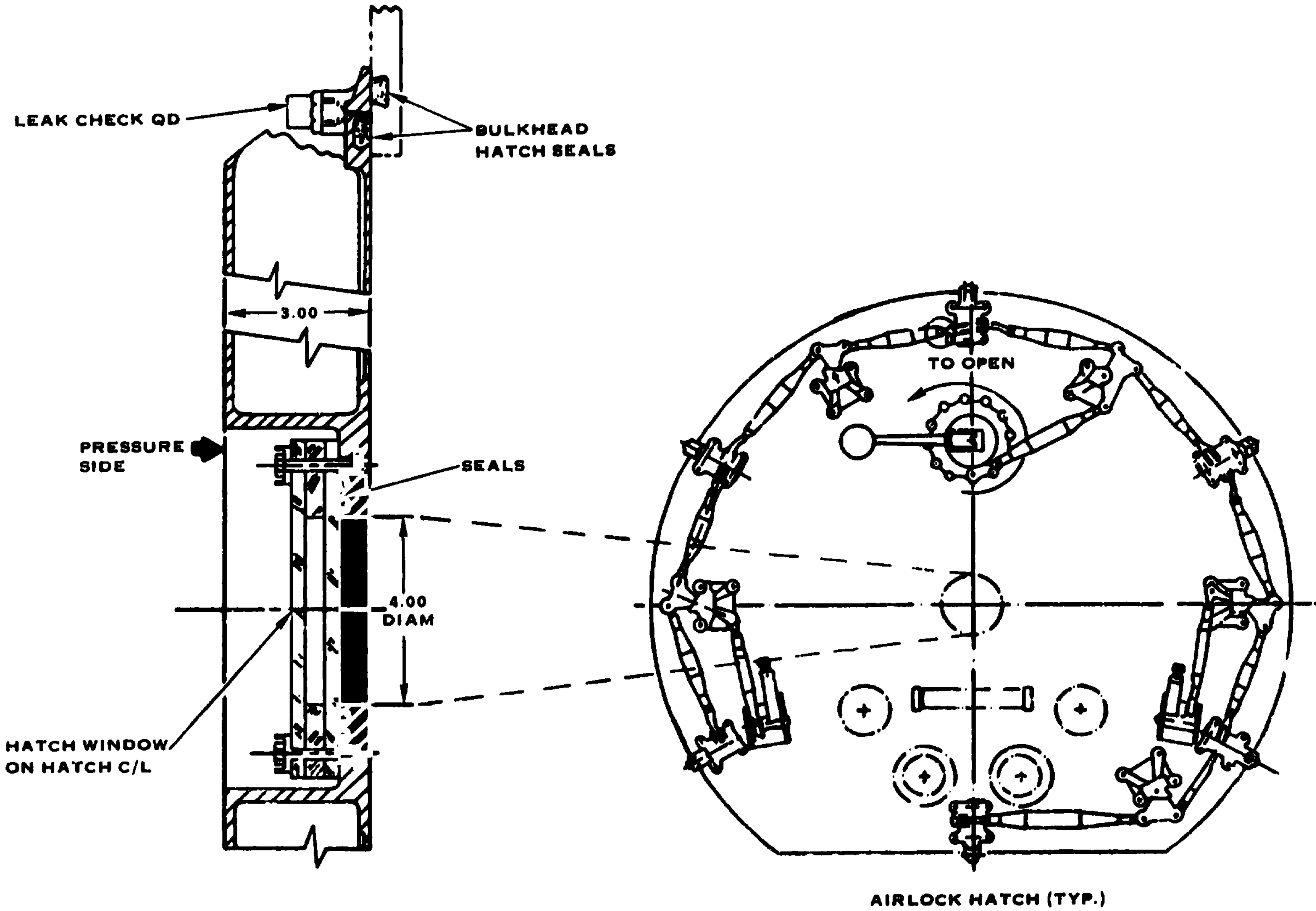


FIGURE 21. AIRLOCK HATCH WINDOW AND PRESSURE SEAL

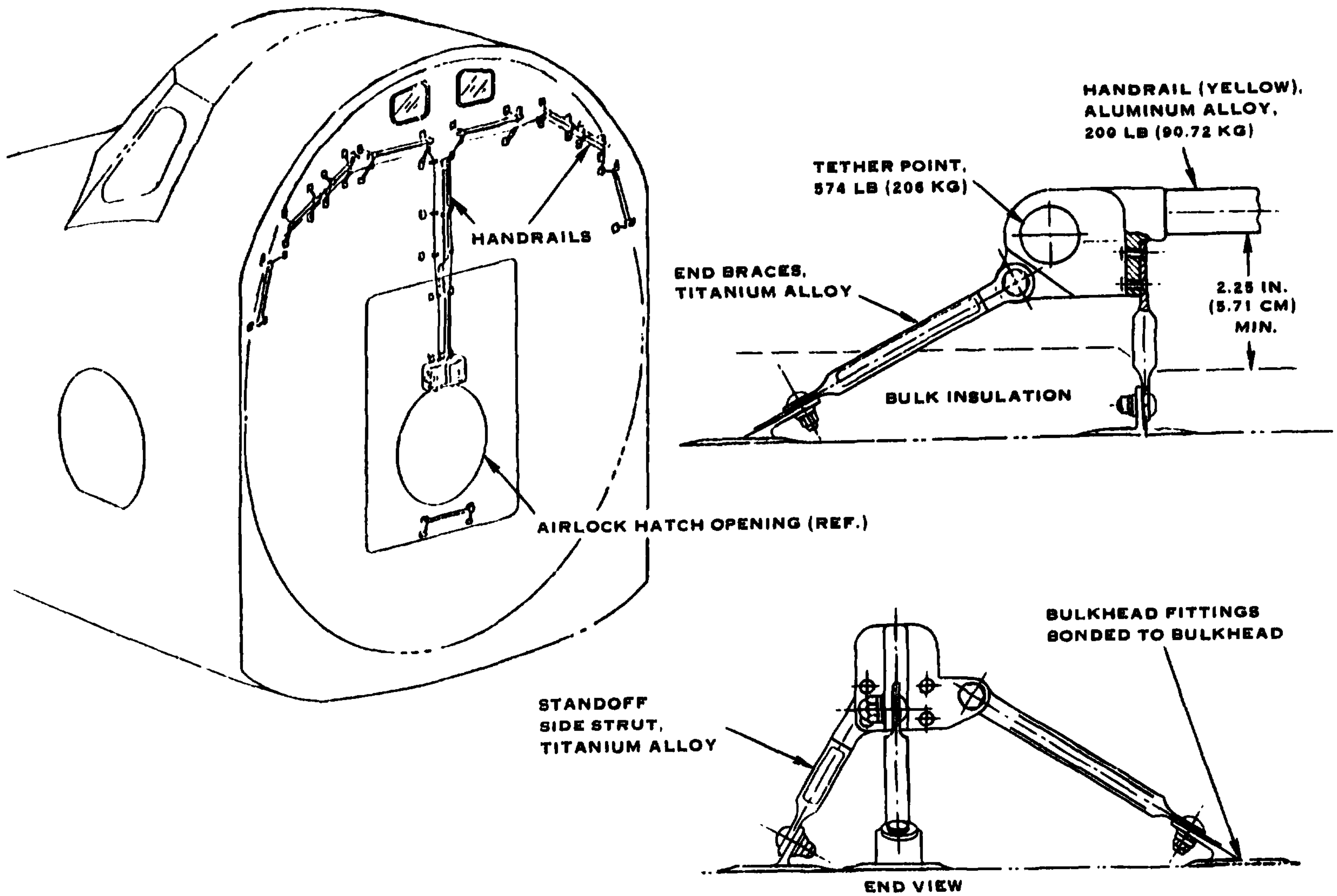


FIGURE 22. PAYLOAD BAY EVA HANDRAILS, BULKHEAD X_O576

5.1.1 (Continued)

Step No. 2

The second step requires the astronaut to translate to the tool storage area (MESA) in order to obtain the equipment necessary to effect a repair on the malfunctioning retention latch. The time associated with this activity has been estimated to be 1.0 minutes due to a translational distance of approximately 10 feet. Handrails located along the sides of the shuttle bay are employed as an aid during the translational activities.

Step No. 3

The third activity requires the astronaut to obtain the necessary equipment from the MESA in order to effect the latch repair. This activity has been estimated to take 5.0 minutes of EVA time. The MESA and equipment layout are shown in Figure 23. Although a predetermined set of tools are required to effect latch repair, a 5.0-minute timeline is required at the MESA since the astronaut must lock into the foot restraint and obtain the proper combination of tools necessary for latch repair. The astronaut tethers the required MESA bags via the caddy tether ring and restraint tethers, thus minimizing problems associated with transporting multiple MESA bags to the repair site.

Step No. 4

Once the astronaut has obtained the proper equipment, he must unlock from the foot restraints and translate via use of the handrails to the RMS end effector. The translational time has been estimated at 1.0 minutes due to the short translational distance involved (approximately 50 feet).

Step No. 5

The next step is for the astronaut to assist in inserting the Manipulator Foot Restraint (MFR) into the RMS end effector via the grapple fixture in the MFR. (The MFR concept is shown in Figure 24.) A typical grapple fixture used for capturing equipment via the RMS end effector is shown in Figure 25, and the RMS end effector itself is shown in Figure 26. Typical operation of the RMS end effector and a grapple fixture is shown in Figure 27. These figures illustrate the straightforward procedure for attaching the MFR to the RMS.

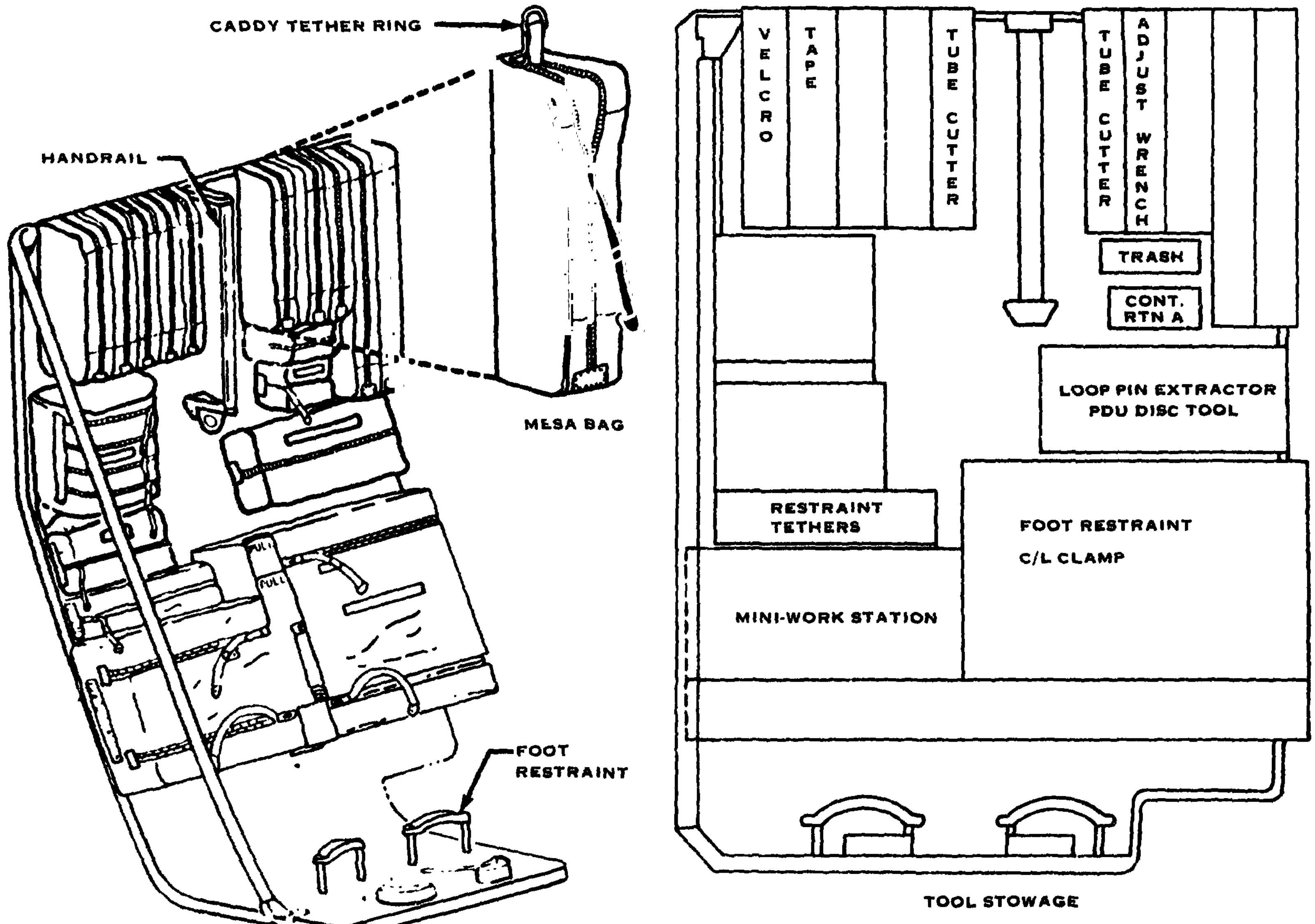


FIGURE 23. MESA AND EQUIPMENT LAYOUT

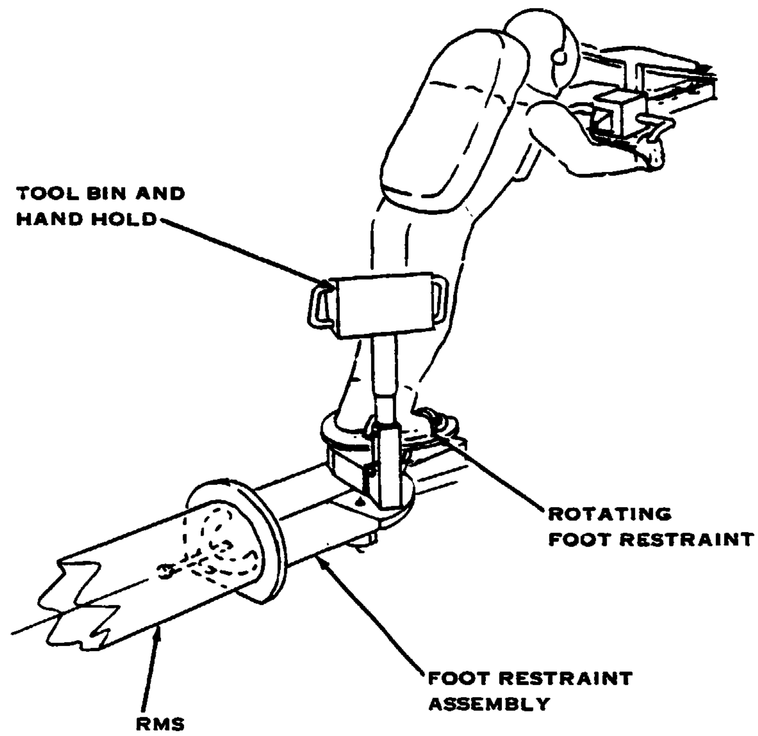


FIGURE 24. MANIPULATOR FOOT RESTRAINT CONCEPT

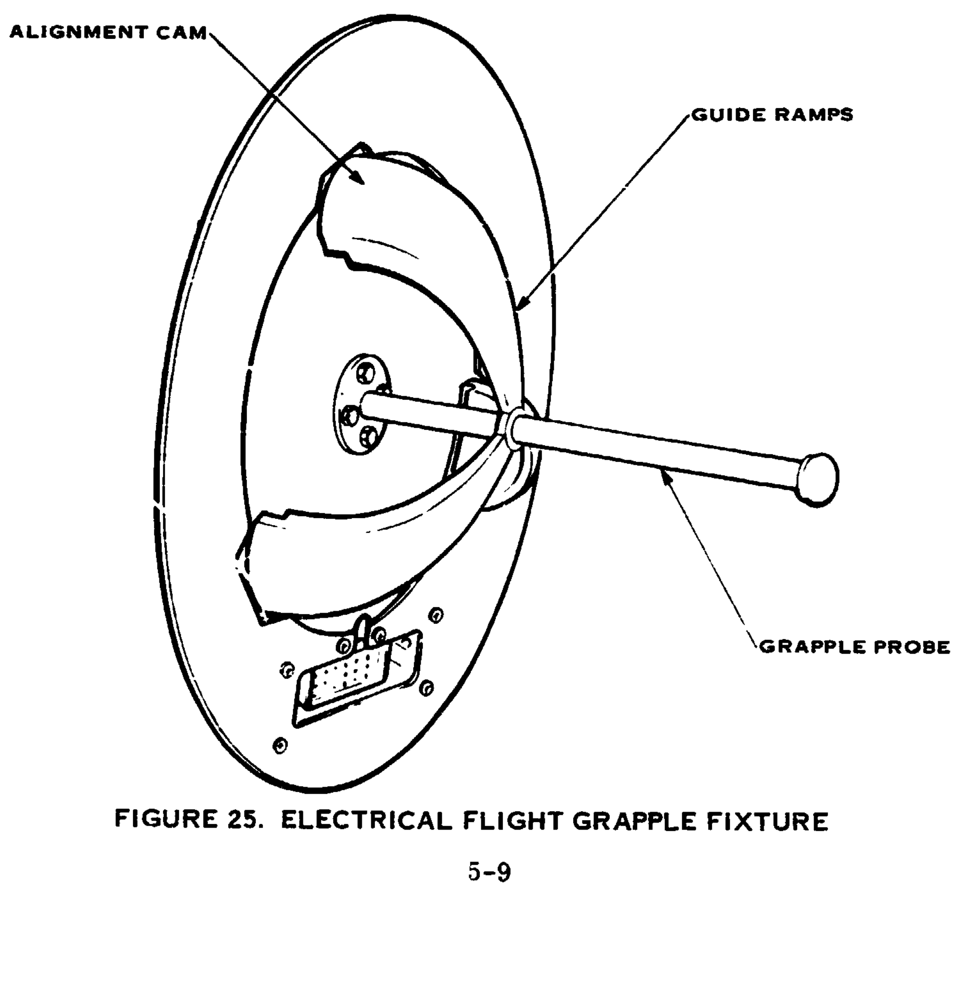


FIGURE 25. ELECTRICAL FLIGHT GRAPPLE FIXTURE

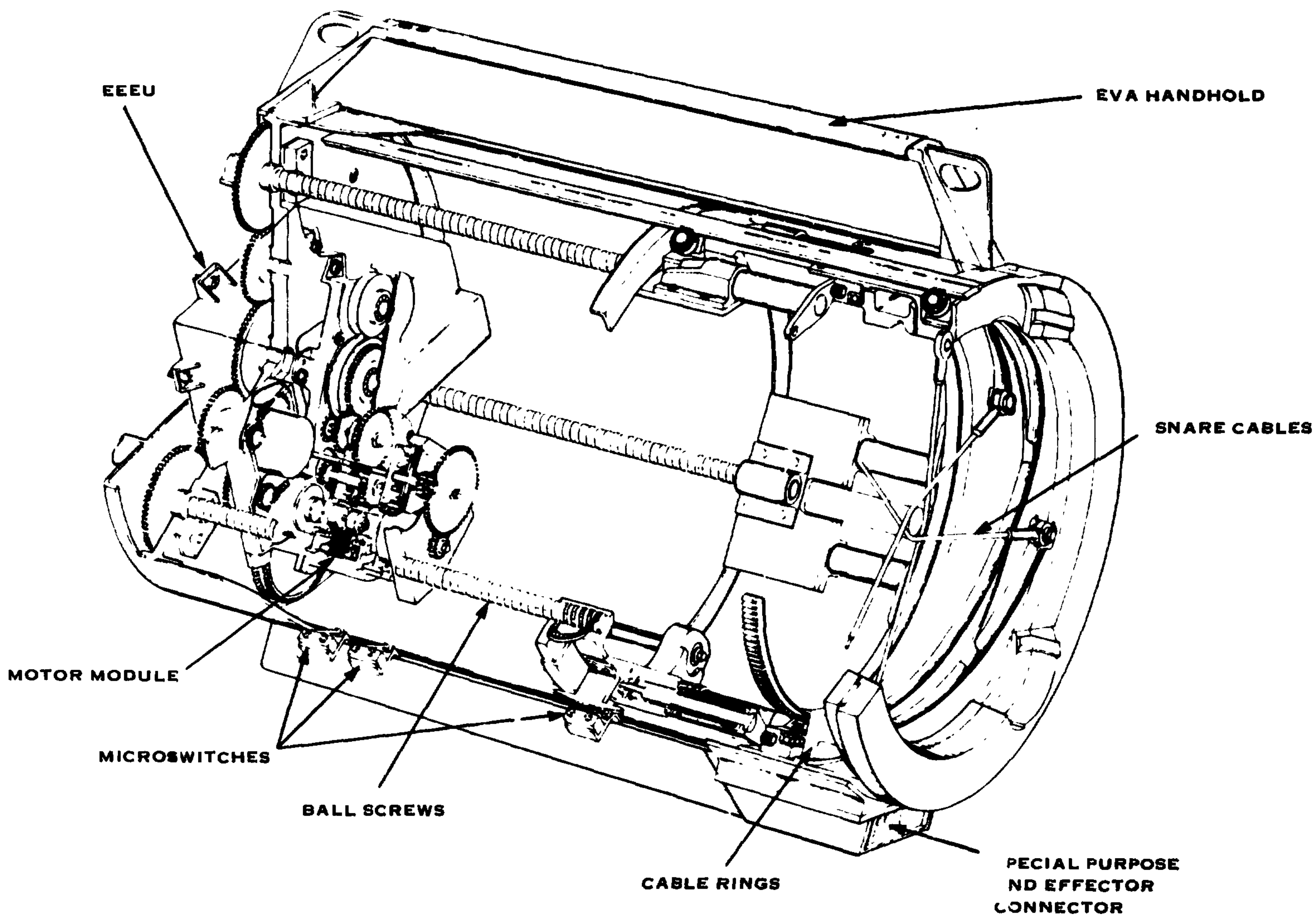


FIGURE 26. STANDARD SNARE TYPE END EFFECTOR

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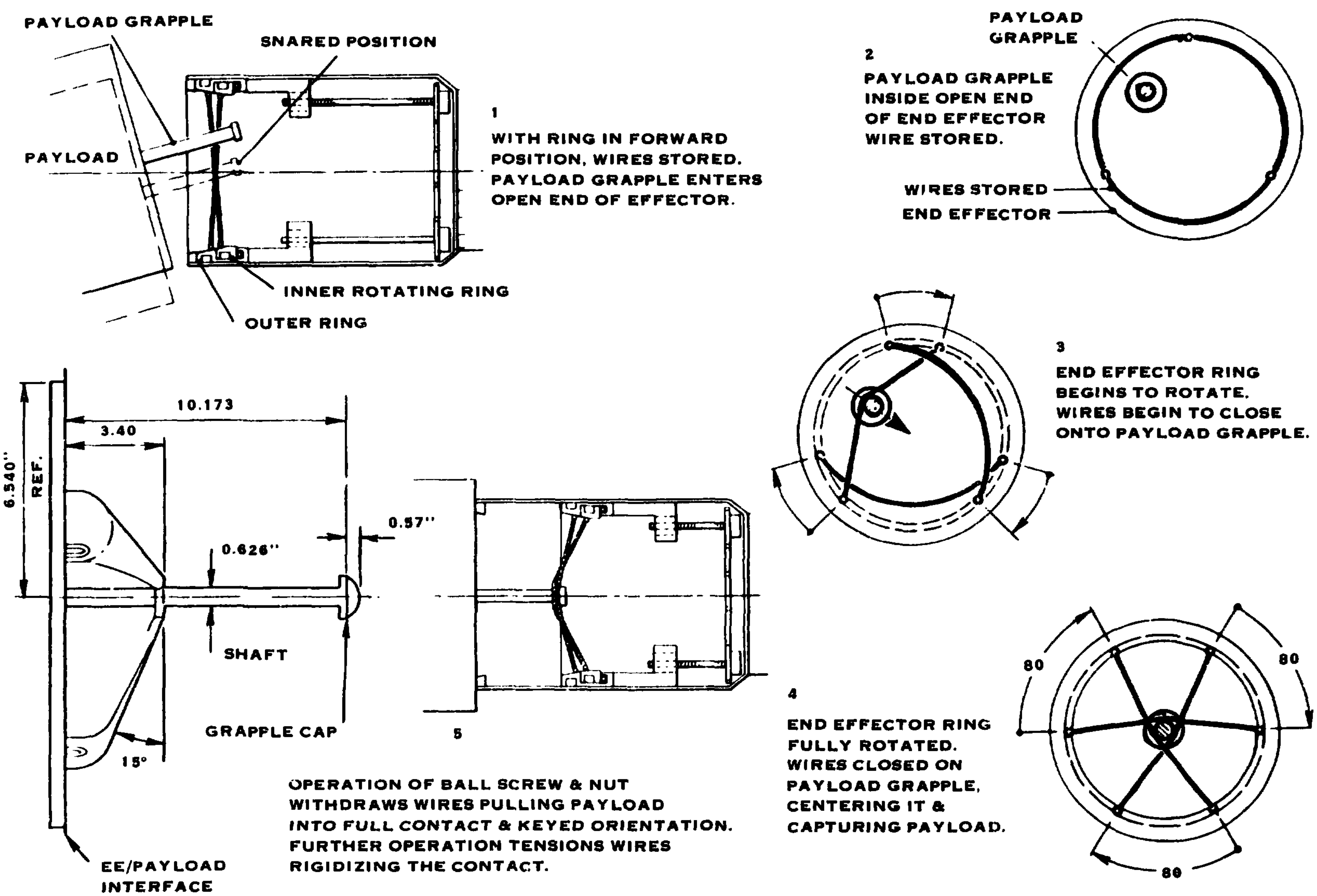
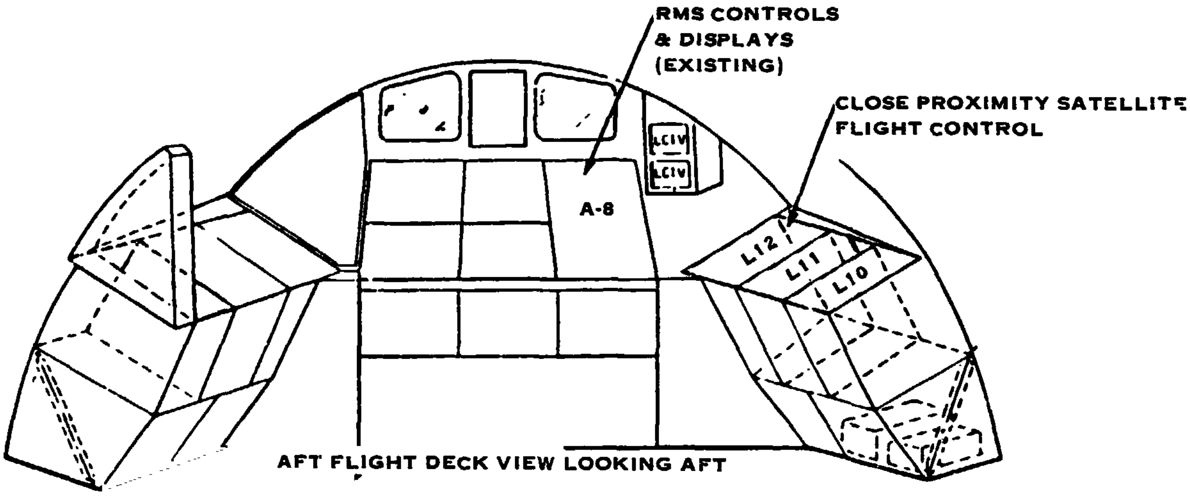


FIGURE 27. SNARE E/E - CAPTURE AND RIGIDIZE SEQUENCE

5.1.1 (Continued)

Insertion of the MFR grapple fixture is a routine task and is estimated to take 0.5 minutes to complete. The actual capture of the grapple fixture with the end effector will be controlled from within the shuttle at the aft flight deck (AFD) with verbal assist from the EVA astronaut in the payload bay. The AFD is shown in Figures 28 and 29.



POTENTIAL LOCATIONS OF AFT FLIGHT DECK (AFD) CLOSE PROXIMITY FLIGHT CONTROL PANEL

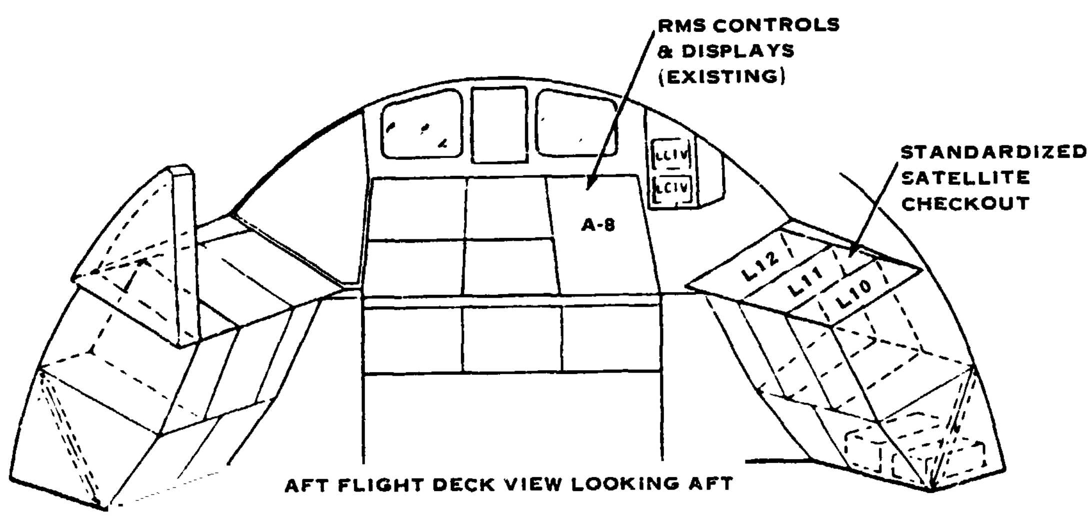


FIGURE 28. POTENTIAL LOCATIONS OF AFT FLIGHT DECK (AFD) STANDARDIZED SATELLITE CHECKOUT CONTROL PANEL

5.1.1 (Continued)

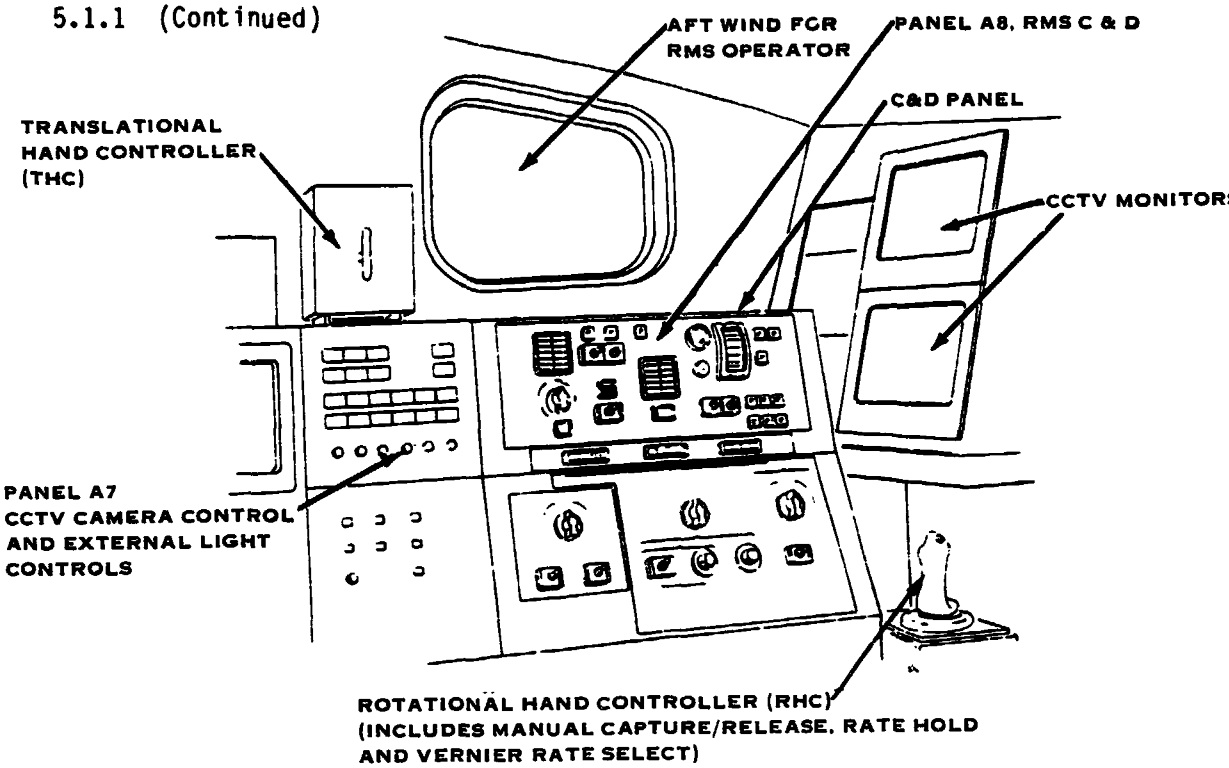


FIGURE 29. RMS OPERATOR STATION

Step No. 6

Once the MFR has been connected to the RMS, the astronaut then mounts the MFR and locks into the foot restraints. The foot restraints are similar to those shown on the MESA (refe.'ence Figure 23). It should take 0.5 minutes for the astronaut to lock into the foot restraints, tether the equipment to the tool bin, and stabilize himself with the hand restraints prior to translation (via the RMS) to the malfunctioning retention latch.

Step No. 7

Translation of the astronaut to the retention latch will be performed from the aft flight deck via control of the RMS. It is estimated that translational time will be minimal (1.5 minutes). Operation of the RMS will be controlled from the AFC. The timeless associated with this step have been estimated based upon two dimensional air bearing floor testing of the RMS and tests in Grumman Aerospace Corporation Large Amplitude Space Simulator (LASS).

5.1.1 (Continued)

Step No. 8

Override of the malfunctioning latch has been estimated to take 10 minutes since the backup mechanism should be mechanically noncomplex. It is noted that timelines associated with repair of malfunctioning equipment remain a function of the complexity of the repair problem and may vary from the estimates.

Step Nos. 9 through 15

Upon completion of the repair (in this case the unlatching of the problem retention latch) the first seven steps of the scenario are repeated in reverse order. The timelines associated with each of these steps are identical to those previously discussed.

Once the MFR has been removed from the RMS end effector, the RMS can be used to grapple the satellite within the payload bay and deploy the satellite, thus saving the mission. The sequence of events detailed in this scenario portray the need for manned EVA in order to insure mission success. Although robotics may at some time be used to effect repairs, robotics can in no way provide the flexibility man contributes to the system operation loop. The development of robotics capable of effecting satellite servicing repairs of a complex nature has been estimated at Battelle Labs to take at least 15 years, while the benefits of manned EVA have been demonstrated via numerous space missions (Skylab, Apollo, Gemini).

5.1.2 Appendage Malfunction

In the analysis of this scenario, it is assumed that a problem exists with a satellite appendage in that the appendage has failed to deploy properly, preventing final deployment of the satellite to the planned orbit. As was the case with the retention latch, astronaut interfacing with the faulty mechanism is necessary in order to insure success of the mission. Several of the steps included in this scenario are common to the previously discussed retention latch scenario and will not be repeated in detail. The previously presented retention latch scenario will be referenced for detailed explanation of the common scenario steps.

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5.1.2 (Continued)

Step Nos. 1 through 3

Table VI presents the activities the astronaut performs in order to complete this scenario. The first three steps of this scenario are identical to those in the previously presented retention latch scenario. In these three steps, the astronaut opens the airlock hatch, steps into the payload bay, closes the airlock hatch, translates to the tool storage area and obtains the equipment necessary to effect the repairs on the malfunctioning appendage. The timelines associated with each of these three steps are identical to those discussed in the retention latch scenario (1.0, 1.0 and 5.0 minutes, respectively).

TABLE VI

Initial Launch

D1 Nominal Deployment Sequence

Backup For Appendage Hangup

	Task Time (Min.)	Cum. Time (Min.)
1. Leave Air Lock	1	1
2. Translate To Tool Storage	1	2
3. Obtain Equipment	5	7
4. Translate To MMU Lock Into MMU	2	98
5. Translate To WRU Lock Into WRU	1	10
6. Translate MMU/WRU To Appendage Hangup	14	24
7. Repair Appendage Malfunction	10	34
8. Translate MMU/WRU To PLB AESA	14	48
9. Unlock From MMU/WRU	1	49
10. Configure MMU And WRU For Re-entry	34	83
11. Translate To Tool Storage	1	84
12. Return Equipment	5	89
13. Translate To Air Lock	1	90
14. Enter Air Lock	1	91

Step No. 4

The fourth step in this scenario requires that the astronaut translate from the tool storage area to the Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU area). This translational activity is estimated to take 1.0 minutes due to the short translational distance involved and is performed with the aid of the EVA handrails located within the Shuttle payload bay. The storage location (PLB AESA) of the MMU within the Shuttle bay is shown in Figure 30.

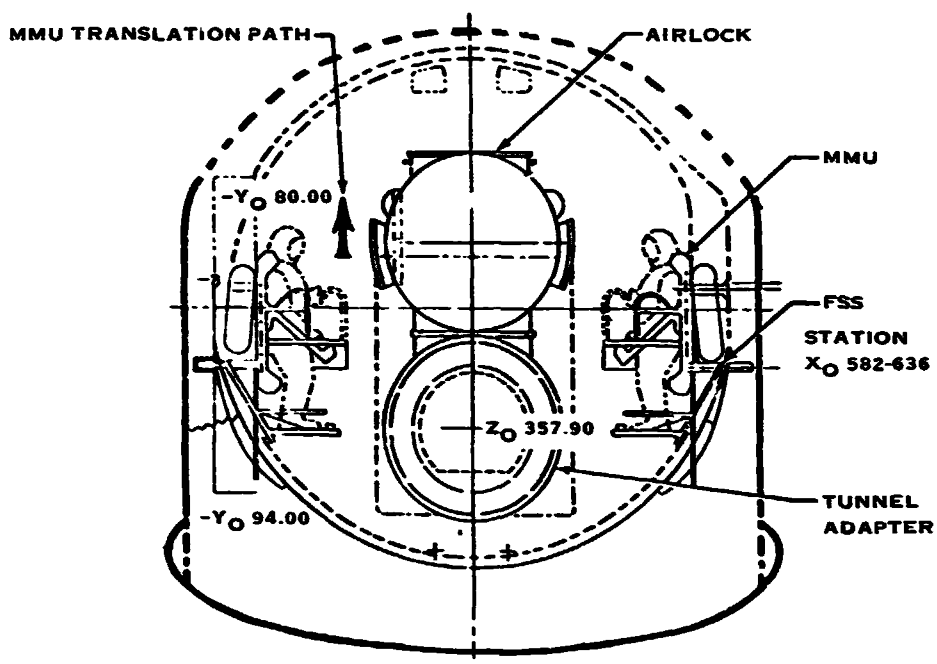

FIGURE 30. MMU LOCATIONS IN CARGO BAY WITH AIRLOCK/TUNNEL ADAPTER

Once the astronaut has reached the MMU storage position he must connect the EMU to the MMU. The MMU by itself and in a donned configuration is shown in Figure 31. Typical dimensions of the MMU were presented in Figure 17. Figure 32 presents a close-up view of the equipment storage area in which the MMU is stowed.

Step No. 5

Martin Marietta Corporation estimates that it will take an astronaut 2.0 minutes to don an MMU and lock into the WRU. This conservative time line allows for proper EMU/MMU interlock. Time variation may occur in the donning of the MMU since the astronaut must back into the unit and lock into the mechanism. Figure 33 displays the MMU donning configuration. The actual EMU to MMU interfacing was detailed in Figure 18. A series of handrails are employed as aids for the astronaut in order to achieve the EMU to MMU interlock.

Once the astronaut has donned the MMU, he must translate to the WRU and lock into the WRU. Locking into the WRU requires two interfaces; first, the astronaut must lock his feet into the foot restraints located on the WRU and

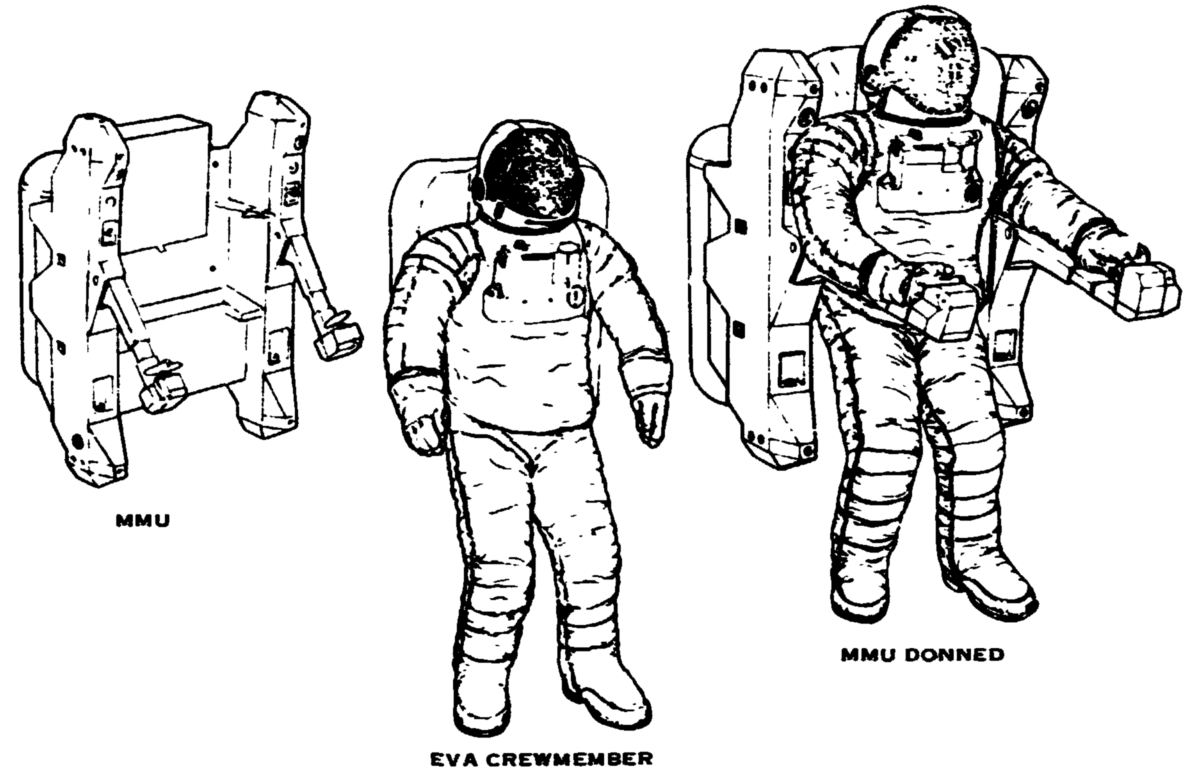

FIGURE 31. SPACE SHUTTLE MANNED MANEUVERING UNIT (MMU)

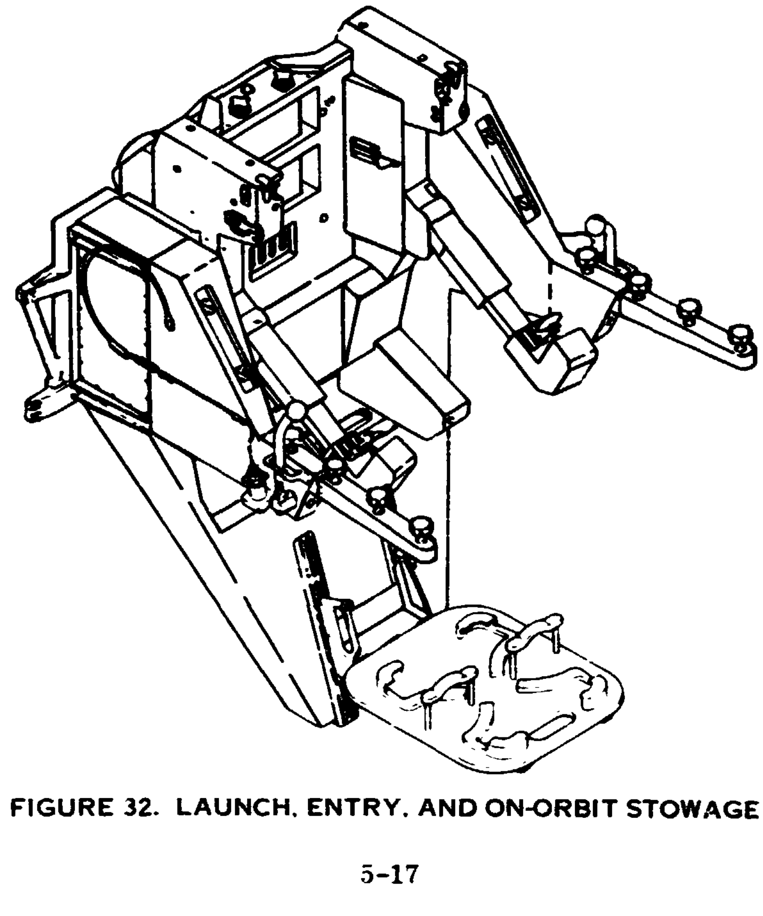

FIGURE 32. LAUNCH, ENTRY, AND ON-ORBIT STOWAGE

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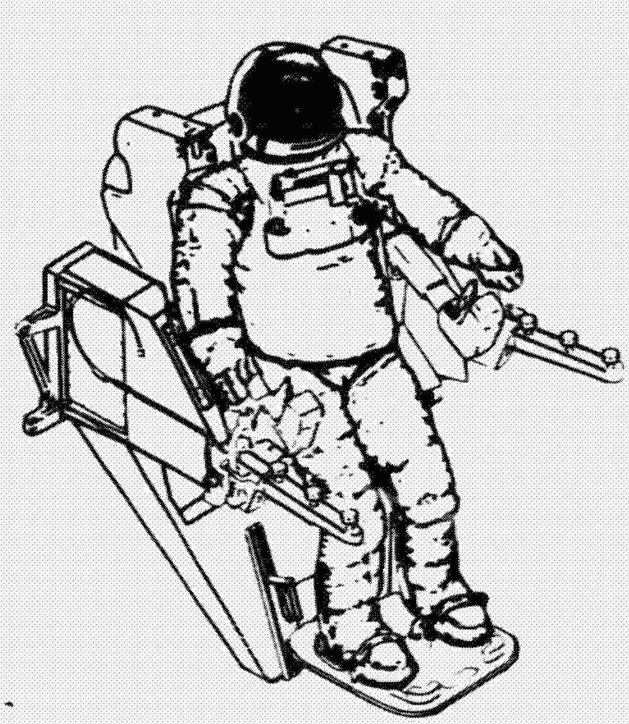
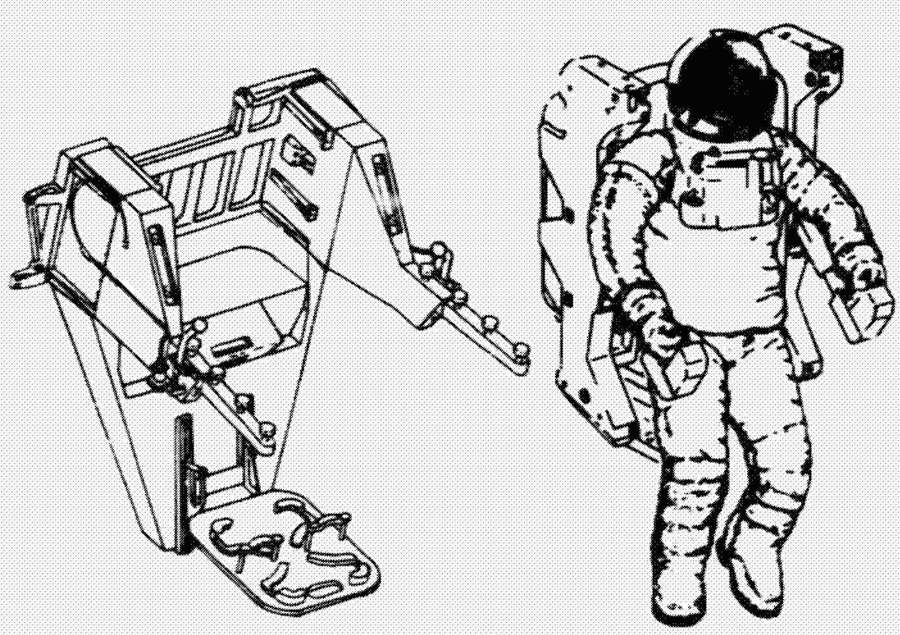


DONNING CONFIGURATION



EGRESS/INGRESS

FIGURE 33. THE MMU/FSS INTERFACE

5.1.2 (Continued)

secondly, engage the MMU with the WRU. The WRU is stored next to the MMU within the payload bay, and as such, minimal translation time is required for movement between the two. An example of the WRU is shown in Figure 34, with the WRU to MMU engagement mechanism shown in Figure 35. Figure 36 displays an example of an astronaut donned to an MMU unit, and completed engagement with the WRU.

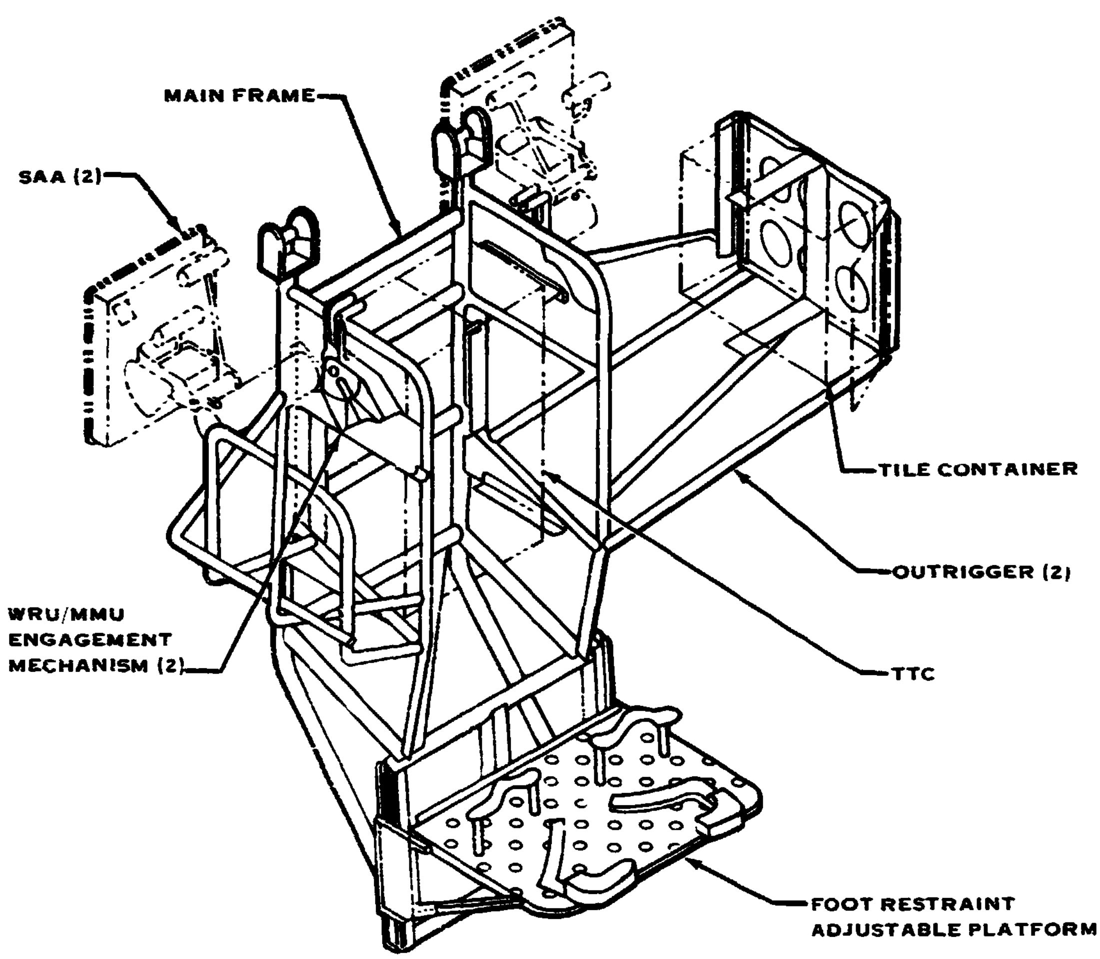


FIGURE 34. WORK RESTRAINT UNIT

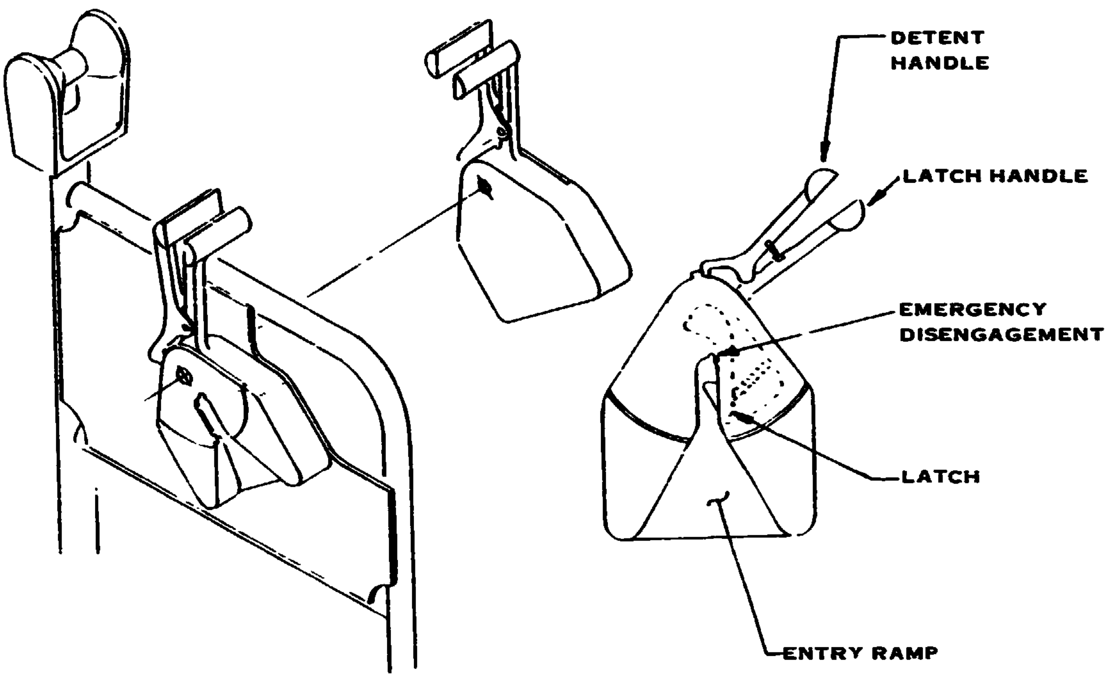


FIGURE 35. THE WRU-TO-MMU ENGAGEMENT MECHANISM

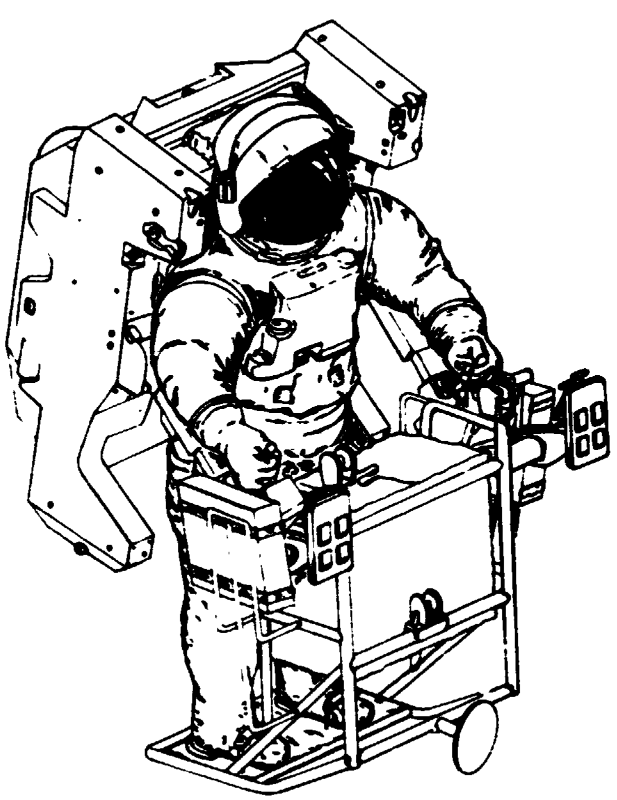


FIGURE 36. WORK RESTRAINT UNIT

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5.1.2 (Continued)

Step No. 6

The sixth step involves the translation of the astronaut and MMU/WRU to the malfunctioning appendage. Based upon testing results performed on the MMU, it has been estimated that a time approximating 14.0 minutes will be required in order to effect the translation. Although this timeline may appear conserva- tive due to the short translational distance involved, it is expected in that the astronaut must manually control his departure from the payload bay and in doing so avoid any accidental impacts with the Shuttle craft. Secondly, the astronaut must position himself next to the malfunctioning satellite appendage so as to be able to effect the required repair easily. The exact positioning of the MMU/WRU may require additional care on the part of the astronaut so as not to collide with the satellite and to attain a position relative to the satellite such that the necessary repair can be easily achieved without taxing the reach limitations of the astronaut.

Step No. 7

A timeline of 10.0 minutes is estimated in order to properly deploy the satellite appendage. This timeline may take more or less than the estimated time based upon the complexity of the repair task involved. Only when the astronaut is capable of accurately assessing damage or contingency operations, will the task complexity be known.

For the initial launch, satellite deployment will be a relatively routine repair task. Appendages will typically be deployed via spring actuation, and as such, required repairs should consist of items such as removal of a restraining pin or simple impartation of a force upon the appendage in order to overcome the malfunction.

Step No. 8

Upon completion of the repair, the astronaut must translate the MMU/WRU back to the storage position within the Shuttle bay. A time of 14.0 minutes has been estimated by MMC for this translational activity due to the care which must be taken 1) in the maneuvering of the MMU/WRU away from the satellite and 2) in the maneuvering of the MMU/WRU within the payload bay to the storage area.

5.1.2 (Continued)

Step No. 9

Disengagement from the WRU and MMU are relatively routine and have been estimated to take a total of 1.0 minutes. As was previously mentioned, the translational distance between the WRU and the MMU stowage position is minimal, and is not a significant factor in this timeline.

Step No. 10

The final task of any operation in which the astronaut uses the MMU involves configuring the WRU and MMU for re-entry. Based upon testing of the MMU (which included time line analysis) completion of this task will take 34.0 minutes. Preparation of the MMU and WRU for re-entry is more complex since a number of tasks are involved. These tasks include recharging of the MMU with gaseous nitrogen (GN_2) and replacement of rechargeable batteries. (Batteries removed from the MMU will ultimately be carried by the astronaut into the Shuttle cabin and recharged.)

Step Nos. 11 through 14

The remaining steps (translation to tool storage, returning equipment, translation to air lock and entering the air lock) have been discussed previously in the retention latch scenario, and will not be repeated here. The timelines associated with each of these four steps are applicable throughout all of the satellite servicing scenarios.

As with the previously discussed retention latch scenarios, WIF tank testing illustrates that the probability of manned EVA providing mission success is high. Increased flexibility is attained through the use of EVA, providing both operating and repair capabilities difficult without the use of man. In addition, the analysis of the eight (8) scenarios demonstrates the important role manned EVA can plan in ensuring success of various Shuttle servicing missions.

5.2 SATELLITE SERVICING SCENARIO D2 - INITIAL LAUNCH

Satellite servicing scenario D2 is an initial launch scenario in which EVA is required for both prime and backup situations. In this initial launch situation, the baseline assumption is that a problem exists with the RMS, thereby rendering the unit inoperative. Whenever the RMS is rendered inoperative

5.2 (Continued)

a man must perform the operations the RMS was scheduled to perform for mission success. Depending upon the complexity of the satellite servicing mission, a second astronaut may be required in order to effect repairs relative to malfunctioning retention latches or appendages. In scenario D2, only one astronaut is required for payload deployment and retention latch malfunction, while a second astronaut is required in order to repair an appendage malfunction. Each of the three scenarios associated with satellite servicing scenario D2 are discussed in the following paragraphs.

5.2.1 Payload Deployment

Astronaut EVA is required in order to deploy the satellite through the use of an MMU/WRU equipped with an RMS type end effector. This piece of equipment is shown in Figure 37.

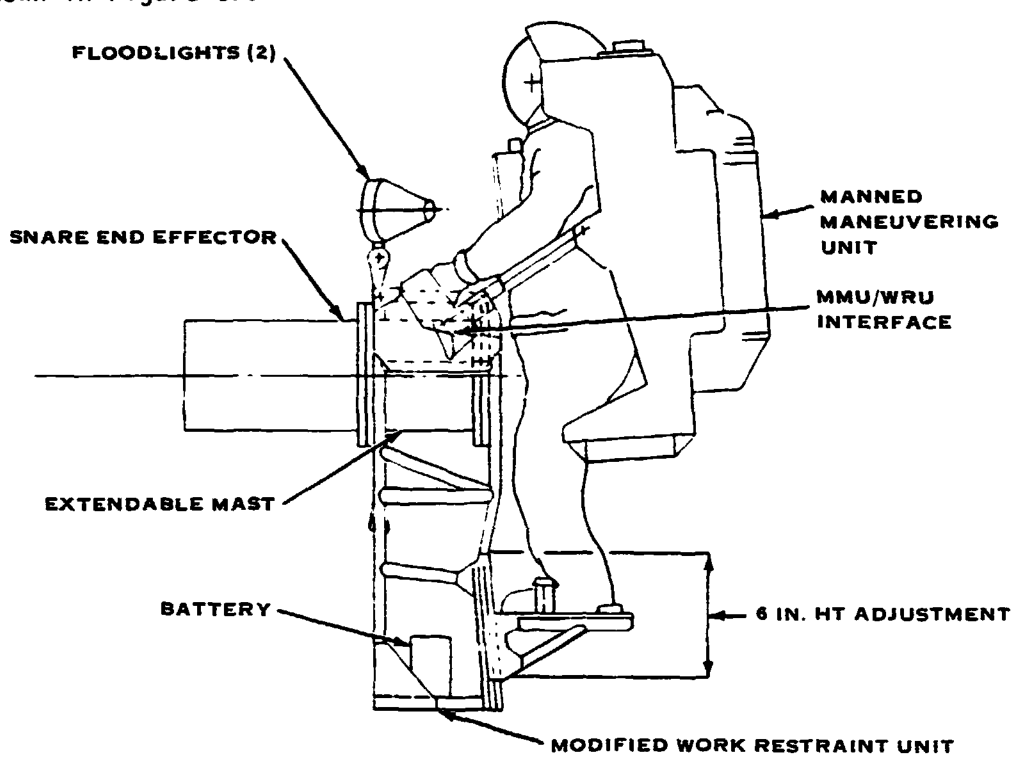

FIGURE 37. CONCEPT FOR MMU/WRU - END EFFECTOR ADAPTATION

Table VII presents a listing of the EVA activities necessary to complete a successful mission. The timelines associated with each of the scenario steps have been estimated based upon translational distance data, complexity of task, data obtained from WIF tank testing conducted upon numerous pieces of equipment, Apollo and Skylab timelines, and simulators.

5.2.1 (Continued)

TABLE VII

INITIAL LAUNCH

D2 RMS INOPERATIVE DEPLOYMENT SEQUEN:E

PAYLOAD DEPLOYMENT	TASK TIME (MIN.)	CUM. TIME (MIN.)
1. LEAVE AIR LOCK	1	1
2. TRANSLATE TO TOOL STORAGE	1	2
3. OBTAIN EQUIPMENT	5	7
4. TRANSLATE TO MMU LOCK INTO MMU	2	9
5. TRANSLATE TO WRU LOCK INTO WRU	1	10
6. TRANSLATE MMU/WRU TO SATELLITE STORAGE AREA	14	24
7. ATTACH MMU/WRU TO SATELLITE	2	26
8. TRANSLATE SATELLITE TO DEPLOYMENT AREA	14	40
9. DEPLOY SATELLITE APPENDAGE	10	50
10. RELEASE SATELLITE FROM MMU/WRU	2	52
11. TRANSLATE MMU/WRU TO PLB AESA	14	66
12. UNLOCK FROM MMU/WRU	1	67
13. CONFIGURE MMU AND WRU FOR RE-ENTRY	34	101
14. TRANSLATE TO TOOL STORAGE	1	102
15. RETURN EQUIPMENT	5	107
16. TRANS "E TO AIR LOCK	1	108
17. ENTER , .OCK	1	109

SCENARIO ASSUMES WRU IS EQUIPPED WITH RMS TYPE END EFFECTOR

Steps Nos. 1 through 5

For the payload deployment portion the first five steps involved are similar to those previously discussed for the appendage malfunction portion of scenario D1. In addition, since these steps are identical to those in scenario D1, the timelines associated with each step are identical to those previously presented. Although tools are not actually required by the astronaut in the payload deployment sequence of this scenario (should all aspects of the scenario be implemented as scheduled), the tools are included should the astronaut encounter a contingency mode (such as a malfunctioning retention latch). Whereas some supplementary EVA time is added in obtaining and returning the tools, this expended time may save the astronaut a significant amount of mission time should he find himself unable to open a malfunctioning retention latch which pre-EVA analysis failed to identify.

Step No. 6

The sixth step requires the astronaut to translate the MMU/WRU from within the payload bay to a position near the stowed satellite. A time of 14.0 minutes

5.2.1 (Continued)

has been allotted for this step based upon Martin Marietta Corporation testing of the MMU. As noted, this conservative timeline is justified since the astronaut must use caution when leaving the payload bay via the MMU/WRU. Secondly, the astronaut must position the MMU/WRU over the RMS grapple fixture such that the fixture may be captured via the RMS type end effector on the WRU. Care must be taken to ensure that accidental collision does not take place between the MMU/WRU and the stored satellite.

Step No. 7

This next step involves the actual capture of the satellite through the use of the RMS type end effector located on the WRU. A time of 5.0 minutes has been estimated for this step. Although the actual capture and rigidization sequence is relatively short, additional EVA time has been allocated to allow for final positioning of the MMU/WRU prior to capture.

Upon completion of the capture and rigidization sequence, the retention latches (which were previously tested from the aft flight deck and determined to be operating correctly) are released permitting the satellite to be translated to the deployment area.

Step No. 8

In this step, the astronaut is required to remove the satellite from the payload bay and translate the satellite to the deployment area. A time of 14.0 minutes has been allowed for this step based upon results of Martin Marietta Corporation testing for translational activities involving the use of the MMU. In addition, the length of this timeline is justified since the astronaut must exercise care when removing the satellite from the payload bay stowage area so as not to damage any equipment. Upon achieving removal of the satellite from the payload bay, actual translation of the equipment to a deployment area is a relatively straightforward task.

5.2.1 (Continued)

Step No. 9

Step No. 9 calls for deployment of satellite appendages. For the astronaut this step is actually a "standby" as he will not be involved in the actual appendage deployment. Appendage deployment will be controlled via ground command with the astronaut simply verifying that deployment has occurred.

A time of 10.0 minutes has been allowed for actual appendage deployment and verification that the appendages have locked into the deployed position. In addition, final operational status/health checks prior to release of the satellite into orbit may be performed during this time frame.

Step No. 10

Upon completion of appendage deployment and final operational status/health checks, the satellite will be ready for release into orbit. Final release of the satellite will be accomplished by the impartation of a translational velocity of approximately 1.0 ft/sec upon the unit through the use of the MMU/WRU. Upon attainment of the desired velocity and orbital direction, the RMS end effector on the WRU will be opened, and thrusters on the MMU used to slow the speed of the MMU/WRU. The satellite, once released from the RMS end effector will move toward its desired orbital position. Thrusters on the satellite may be controlled via ground command for imparting final satellite orbital and attitude adjustments.

A time of 2.0 minutes has been estimated for final release of the satellite.

Step Nos. 11 through 17

The remaining steps in this scenario have been presented previously in the appendage malfunction portion of satellite servicing scenario D1. The timelines presented for each of these steps are applicable for all scenarios requiring use of the MMU throughout all of the satellite servicing scenarios discussed in this report.

The importance of manned EVA capabilities is again exemplified since successful completion of the mission objectives occurs in spite of a malfunctioning RMS. Should manned EVA capabilities fail to be developed to their utmost potential, the success probability of most satellite servicing scenarios becomes questionable.

5.2.2 Retention Latch Malfunction

In this scenario, it is assumed that the retention latch mechanism fails to unlatch, thereby preventing removal of the satellite from the payload bay (via the MMU/WRU) prior to deployment. The actions required by the astronaut include steps previously described in scenario D1 - Retention Latch Malfunction and scenario D2 - Payload Deployment Malfunction.

Due to the beauty of the "building block' approach, many of the satellite servicing scenarios described have been analyzed by combining isolated information. This methodology allows detailed analysis of any of the one hundred eighty-four (184) satellite servicing scenarios identified by Grumman Aerospace Corporation.

Table VIII presents the series of steps which comprise a retention latch malfunction for satellite servicing scenario D2. Since the logic which was incorporated into the development of timelines for each of these steps has been previously described, it shall not be repeated in the analysis of this scenario. The previously described scenario D1 may be reviewed for a detailed analysis of the actions which comprise this scenario.

TABLE VIII

Initial Launch

D2 RMS Inoperative Deployment Sequence

Backup For Retention Latch Hangup

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MMU Lock Into MMU	2	9
5.	Translate To WRU Lock Into WRU	1	10
6.	Translate MMU/WRU To Retention Latch	14	24
7.	Manually Release Retention Latch	10	34
8.	Translate MMU/WRU To Satellite Stowage Area	3	37
9.	Attach MMU/WRU To Satellite	2	39
10.	Translate Satellite To Deployment Area	14	53
11.	Deploy Satellite Appendages	10	63
12.	Release Satellite From MMU/WRU	2	65
13.	Translate MMU/WRU To PLB AESA	14	79
14.	Unlock From MMU/WRU	1	80
15.	Configure MMU And WRU For Re-entry	34	114
16.	Translate To Tool Storage	1	115
17.	Return Equipment	5	120
18.	Translate To Air Lock	1	121
19.	Enter Air Lock	1	122

Scenario Assumes WRU Is Equipped With RMS Type End Effector

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5.2.3 Appendage Malfunction

In this scenario, the appendage(s) has failed to deploy properly, preventing ultimate deployment of the satellite. The astronaut performs a combination of steps previously described in scenario D1 - Appendage Malfunction and scenario D2 - Payload Deployment Malfunction. However, since the RMS has been rendered inoperable due to an equipment malfunction (and an astronaut is required to perform the activities which would have been performed by the RMS), a second EVA astronaut is required in order to repair the appendage and complete the mission.

The sequence of steps necessary to complete this mission are presented in Table IX.

TABLE IX

Initial Launch

D2 RMS Inoperative Deployment Sequence

Backup For Appendage Hangup

	First MMU/WRU	Second MMU/WRU	Task Time (Min.)	Cum Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		1	8
5.	Translate To WRU Lock Into WRU		2	10
6.	Translate MMU/WRU To Satellite Storage Area		14	24
7.	Attach MMU/WRU To Satellite		2	26
8.	Translate Satellite To Deployment Area		14	40
9.	Deploy Satellite Appendages		10	50
10.	Standby	Leave Air Lock	1	51
11.		Translate To Tool Storage	1	52
12.		Obtain Equipment	5	57
13.		Translate To MMU Lock Into MMU	2 9	58
14.		Translate To WRU Lock Into WRU	1	60
15.		Translate MMU/WRU To Appendage	14	74
16.		Repair Appendage Malfunc	10	84
17.		Translate Away From Sat [illegible]e	7	91
18.	Release Satellite From MMU/WRU	Standby	2/-	93
19.	Translate MMU/WRU To PLB AESA	Translate MMU/WERU To PLB AESA	14/14	107
20.	Unlock From MMU/WRU	Unlock From MMU/WRU	1/1	108
21.	Configure MMU And WRU For Re-entry	Configure MMU And WRU For Re-entry	34/34	142
22.	Translate To Tool Storage	Translate To Tool Storage	1/1	143
23.	Return Equipment	Return Equipment	5/5	148
24.	Translate To Air Lock	Translate To Air Lock	1/1	149
25.	Enter Air Lock	Enter Air Lock	1/1	150

Scenario Assume [illegible] Equipped WRU Is Equipped With PMS Type End Effector [illegible]

Step Nos. 1 through 9

For the first astronaut, the first nine steps are identical to those described in the payload deployment malfunction of scenario D2. A problem arises during the 9th step in that an appendage has failed to deploy itself properly via the ground control deployment operation. A second astronaut will then be required to repair the satellite and complete the mission scenario.

5.2.3 (Continued)

Step Nos. 10 through 16

Step Nos. 10 through 16 apply to the second astronaut. These steps are identical to the first seven steps used in appendage malfunction for scenario D1 and are referenced for a detailed analysis of the timelines estimated for each of the actions.

It has been assumed in all satellite servicing scenarios that the second astronaut has performed prebreathe activities, donned a suit, verified the operational health/status of a second EMU, and is ready to begin an EVA from the point of the airlock hatch.

Step No. 17

Upon completion of the effected appendage repair, the second astronaut will translate away from the satellite in order for the first astronaut to continue with the planned deployment sequence. A time of 7.0 minutes has been allowed for this step. This time is exactly 1/2 the timeline determined for translational activities through Martin Marietta testing of the MMU. It is believed that a shorter time frame is applicable for this step since the translational distance is short and the activity potentially uncomplicated. The second astronaut must translate away from the satellite and attain a standby position, prepared to aid the first astronaut should additional problems develop during deployment activities

Step No. 18

During Step Nos. 10 through 17 the first astronaut has remained in a standby position, stabilizing the satellite while the appendage repairs were being effected. Upon completion of the repairs, the first astronaut is ready to continue the mission by deploying the satellite towards its orbital position. The actual deployment sequence has been previously described in the payload deployment malfunction of scenario D2.

During this 2.0 minute step in the scenario, the second astronaut will remain in a standby mode, ready to aid should any additional problems arise.

Step Nos. 19 through 25

Step Nos. 19 through 25 are identical to the final seven steps described in the payload deployment sequence of scenario D2, provided that both astronauts

5.2.3 (Continued)

perform the activities in parallel. The timelines for each of the steps are identical to those previously described.

Timeline analysis for each of the eight (8) key scenarios detailed in this report may be found in Appendix A. The logic employed in the development of each scenario is identical to that used used in the development of these two (2) scenarios. Based upon the analysis of these two scenarios, it may be shown how portions of any two (2) or more scenarios may be combined to estimate timelines for any portion of the one hundred eighty-four (184) scenarios identified by Grumman Aerospace Corporation.

The analysis of eight (8) scenarios demonstrates the requirement for manned EVA in order to provide flexibility of operations and insure mission success. In addition, it has been shown that redundant, standardized operational procedures can be utilized throughout numerous satellite servicing scenarios and will minimize the amount of time required to train astronauts for each mission. The use of manned EVA is a proven operational tool (demonstrated through the Skylab missions) and is currently available for satellite servicing.

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SECTION 6.0
SUPPORT EQUIPMENT CONCEPTS

The preceding sections discussed satellite service in terms of deployment, retrieval and service operations.

This section identifies some manned EVA techniques and equipment for supporting deployment, retrieval and service operations, and discusses them as required to supplement the Grumman Aerospace Corporation scenarios. Discussion of specific tool and equipment requirements are restricted to handheld, direct contact categories.

6.1 INITIAL LAUNCH EQUIPMENT

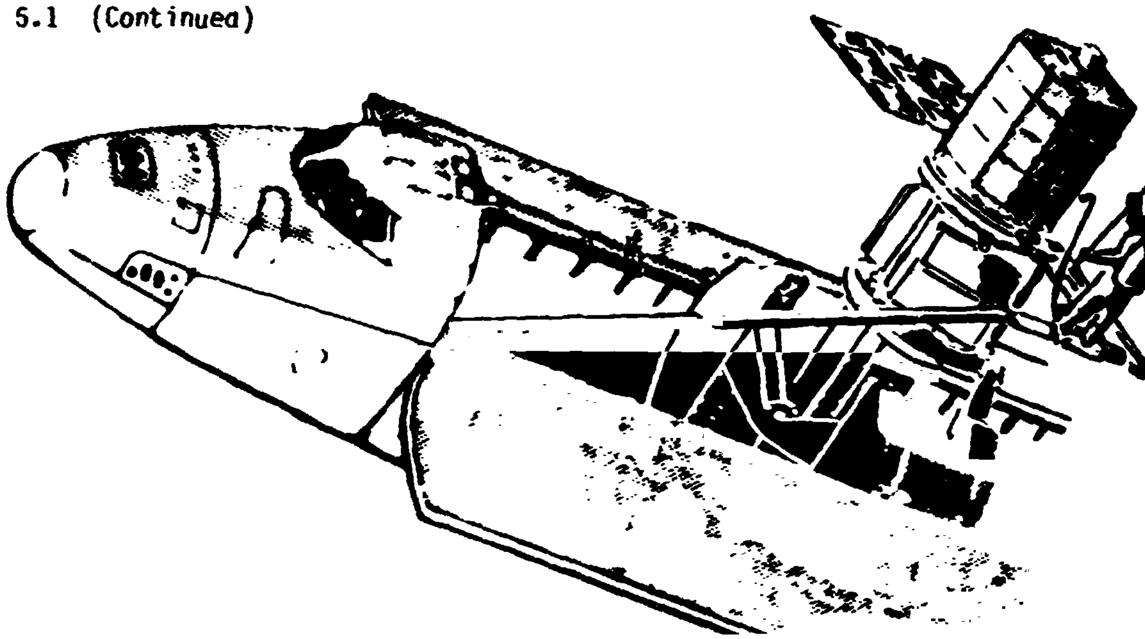
The following types of equipment will be required to initially launch or deploy satellites.

Deployment Operation	Representative EVA Service Equipment Required
Normal Deployment	Flight Support System (FSS) Remote Manipulator System (RMS) Tilt Table, Spin Table Payload Installation & Deployment Aid (PIDA) Handling & Position Aid (HPA) Maneuverable Television (MTV)
Contingency Deployment	FSS, RMS, Hand Tools, Tram Line Extravehicular Mobility Unit (EMU) Manipulator Foot Restraint (MFR) Manned Maneuvering Unit (MMU) Work Restraint Unit (WRU)

Normal Deployment - Normal deployment is expected to be automated, with all crew activity being IVA.

Contingency Deployment - Contingencies could alter normal deployment at any step. In the accompanying illustration (Figure 38), EVA is shown supporting final assembly and checkout using a tram line to tether and move large panel sections. In addition, simple hand-held tools will be required to unbolt or unlatch jammed mechanisms.

5.1 (Continued)



PAYLOAD DAMAGE-CONTINGENCY

FIGURE 38. CONTINGENCY DEPLOYMENT

6.2 RETRIEVAL EQUIPMENT

The following types of equipment will be required to retrieve satellites during Revisit or Earth Return scenarios.

	Retrieval Operation	Representative Service Equipment Required
1.	Satellite Retrieval	Versatile Service Stage (VSS), EMU, RMS, MMU/WRU, Proximity OPS Module (POM) via WRU or MTU-POM
2.	Satellite Stabilization	VSS, EMU, Manned Maneuvering Unit (MMU), POM
3.	Preberthing	
	Subsystem Safetying	Subsystem safetying kit
	Vent pressure vessels	Fluid Service Facility
	Fold or trim deployed appendages	Cutters

6.2 (Continued)

	Retrieval Operation	Representative Service Equipment Required
4.	Berthing Assist	MMU/WRU, RMS, PIDA, HPA
5.	Debris Management	VSS with debris capture kit

Retrieval - Retrieval is concerned with passive satellites having no fly-to-Orbiter capability. A typical retrieval would involve use of a proximity operations module (POM) or versatile service stage (VSS) to bring the unpowered satellite within the snaring envelope of the RMS.

Stabilization - Stabilization is concerned with satellites that are out-of-control. Unstable satellites will be retrieved by the use of unmanned equipment components where applicable so as to limit any extraordinary hazard potential to the astronaut. Satellite stabilization could be achieved through the use of a VSS equipped with an RMS type end effector. Once stabilized by a VSS, the satellite would then be returned to the orbiter. However, unless the extraordinary hazards exist this operation may be completed by a crewmember.

The VSS will be controlled from the AFD within the Shuttle. Closed circuit television will be employed to provide visual feedback to the astronaut in the AFD while the VSS is maneuvered to synchronize its motion with that of the satellite. The RMS end effector (which is mounted on an extendable boom on the VSS) will then be used to capture the grapple fixture on the satellite. Upon capture of the satellite, thrusters on the VSS will be employed in order to eliminate the rotational motion of the satellite. The VSS will then be used to transport the satellite back to the Shuttle.

Figure 39 shows a VSS with an RMS type end effector which can be used to capture unstable satellites.

Preberthing - Normal preberthing activities consist of safetying the satellite subsystem to protect against inadvertent thruster firing, folding or unfastening appendages to permit the satellite to fit into the payload bay, and subsequently deactivating subsystems.

Contingency preberthing activities deal with damaged or stuck appendages, or performing safing activities such as antenna removal, electrical deactivation, pressurant release or mechanical baffling of thrusters. These activities are depicted in the accompanying illustration (Figure 40).

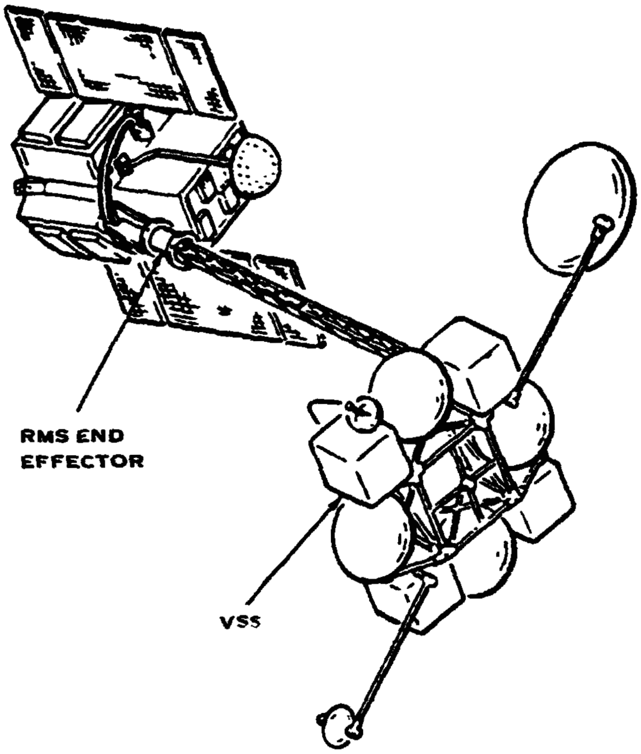


FIGURE 39. VSS WITH END EFFECTOR KIT

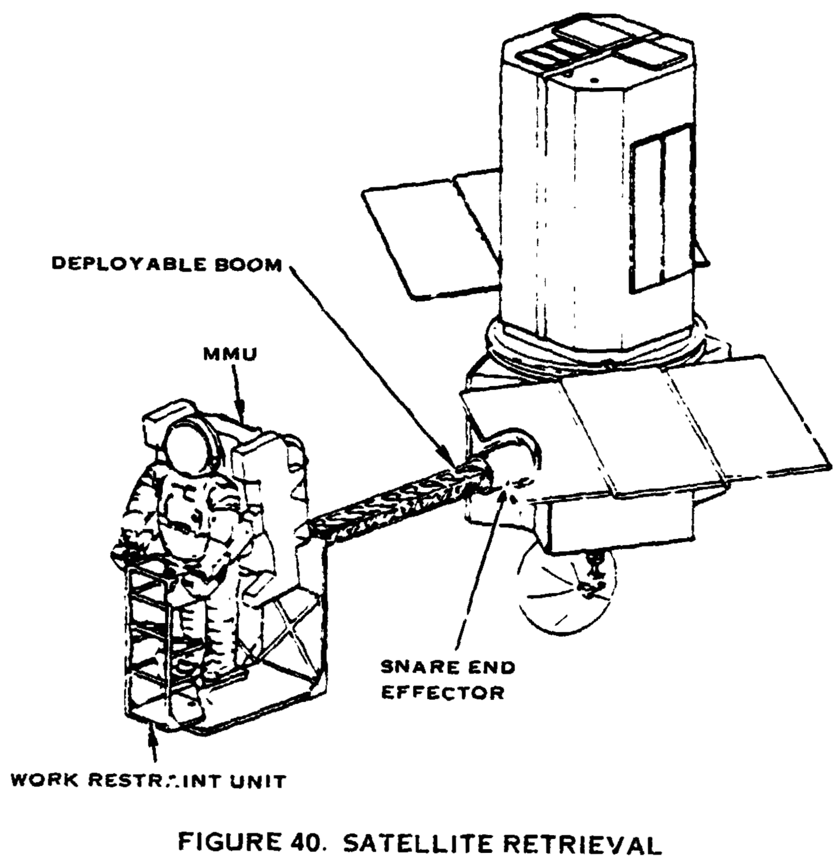


FIGURE 40. SATELLITE RETRIEVAL

6.2 (Continued)

Safetying activity may be required to make a satellite safe before it can be berthed to the Shuttle. A safetying kit has been concepted for removing appendage restraints, sharp edge padding, sensor protection, and equipment for thruster baffling.

Debris Management - Debris management is the activity associated with collecting orbital debris, damaged satellite appendages removed during preberthing, transporting debris to the Orbiter, and stowing the debris in the payload bay for return to Earth.

Debris may be collected and transported to the orbiter using the Versatile Service Stage (VSS) equipped with a debris capture kit. This equipment is shown in Figure 41. The VSS, with its dexterous manipulators, is able to snare and hold onto debris. In addition, the rotating platform on the VSS can be used to synchronize motions with tumbling debris, enabling capture and retrieval of unstable materials.

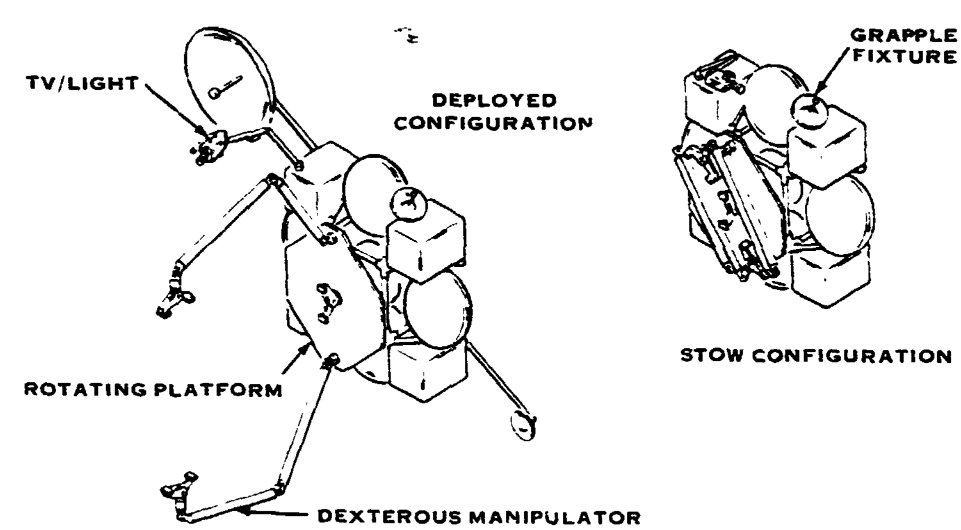


FIGURE 41. VSS–DEBRIS CAPTURE KIT

6.3 Satellite Service Equipment

The following types of equipment will be required to perform satellite servicing operations. The equipment components and their use are discussed in the following pages.

Service Task Description	Potential Service Equipment Required
Transport of supplies and tools to work site	MMU/WRU, OCP
Fluid Service	Refuel/defuel fluid transfer concept
Heavy-duty hand tool work	Hand power tool and drill, impact and torque socket wrench, screwdriver, and saw
Payload handling, payload bay and vicinity	RMS,OCP, MMU/WRU
Crewman transport to satellite	MMU, POM-MMU/WRU
Leak detection	IR detector, mass spectrometer
Item inspection	Optical magnifying device
Optical alignment	Portable laser
Other hand tool operations	Fuse bond/weld/rivet tool, tools to measure/set mechanical clearances, pliers, vice grips, mirror, hammer, strap, camera, EVA adhesive tape, lens cleaner
Diagnostics, Visual Inspection	MMU, MTV

Hand-Held Power Tool - The hand-held power tool is a tool system consisting of a hand-held power head plus magazine attachments. Magazines contain pre-selected assortments of fastener drivers and drills. Attachments are also included for shearing, cutting and riveting. The power head is a variable speed impact type of device which permits torque selection. The tool power source would be a portable battery.

6.3 (Continued)

More Distant Inspection - In the accompanying illustration (Figure 42) an EVA crewman has left the Shuttle to inspect operational status of a satellite orbiting close to the Shuttle. The maneuverable television MTV provides information input to the IV crewman for decisions such as to retrieve or abandon the satellite, or to service it at the Orbiter. Remote inspection via the MTV adaptation of the POM may also include visual assessment of the satellite condition and a diagnostic checkout of satellite subsystems suspected of malfunction. Inspection is expected to precede service operations to pre-identify all service operations required.

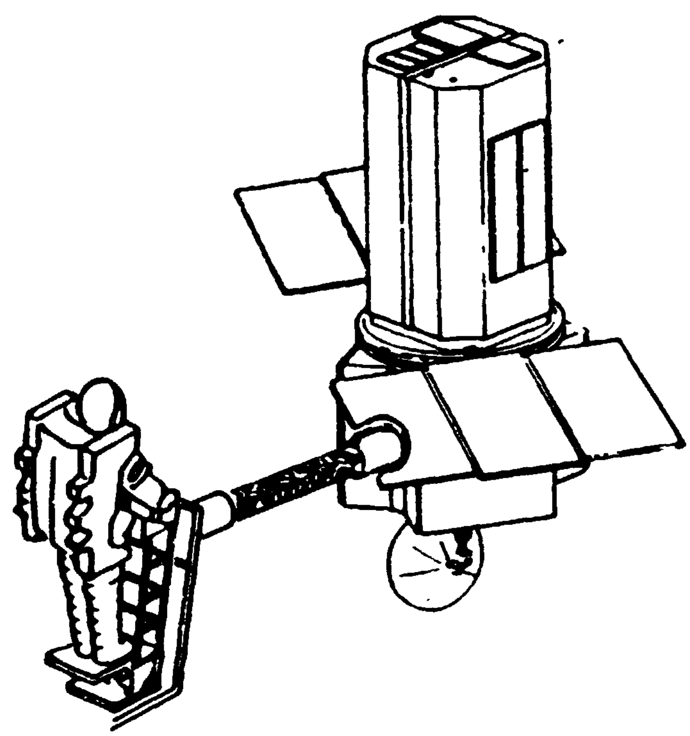


FIGURE 42. REMOTE EVA INSPECTION

6.3 (Continued)

Service at Shuttle - The view in (Figure 43a) shows an EVA crewman in the payload bay on an RMS work platform about to remove a module for subsequent installation.

Payload bay service includes system checkout, instrument change out, or replacement of modular elements such as solar arrays and antennas.

In (Figure 43b) the crewman on the right is shown performing service checkout of satellite systems by way of the HPA work platform/OCP.

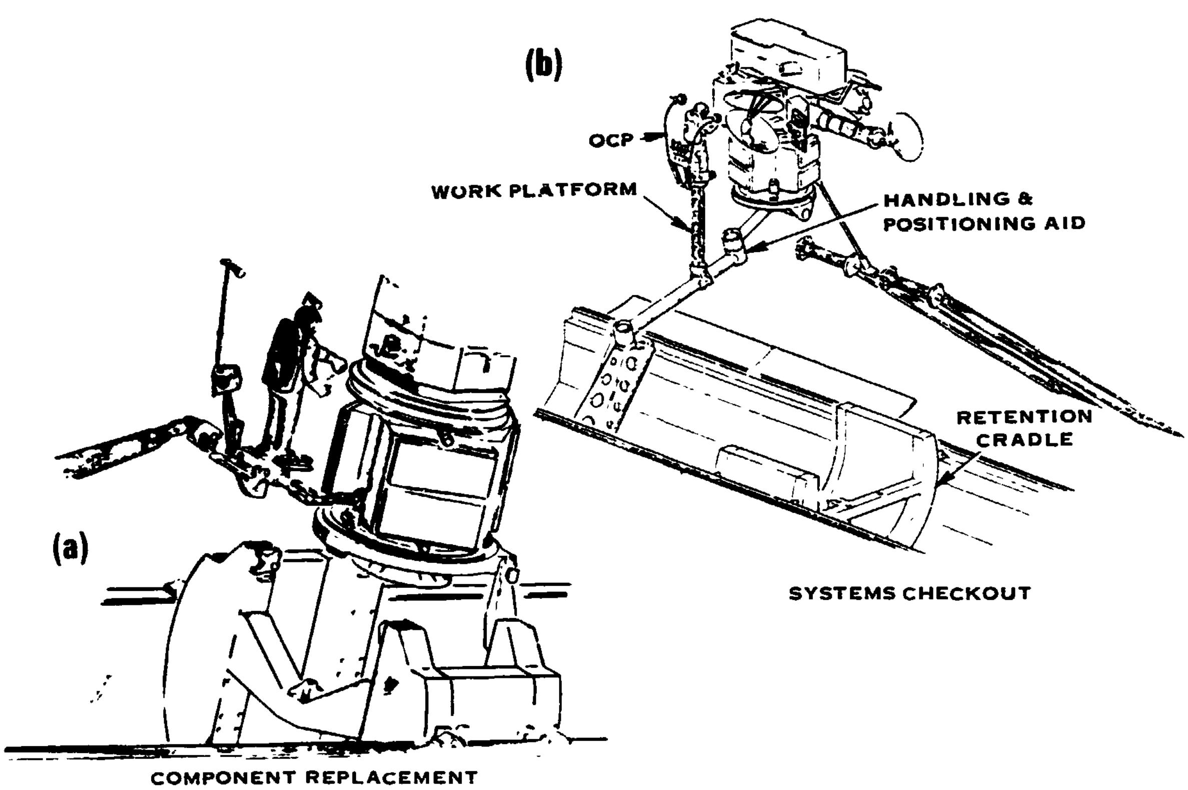


FIGURE 43. SATELLITE SERVICE AT SHUTTLE

6.4 EVA SUPPORT EQUIPMENT

The following pieces of equipment will be used to support EVA while performing satellite servicing scenarios.

Requirement	Approach
EMU	
Eliminate Prebreathe	8 psi suit with or without scheduled depressurization to 4 psi, or 9 psi shuttle with a 4-psi suit
Work Lights	Lights on helmet, hand-held spotlight, area flood lights
IV/EV Communication	MTV, EMU EVCS
Sun Shielding	Automatic visor
No Water Vapor Contamination	No vent regenerable heat sink
Expanded Computer	Diagnostic capability, voice control of MMU, remote temperature sensor, transfer trajectory orbital mechanics, rate-range-spin, automatic PLSS control
MMU	
Satellite Service MMU	Quick partial recharge, thruster CG shift trim, control from EMU, fully folding arms, greater V
Work System	
Transport Supplies and Parts in Payload Area	RMS, MMU/WRU
Transport Tools	Tool caddy
Astronaut Restraint	Tethers, manipulator foot restraints, workstands
Work Bench Mount	Work Platform (i.e., OCP)

6.4 (Continued)

Requirement	Approach
Hardware Restraint	Tether, velcro, clips, cart
Crewman Transport	MMU, RMS, POM
Equipment Transport	RMS, MMU/WRU

6.5 SATELLITE SERVICE WORK AIDS

The following paragraphs detail equipment which will be used to aid the astronaut during the performance of satellite servicing functions.

Tool Caddy - Two tool caddy concepts are presented as shown in the accompanying illustration (Figure 44a) to provide EVA crewman easy access to hand tools. The first is a sliding tray mounted on the side of the MMU unit between upper and lower thruster modules. The second is for use by crewman working in the Shuttle bay, and consists of a thin, transparent shell that can be rotated forward from behind the helmet. Tools would be mounted within the shell or on the outside. An alternative approach would be a tool caddy stored behind the helmet that would pivot up and then down in front of the crewman's helmet.

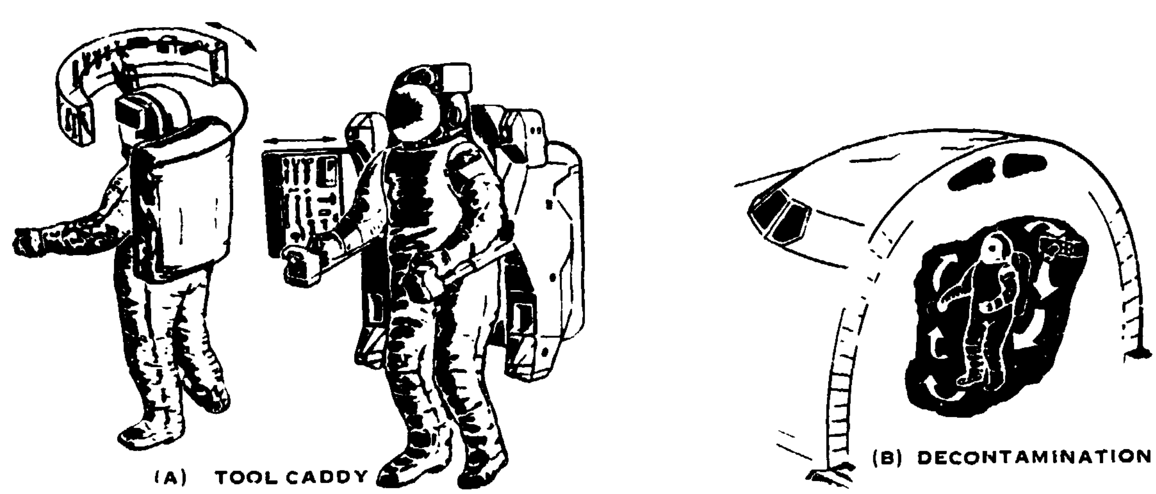


FIGURE 44. SATELLITE SERVICE WORK AIDS

6.5 (Continued)

Crewman Restraint - The concept involves an adjustable rigid restraint mechanism (stabilizer) that is part of the crewman MFR, POM and OCP. The adjustable restraint mechanism then attaches to fixed satellite restraint points, is adjusted and clamped in place to provide rigid crewman restraint during EVA work activities.

Restraint Attachment Points on Satellite - The proposed concept involves hot-melt adhesive-bonded adapters that can be bonded to work site surfaces and subsequently removed without scar. A bonding tool has been concepted for attaching such adapters at work sites where fixed adapters have not been provided. Crewman restraint mechanisms can then be attached to the bonded adapters to effect rigid crewman restraint.

6.6 SATELLITE SERVICE EMU

The following capability added to the existing Shuttle EMU would provide expanded crewman EVA satellite service capability:

- Automatic Visor - Multi-zone helmet visor or electronic goggles automatically responsive to sunlight intensity. Liquid crystal or bi-refrigerant solid crystal principles represent two possible approaches.
- High Tactility Glove - Suit glove incorporating improved dexterity joint construction, pin surface construction thermal protection and improved tactility.
- No-Vent Regenerable Heat Sink - Possible approach might be ice phase-change regenerable heat sink, which would involve no-venting of expendables. This type of EMU cooling would be used in servicing satellite payloads sensitive to contamination by water vapor.
- No-Prebreathe Requirement - This EMU suit would reduce time and simplify EVA preparation.
- Work Lights - Battery operated lights mounted on the crewman are concepted for use in remote EVA, including a compact spotlight located on the hand for fine-detail inspection.

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6.6 (Continued)

- TV Monitor - A portable TV monitor to provide a real-time visual data link to IV crew supporting the EVA task.
- Expanded EMU Computer - Convenient input/output access to the EMU computer can be achieved via a wrist terminal unit. The following additional computer capability is concepted:
  - Range-Rate-Spin Detector - Device for determining range, range closing rate and spin/tumble dynamics of target vehicles. The detector analog signal would be fed to the microprocessor for processing and display. Radar and laser techniques represent possible approaches.
  - Temperature Sensor - An IR sensor control can be located on the glove to provide an analog temperature signal for microprocessor processing and display. This capability would make surface temperature known before the crewmember touches it.
  - Voice Control - Voice control techniques could be used by the EMU microprocessor to allow the EVA crewmember to control the MMU by voice command. This would keep the hands free for other purposes.

6.7 SATELLITE SERVICE MMU

The following features are proposed to be added to the basic MMU propulsion unit to provide increased satellite service capability.

- Fully Retractable Control Arms - To permit closer approach to the service work site.
- Command Provision for the EMU Computer - In response to voice command signals.
- Quick Partial Recharge Capability - To permit refuel without doffing by the crewman to extend EVA time.
- Thruster Trim Provision - To account for variable center of gravity of MMU/EMU/WRU/Payload System.
- Higher ΔV - To permit retrieval of larger satellites via the manned MMU/WRU Proximity Operations Module (POM)

SECTION 7.0

EXTRAVEHICULAR MOBILITY UNIT (EMU) MODIFICATIONS

The Space Shuttle EMU has been designed to provide crew EVA productivity as well as maximum safety. The baseline design was selected so that the suit may evolve incrementally with mission requirements. By utilizing deliberate design parameters such as modularity, subsystem positioning and expendables management the EMU can be modified for anticipated use in any environment. The EMU areas which affect EVA satellite servicing are as follows:

- non-venting heat sink
- high energy battery
- increased microprocessor capability
- SSA joint improvements
- glove improvements

7.1 THERMAL CONTROL - NON-VENTING HEAT SINK

The current means of thermal control (i.e., water sublimator) prohibits the EVA astronaut from working within several feet of cryogenically-cooled sensors.

The EVA PLSS discharges water at a rate of 1.72 lb/hr. The water may condense onto cryogenically-cooled surfaces, impeding the performance of sensors. The MMU expends cold nitrogen gas and is essentially non-contaminating. The rate of propellant discharge is a function of each specific EVA sortie. In total, the propellant tanks contain 40 lbs of GN_2, is essentially benign (i.e., will not condense on surfaces) and does not present a contamination problem.

A number of non-venting heat sink concepts have been evaluated with results indicating that phase change materials (PCM), radiators, and hybrid systems containing both, offer the best alternative non-venting systems. Table X lists the pros and cons of each system while Figures 45 and 46 illustrate the two methods.

7.1 (Continued)

TABLE X.

	PROS	CONS
WATER PCM	AUTONOMOUS SYSTEM TECHNICALLY SIMPLE COMPACT RELIABLE EVOLUTIONARY MISSION FLEXIBILITY	SHIPBOARD REGENERATION
RADIATORS	NO SHIPBOARD REGENERATION TIME INDEPENDENT	POWER REQUIREMENTS MAINTAINABILITY LARGE VOLUME UMBILICAL REQUIREMENT WILL NOT WORK IN MANY AREAS REQUIRES SENSORS FOR ALIGNMENT COMPLEX CANNOT ENTER AIRLOCK EFFICIENCY TRADEOFF VS. ENVIRONMENT Δ°T CONNECTION IN VACUUM

7.1.1 Phase Change Materials (PCM)

Thermal storage is a regenerable thermal control concept that uses the heat of phase change and the heat capacitance of a material to provide thermal control. An example of a thermal storage material is ice. The heat of fusion of ice is 143.4 Btu/lb. A schematic of a typical thermal storage concept is shown in Figure 45. Water pumped through the thermal storage device is cooled to 40°F, and then flows to a three-fluid heat exchanger where it cools the LCG loop and the gas loop. The heated water is returned to the thermal storage device for recooling.

Based upon preliminary analysis, ice is thought to be the best thermal storage material for current systems, yet salts such as potassium bifluoride, KHF_2, offer promise for further investigation. A subsystem using ice has no moving parts, is not affected by the environment, does not require a heat pump, and has the smallest volume and lowest vehicle weight of non-venting heat sink concepts. The main disadvantages are that a cold (<30°F) source of cooling fluid is required in the vehicle for re-freezing the thermal storage material between EVA sorties.

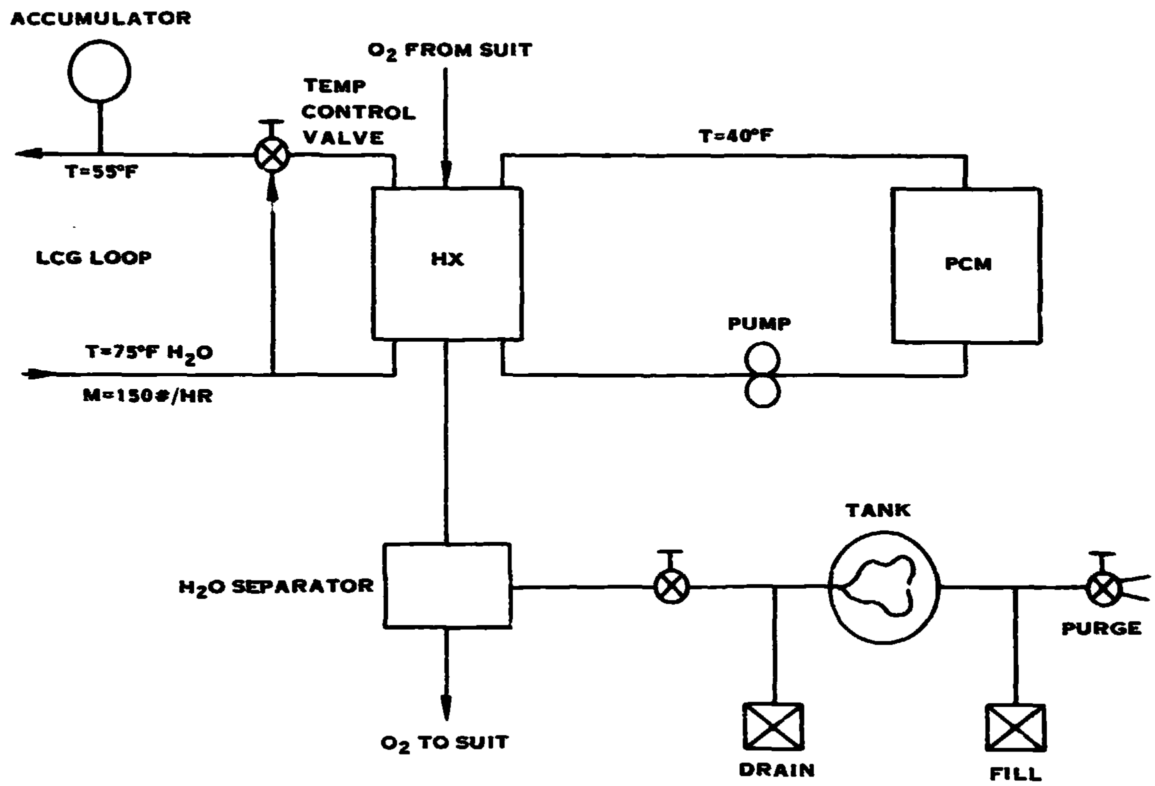


FIGURE 45. HEAT STORAGE WITH PHASE CHANGE MATERIAL

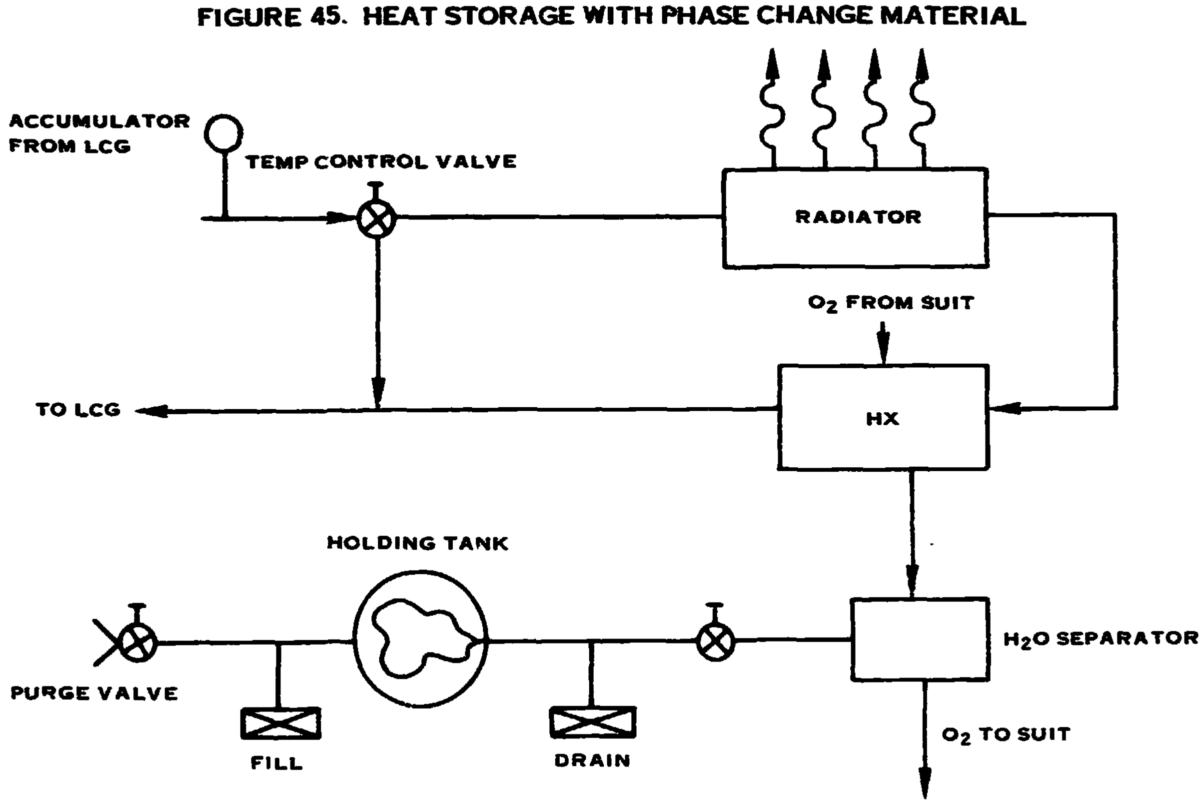


FIGURE 46. SCHEMATIC OF DIRECT RADIATIVE COOLING CONCEPT

7.1.2 Radiators

Direct radiative cooling is a non-expendable concept that dissipates heat to deep space. A schematic of a radiator cooling system is shown in Figure 46. For this system the LCG loop is cooled by the radiator. The cool LCG water then flows to the heat exchanger where the gas loop heat is dissipated. An automatic temperature control valve varies flow to the radiator to control temperature.

Since the radiator is sized for the nominal thermal load, prevention of over-cooling of the crewman and/or freezing of the LCG loop at low load conditions is required. Sizing is affected by the solar heat input, the structure temperature and view factor, the ground view factor, and the radiator values of emission and absorbtivity. Assuming no heat input from the environment and an emissivity of 1.0 (maximum), 15 square feet of radiator surface would be required to reject the peak heat load at 50°F. Examination of a potential LSS package shows that only about 8 square feet of surface area could be available. Examination of the current Shuttle suit shows that very little additional surface area could be used for radiators, as electrical equipment, moving joints, connectors, seals, and equipment that must be visually monitored or manually controlled take up the majority of the suit exterior surface, a situation expected to exist with an advanced suit. In addition, for environments such as the Shuttle Payload Bay, a radiator over 60 ft^2 would be required to handle the heat load.

As the surface area required for radiation is proportional to the 4th power of the "absolute temperature", a heat pump could be used to raise the radiating temperature. The accompanying figure shows a schematic of a heat pump system to raise the radiating temperature from 50°F to 90°F. This would reduce the radiator area requirement from 15 ft^2 to 13 ft^2, which is not a significant benefit. The reason that the area savings is so small is because the heat of the compressor must also be rejected by the radiator, thus increasing the heat rejection rate.

The largest unknown in the radiator subsystem is the heat picked up by the radiator from the structure on which the crewman in working. As the structures can be hot (up to +200°F) and will radiate in the infrared region, the radiator

7.1.2 (Continued)

may pick up heat instead of rejecting it. The uncertainty of structural heat pick up prevents radiators from being considered as the sole heat rejection means for non-venting satellite servicing work. Hybrid concepts which use radiators for nominal heat load rejection while supplemented by thermal storage material to handle peak loads have been investigated, yet invariably are much larger and more complex than utilizing a 100% PCM heat sink.

7.2 HIGH ENERGY DENSITY BATTERIES

The tasks required for satellite servicing demand the use of ancillary equipment as well as EMU modifications. The power source available to satisfy these needs must first have a high energy and density discharge rate and secondly, be practical enough so as to remain within reasonable cost limits. The current EMU utilizes a silver zinc-oxide battery energy source. Although satisfying all current requirements, this battery may prove too restrictive for satellite servicing.

The operational benefits obtained from eliminating prebreathe are highlighted by the savings of almost four hours of pre- and post-EVA preparation. The 8 psi system needed to allow almost immediate egress from the airlock brings with it an increased power requirement. This requirement may be fulfilled via two subsystems. The first subsystem utilizes the current silver zinc-oxide battery to handle the increased load, with the drawback of diminishing the recharge cycle life. The second subsystem requires developing the high energy density lithium battery types to replace the silver zinc-oxide. This second alternative offers potential benefits as are demonstrated in the following lithium battery analysis.

The following sections briefly outline the benefits of both primary Li/BCX and Li/SO_2Cl_2 cells and also secondary Li/TiS_2 cells, both of which appear to be viable alternative energy sources.

7.2.1 Lithium Bromine Complex - Li/BCX

The lithium bromine complex primary cells include a lithium based soluble cathode electrochemical system using a non-aqueous bromine complex electrolyte. Preliminary tests (acceptance and performance) conducted by NASA/JSC at White

7.2.1 (Continued)

Sands Test Facility (WSTF) indicate that the Li/BCX meets safety and performance criteria and warrants further development.

7.2.2 <u>Lithium Sulfuryl Chloride Cells - Li/SO_2Cl_2 - 93</u>

The lithium sulfuryl chloride - 93 battery differs from other lithium batteries by the depolarizer used. In the sulfuryl chloride battery, lithium aluminum chloride ($LiAlCl_4$) dissolves in sulfuryl chloride, thereby forming the electrolyte. This electrolyte also contains a small amount of chloride which seems to modify the cells discharge, and consequently improves cell performance at high discharge loads. In addition to this, the chloride barrier on the electrodes aids in storage life, providing up to 15-year storage life - as compared to the 90-day silver zinc-oxide storage life.

The Li/SO_2Cl_2 battery will provide up to twice the energy density of the Ag/Zn and could accommodate the added power load of an 8-psi system, non-venting thermal control, and ancillary equipment. Whereas further development testing is required, the Li/SO_2Cl_2 battery should receive serious consideration as an alternative to Ag/Zn.

7.2.3 <u>Lithium Titanium Disulfide Cells - Li/TiS_2</u>

Secondary lithium batteries possess the advantages of primary lithium batteries and additionally provide many charge/discharge cycles (potentially up to 10x those of Ag/Zn). Long-term projections of satellite servicing activity indicate that secondary energy sources must be used, otherwise, expense in weight and volume would be astronomical.

The technology in this area is rapidly advancing to a stage where lithium recharge efficiencies have reached 97%. (This has characteristically been a problem, driving the search for more efficient electrolyte solutions.)

The laboratory Li/TiS_2 cell has been shown to provide 100 charge/discharge cycles and new technology cathodes aim to provide over 1000 cycles. The battery volume may be reduced substantially should only 50 cycles be required. Even with reduced cycle life, the Li/TiS_2 batteries provide both longer life and higher energy density/rate than current Ag/Zn batteries.

7.3 INCREASED MICROPROCESSOR CAPABILITY

EMU improvements currently under development call for increased microprocessor capabilities, providing increased control and monitoring capabilities for the EMU. Benefits derived from increased microprocessor capability are discussed below.

7.3.1 Large Scale Integration

Current research involves the use of large scale integration in the development of chip assemblies. Increased integration will decrease the number of chip assemblies required (i.e., 4 or 5 required chips will be reduced to 1 or 2 chips).

7.3.2 Improved Memory Capability

Microprocessors currently in use contain read only memories (ROM). These units are preprogrammed at the time of their construction resulting in a chip that is inflexible to program modifications. Program modifications must be effected via construction of a new chip, a process which currently takes up to one year.

Industry is currently involved in the development of a programmable ROM. This chip assembly has the capability of being programmed and constructed via in-house operations. Construction time of the programmable ROM will be reduced from the current one year time frame to several months.

7.3.3 Increased Memory Capabilities

The current microprocessing unit of the EMU has a maximum 8K byte memory. Development is currently being undertaken to increase the memory up to a maximum of 32K bytes. Increased memory capabilities will allow for the use of higher programming language, making the unit more compatible with simulators. In addition, the higher program language will aid in debugging operations, since programming problems will be relatively smaller.

Development is also being undertaken at the present time to make the 32K byte memory expandable to 64K bytes. This will be accomplished through the use of a new family of chips, or by design modifications to the current box housing to extend the box size.

The EMU microprocessor capability is devoted to the optical coupler link with the MMU at the present time. This link provides for monitoring of the MMU ex-

7.3.3 (Continued)

pendables (GN_2), thruster performance and battery power capabilities. The control logic employed in the development of the EMU/MMU interface may be ex-panded in order to provide control and monitoring capabilities to equipment that is compatible with the EMU/MMU. This would be most applicable to equip-ment components such as the manned proximity operations module (POM) in which monitoring of expendables would play a critical role.

7.3.4 Voice Control

Recent research has demonstrated the feasibility of using voice data input into computers in order to initiate a command. For satellite servicing, the use of such a system would allow the astronaut free use of both hands while monitoring functions and attitude control functions by use of verbal command. For example, specific benefits may be gained for equipment such as:

- EMU - An increased capacity computer memory houses a voice synthesis/ voice recognition system whereby the computer verbally instructs the astronaut as to life support systems status, external environment, and communications. This system would eliminate the need for the Display and Control Module (DCM) as well as provide two-handed work capability.
- MMU - By synchronizing the voice recognition system to the MMU micro-processor, the astronaut would enjoy the freedom of verbally controlling attitude control and again free the use of both hands.
- Satellite Repair - As satellite payloads become more varied and complex, the crewmember will require supplementary information. By providing disc cassettes for each satellite to guide the crewmember through repair scenarios and operational status norms, the computer will allow the crewmember to avoid memorizing many specific specs, designs, etc., and allow him to concentrate on other aspects of ensuring mission success.

7.4 PRESSURE ENCLOSURE DEVELOPMENT ISSUES

The following areas of the pressure enclosure require emphasis:

7.4 (Continued)

- Joints
- Bearings and intermodule connections
- Entry closure
- Fabric module construction
- Leg mobility issues

These areas are discussed in turn in the following pages.

7.4.1 Joints

Four basic joint types have been developed for EVA enclosures to date. They are:

- Flat Pattern
- Rolling Convolute
- Toroidal
- Stove Pipe

7.4.1.1 Flat Pattern Joints

These joints represent a low cost joint construction adequate for the Shuttle EMU program, which requires a joint life of 7,000 to 100,000 cycles, depending on the particular joint, at 4 psig operating pressure. These joints are constructed of flat, gore shaped fabric sections which are stitched together and sealed at the seams. When the joint is flexed, the fabric on the inside of the bend is allowed to pucker.

This concept (shown in Figure 47, achieves high mobility and low bulk, and is very inexpensive to manufacture. It is also highly resistant to impact damage. The chief disadvantage for long-term EVA use is life. It is doubtful if these joints can be developed for the 5,000,000-cycle life required for long-term satellite servicing use.

7.4.1.2 Rolling Convolute Joints

This joint consists of a single convolute bellows construction, in which the bellows rolls over the hard end-section as the joint is flexed.

This concept (shown in Figure 48) achieves high mobility, and is amenable to stepped or tapered construction, which is desired for shoulder joints. The chief disadvantages are that it is bulkier and is more impact sensitive than other concepts.

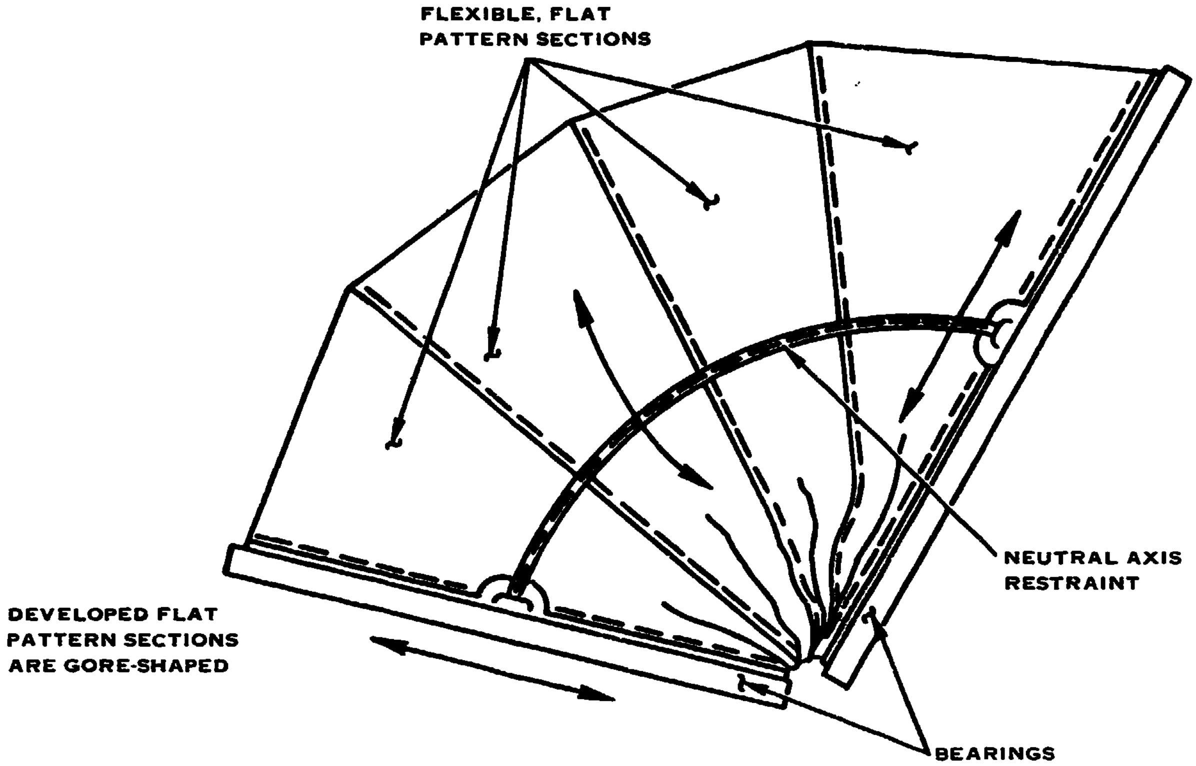


FIGURE 47. FLAT PATTERN JOINT

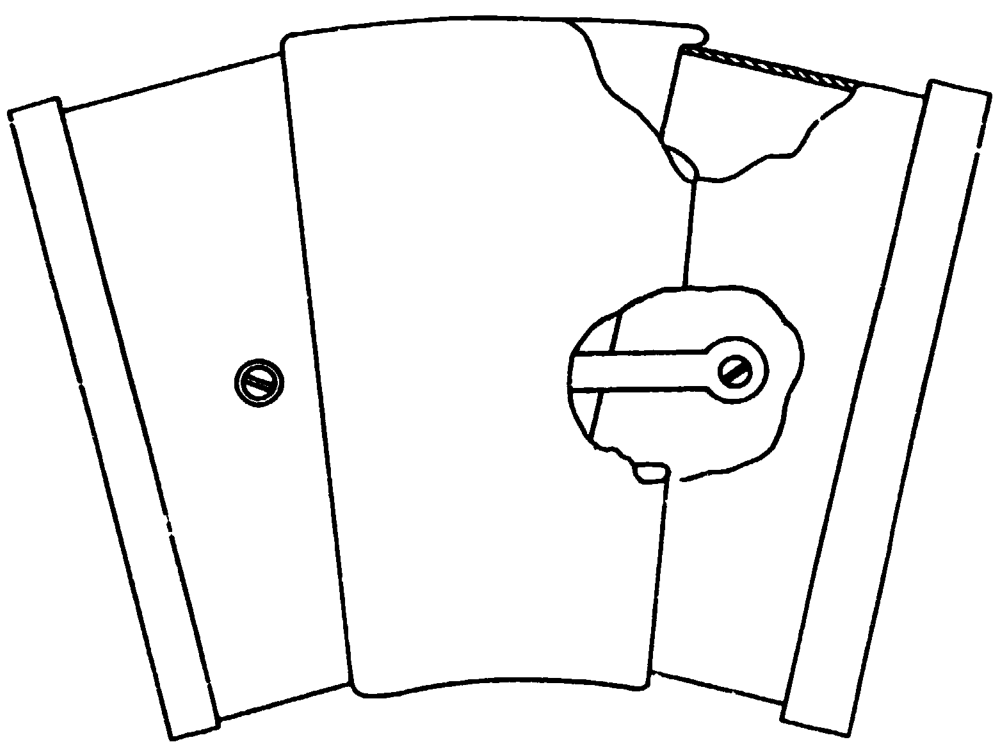


FIGURE 48. ROLLING CONVOLUTE JOINT

7.4.1.3 Toroidal Joints

This joint resembles a wire-reinforced molded bellows. External wire-ring elements keep the minor diameter portions from ballooning under pressure, and internal wire-ring elements keep the minor diameter portions from collapsing under flexion. When the joint is flexed, the excess material on the inside of the bend is accompanied by a radial shift between the internal and external wire ring elements, which increases the difference between the major and minor radium, thus "swallowing" the excess material. On the outside of the bend the radial shift decreases the difference between major and minor radii, thus releasing material longitudinally to follow the longer outside curve. The toroidal joint flexes without puckering, which contributes to its long life and excellent flexibility. The toroidal joint is shown in Figure 49.

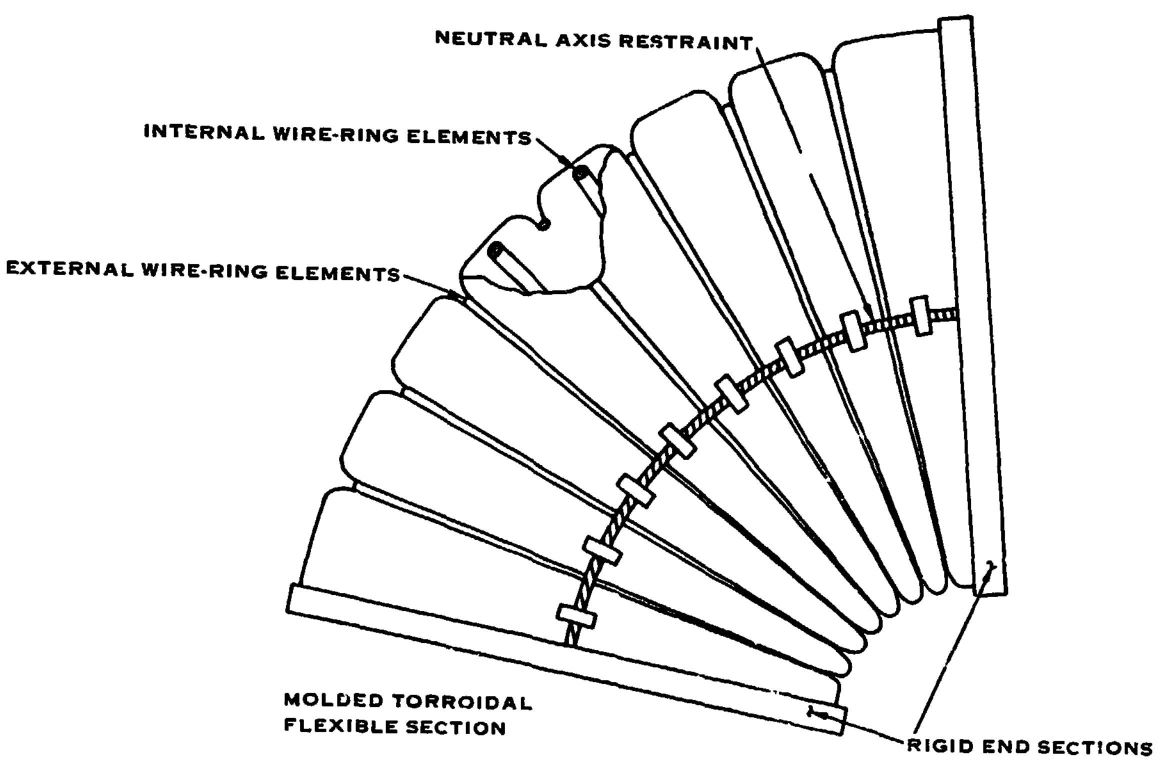


FIGURE 49. TORROIDAL JOINT

The advantages of this concept are its very high flexibility and potential for long life. It is also very stowable, and has high impact resistance.

The chief disadvantages are it is of molded construction and its bulk. It is a long joint when used for sharp bends.

7.4.1.3 (Continued)

The chief disadvantage for shoulder joint use is that it cannot be made tapered, because tapered toroidal joints tend to "bunch up" at the small end, owing to the area differential between the large and small ends, causing a loss of flexibility and mobility range. However, research is currently being conducted to remedy this situation.

7.4.1.4 Stove Pipe Joints

These joints consist of obliquely-truncated cylindrical or conical elements, joined together by sealed bearings. Flexure is achieved by rotating the adjacent sections relative to one another. Flexure occurs when the force producing the flexure is resolved by the obliquely-mounted bearings causing the adjacent sections to rotate. An example of a stove pipe joint is shown in Figure 50.

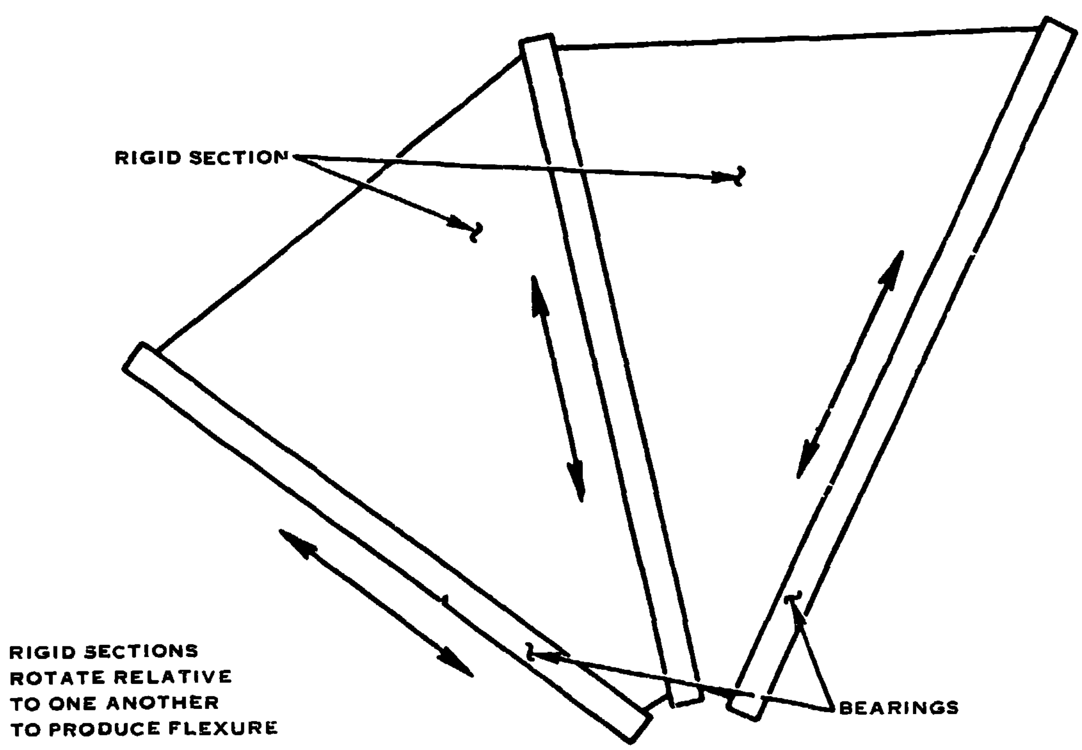


FIGURE 50. STOVE PIPE JOINT

7.4.1.4 (Continued)

The advantages of this joint concept are its extremely long life, low cost, and the fact that it can be made in a tapered configuration, a singular requirement of shoulder joints, in that a minimum bulk design is desired. The scye bearing at the chest wall is large, to permit donning and doffing, while the upper arm bearing is smaller, to permit the arms to hang down freely, unencumbered by a large bearing diameter over the biceps.

The disadvantages of this concept are that the joint sections must be carefully designed to avoid "lock up", a configuration in which the flexion motion cannot be resolved to produce rotation. This requires subsequent programming of the motion sequence to free the joint. Current designs minimize this problem by employing at least three bearings. In addition, impact resistance must also be considered in the design because of the potential for knocking the sections out-of-round, thus restricting the relative rotation of adjacent joint sections.

7.4.2 Joint Recommendations

The toroidal joint is the recommended implementation for most EMU EVA enclosure joints, including the waist. The singular exception is in the shoulder, where a tapered configuration is required to reduce on-the-person volume.

The recommended development program for toroidal joints is to demonstrate 5,000,000-cycle life at 8 psig, and to reduce the manufacturing cost.

The recommended development program for the shoulder stove pipe joint consists of refining the design to minimize the motion-programming requirement, and to ruggedize the joint for impact resistance.

7.5 EVA GLOVES

EVA gloves are the active interface between the EVA crewman and the work being performed. All manipulative tasks performed with body forces and motions are performed through the gloves, and the tactile sensation used to control the motions are fed back through the gloves. Accordingly, EVA gloves must provide a proper balance of mobility, tactility, comfort and protection from workplace hazards to support the particular requirements of EVA work.

7.5 (Continued)

Present NASA EVA glove designs were not designed for heavy work, such as EVA construction, but rather were designed to meet payload support requirements or to demonstrate the particular design features required to meet 8 psig or 14.7 psig operation. They feature good comfort and mobility are acceptable for minimal satellite servicing activity but are either too light to support EVA construction work or are too bulky to permit comfortable, long term use of hand tools.

The design challenge of EVA gloves is to combine comfortable use with protection from workplace hazards, while performing the full range of EVA tasks. Representative EVA tasks are as follows:

- Position and replace equipment modules on satellites.
- Perform maintenance, repair and replenishment of expendables.

Manual tasks associated with the EVA glove activity will include:

- Using tools for mechanical assembly, welding or fuse bonding.
- Using supplies for cleaning and servicing.
- Manually opening payload access panels and/or operating payload controls.

7.5.1 EVA Glove Requirements

The following requirements define the basic performance and operating requirements to guide the concepting of EVA gloves.

7.5.1 (Continued)

1. General

EVA gloves shall protect the crewman's hands during EVA, retaining suit pressure, while permitting the crewman to perform all manual EVA tasks. The gloves shall flex in a natural manner.

2. Hand Motions

The EVA glove shall permit hand motions typified by the following:

- Finger twirling as required to engage mechanical fasteners and turn finger-tight. Minimum object diameter is expected to be 0.5 inch (1.3 cm).
- Finger-palm grip and wrist rotation, as required to tighten a fastener with a screwdriver. Minimum tool handle diameter is expected to be 1.0 inch (2.5 cm).
- Palm grip with forearm rotation, as required to torque a fastener with a ratchet wrench.
- Delicate grip with thumb and index finger, as required to position a wiring harness.
- Moderate grip with thumb and all fingers, as required to grasp solid objects such as wave guides.
- Hard grip with thumb and all fingers against the palm, as required to turn a turnbuckle or crank.
- Outstretched palm and fingers are required to push a large object away.

3. Mobility

The following specific motions shall be required:

	Range	Torque (ft. lb)
Wrist - flexion, extension, abduction	±60°F	0.5
adduction	±30°	0.5
Fingers - first metacarpal flexion	90°	0.1

7.5.1 (Continued)

	Range	Torque (ft. lb)
Thumb - first metacarpal flexion, extension	±30°	0.1

Thumb and fingers shall be capable of opposition. Other finger and thumb joints shall be capable of flexion to complete the grasp of a 0.5-inch diameter object.

4. Cycle Life

The EVA glove shall have a cycle life of 500,000 joint cycles. This is consistent with such requirements as one 180-day mission, with EVA usage as follows:

$$\frac{\text{6 Joint Cycles}}{\text{Min.}} \times \frac{\text{60 Min}}{\text{Hr.}} \times \frac{\text{8 Hours}}{\text{EVA Sortie}} \times 154 \, \frac{\text{EVA Sorties}}{\text{180-Day Mission}} = 433{,}520 \, \frac{\text{Cycles}}{\text{Mission}}$$

5. Temperature Environment

-180°F to +200°F at an application pressure of 2.0 psi for two minutes. Occassionally there will be a requirement to handle objects as hot as 450°F.

6. Leakage

The glove leakage shall not exceed 5 scc/min at 4 psig.

7. Pressure Level

Mobility requirements shall be met at 8.0 psig.

8. Radiation Protection

The EVA glove shall meet the following schedule of radiation shielding requirements:

Orbit Inclination;°	28 1/2		55		0
Altitude, KM	40	500	400	500	36K
Shield Requirements gm/cm^2	0.1	0.3	0.5	0.7	1.2

9. Sizing

The following factors shall be considered relative to crewman comfort during repetitive, EVA use:

7.5.1 (Continued)

- Glove and human joint centers shall coincide.
- The EVA glove shall be free of pressure points and chafe areas.
- The EVA glove design shall consider sizing to fit a large segment of the population, for example 5th to 95 percentile male and female crew members in the 1985 time frame.
- On-orbit sizing shall include the provision for changing the wrist-to-palm segment length to accommodate changes in arm and shoulder fit.

10. Wrist Disconnect

The EVA glove shall be connected to the EVA enclosure forearm via a quick disconnect of the type used in the Shuttle EMU.

The thermal design basis of an EVA glove concept should include:

- The human body strives to maintain blood temperature at 98.6°F. The comfortable hand skin temperature range is 83 to 84°F.
- Discomfort is produced commensurate with the departure of the hand skin temperature from the comfortable range.
- The maximum level of discomfort that can be sustained for two minutes or more corresponds with high and low hand skin temperatures of 113°F and 50°F. These are the limits to be used for EVA glove design. Beyond these limits the discomfort (pain) increases very rapidly, permitting only short exposure durations. For example, one can withstand a hand temperature of 120° for only approximately 12 seconds.
- Glove insulation design is driven by the +200°F surface touch temperature requirements.
- On the basis of the above, using an assumed glove laminate wall thickness of 0.030 inch (< 1 mm), an uninsulated glove would protect against a maximum surface touch temperature of only 115°F. Thus, a practical EVA capability requires that insulation be provided at all times. This is a driving consideration in concepting the insulation as an integral, inseparable part of the glove wall laminate.

7.5.1 (Continued)

- Thermal radiation requirements would be met by including radiant reflective layers within the laminate, thus providing thermal radiation protection over the entire glove surface.
- The requirement to handle objects occasionally at +450°F would be met by using a protective mitten.

The EVA glove design concept is shown in Figure 51.

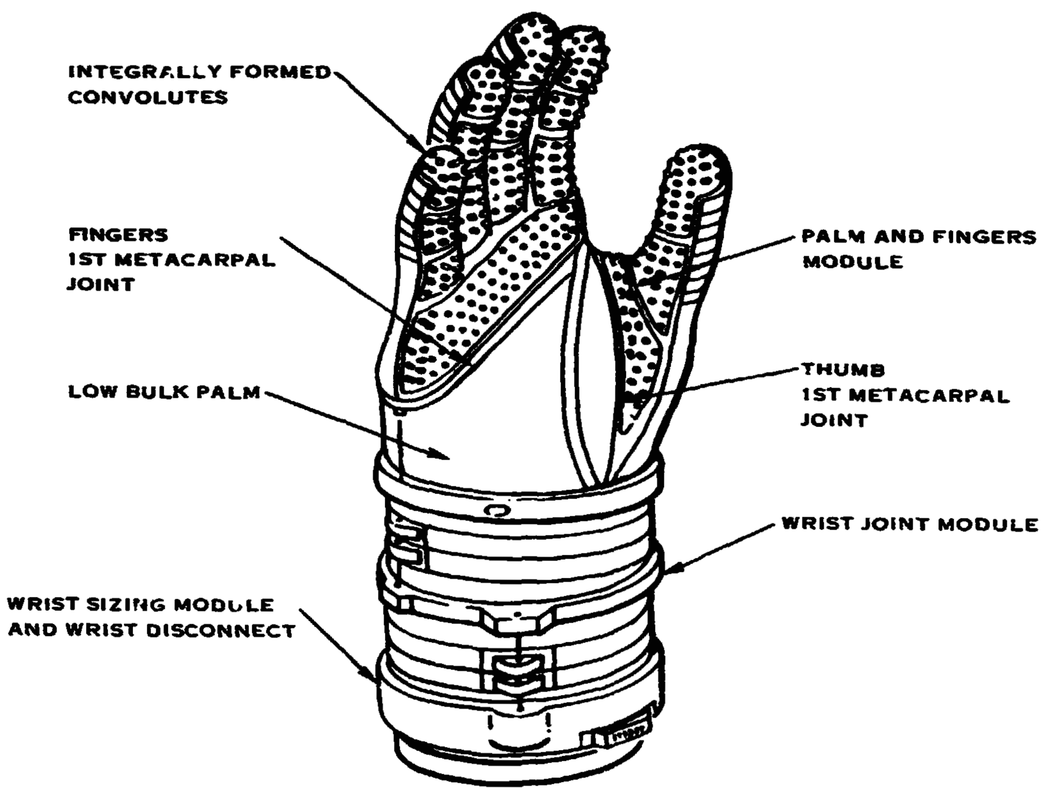


FIGURE 51. GLOVE DESIGN CONCEPT

7.5.2 Workplace Hazards

Workplace hazards subject the EVA glove to damage from cutting, puncture and abrasion. Laminated fabric construction exhibits good intrinsic abrasion resistance when the fabric can deflect and "flow" over the rough surface, without snagging on small projections, in much the same way as a rubber boat slides over a sandbar in shallow water, or incurs minimal damage with repeated beachings.

7.5.2 (Continued)

Resistance to puncture and cutting can be improved by imbedding bands of fine wire mesh within the laminated structure. The mesh would be confined to the interjoint areas of the fingers, palm and back of the hand, and left out of the joint areas, so as to retain the joint flexibility. This construction is analogous to steel-belted radial tires, in which the wire mesh belts protect the treads from penetration, but retain the flexibility of the sidewalls. The insulation pins also contribute to workplace hazard protection by standing the glove wall away from burrs and splinters on the work surfaces. In addition, the pins themselves offer an abrasion-sacrifice surface.

By coloring the outer layers of the EVA glove lamination in highly contrasting colors, surface damage can be made highly visible, with the depth of damage being indicated by the color of the layer exposed. Layer thicknesses would be designed to reveal superficial surface damage before significant structural or thermal properties degradation occurs. Thus, a worn out or damaged glove module would be replaced before it becomes unsafe to use. This is analogous to the tread wear bars in automobile tires that signify tire replacement when only 2/32 in. of tread remains.

UNITED TECHNOLOGIES HAMILTON STANDARD

SECTION 8.0
HAZARDS ANALYSIS

The equipment identified for EVA use during the eight (8) key satellite servicing scenarios was examined in order to determine the extent to which the astronaut is expected to interface with each piece of equipment. Based upon the type and duration of astronaut interfaces and the operational mode in which the equipment is used (initial launch, revisit, or earth return) an analysis of any hazards associated with the use of each piece of equipment was undertaken.

Table XI presents a listing of equipment components with which an astronaut may interface during EVA activities. For each piece of equipment listed in the table, the component location and/or area in which the component will be used has been identified along with the operational mode associated with the component. A detailed analysis of potential hazards (if any) associated with the use of each piece of equipment is also presented in the table. A hazard analysis has been performed for both the nominal and optional equipment components. The hazards identified for the Grumman Aerospace Corporation equipment are described below.

- Sharp Edges, Protruding Fixtures

  Protruding fixtures must be approached with care so as not to puncture or interfere with the EMU.

- Radiation

  Prolonged exposure of the EVA astronaut during passes through the South Atlantic Anomaly should be avoided.

- Temperature

  For all cases, temperatures which exceed the EMU limit of -170°F to +200°F must be handled by use of thermal protection garments or work restriction areas.

TABLE XI. EQUIPMENT COMPON

EQUIPMENT COMPONENT	COMPONENT LOCATION/USAGE	OPERATIONAL MODE	SHARP EDGE PROTRUDING FIXTURES	RADIATION	TEMPERATURE	CONTAMINATION	SPRING RELEASE	DEBRIS	MATING/BREA VACUUM CONNECTION	ELECTRO-MAGNETIC	ATTITUDE CONTROL
Retention Structure	Within The Payload Bay	Initial Launch Earth Return	X				X				
"Special" Retention Structure	Within The Payload Bay	Initial Launch Earth Return	X				X				
Equipment Storage Provision	Within The Payload Bay Close To The Orbiter	Revisit Earth Return	X		X						
Fluid Transfer System	Within The Payload Bay Close To The Orbiter	Revisit				X			X		
Tilt Table	Within The Payload Bay	Initial Launch Revisit Earth Return	X		X		X				
Spin Table	Within The Payload Bay	Initial Launch	X		X		X				
Payload Installation And Deployment Aid (PIDA)	Within The Payload Bay Close To The Orbiter	Initial Launch Earth Return	X					X			
Remote Manipulator System (RMS)	Within The Payload Bay Close To The Orbiter	Initial Launch Revisit Earth Return	X		X						
Open Cherry Picker (OCP) Tilt Table Work Platform	Within The Payload Bay	Revisit Earth Return	X		X	X					
OCP/RMS	Within The Payload Bay Close To The Orbiter	Revisit Earth Return	X	X	X	X		X		X	
Manipulator Foot Restraint (MFR) MFR/RMS	Within The Payload Bay Close To The Orbiter	Initial Launch Revisit Earth Return	X		X						
Proximity Operations Module (POM) Manned Version	Within The Payload Bay Close To The Orbiter Near The Orbiter	Revisit Earth Return	X	X	X	X					X
Versatile Service Stage (VSS) VSS - Delivery/Retrieval	Within The Payload Bay Close To The Orbiter Near The Orbiter	Initial Launch Revisit Earth Return	X	X	X	X				X	X
VSS - End Effector Kit	Within The Payload Bay Close To The Orbiter Near The Orbiter	Revisit Earth Return	X	X	X	X				X	X
VSS - Debris Capture Kit	Within The Payload Bay Close To The Orbiter Near The Orbiter	Earth Return	X	X	X	X		X		X	X
Aft Flight Deck (AFD) AFD - RMS Control AFD - Satellite Checkout AFD - Close Proximity Flight Control	Within The Shuttle Cabin	Initial Launch Revisit Earth Return									

FOLDOUT FRAME

COMPONENT USAGE/HAZARD ANALYSIS

OPTIONAL EQUIPMENT COMPONENTS	COMPONENT LOCATION/USAGE	OPERATIONAL MODE	SHARP EDGE PROTRUDING FIXTURES	RADIATION	TEMPERATURE	CONTAMINATION	SPRING RELEASE	DEBRIS	MATING/BREAK VACUUM CONNECTIONS	ELECTRO-MAGNETIC	ATTITUDE CONTROL
Sun Shield	Within The Payload Bay	Initial Launch		X	X						
Orbital Storage	Within The Payload Bay Close To The Orbiter	Initial Launch Revisit	X	X	X	X				X	
Attitude Transfer Package	Within The Payload Bay	Initial Launch Revisit Earth Return				X					X
Lighting Enhancement	Within The Payload Bay Close To The Orbiter Near The Orbiter	Initial Launch Revisit Earth Return									
Manned Maneuvering Unit (MMU) Work Restraint Unit (WRU)											
MMU/WRU With RMS End Effector	Within The Payload Bay Close To The Orbiter	Initial Launch Revisit Earth Return	X	X	X	X		X		X	X
Proximity Operations Module (POM) MTV Adaptation	Within The Payload Bay Close To The Orbiter Near The Orbiter	Revisit Earth Return			X						X
Handling And PositioningAid (HPA)	Within The Payload Bay Close To The Orbiter	Initial Launch Revisit Earth Return	X	X	X						
Non-Contaminating Attitude Control System (ACS)	Within The Payload Bay Close To The Orbiter	Revisit Earth Return				X					
Maneuverable Television (MTV)	Within The Payload Bay Close To The Orbiter Near The Orbiter	Initial Launch Revisit Earth Return									
MMU/WRU With Stabilizer	Within The Payload Bay Close To The Orbiter	Initial Launch Revisit Earth Return	X		X						X
MMU/WRU With Payload Handling	Within The Payload Bay Close To The Orbiter	Revisit	X		X		X				X
MMU/WRU-Proximity Operations Module (POM)	Within The Payload Bay Close To The Orbiter Near The Orbiter	Revisit Earth Return	X	X	X	X					X

FOLDOUT FRAME

2

8.0 (Continued)

- Contamination

  A major concern for revisit satellite servicing lies with contamination. Whereas most contaminants will vaporize once in vacuum, various fluids such as freon will be dangerous if placed near the EMU helmet.

- Spring Release Mechanisms

  For satellite deployment and various appendage deployment, the automated mode consists of a spring-loaded mechanism which may be manually actuated should malfunction occur. The force exerted by the spring must not exceed the astronaut's stability force and the deployed structure should avoid striking the astronaut.

- Debris

  Debris could cause safety problems should an astronaut be required to interface with it. The debris will require unique operational cautions for both the crewmember and the Shuttle. However, if possible, debris should be handled via mechanical means.

- Attitude Control

  The MMU operates on an essentially benign gas, GN_2, and will not pose a contamination problem. The MMU guidance system must be operating flawlessly to provide safe transversal to and from work sites.

- Equipment Restraint Tethers

  Video recordings of satellite servicing performed on a mockup of the space telescope during WIF tank testing has revealed that tool restraint tethers can interfere with the astronaut's ability to perform a repair task. The restraint tethers have the tendency to wrap around the astronaut's arms, placing unwanted restrictions on the astronaut's reach envelope. The number of restraint tethers required for satellite servicing equipment should be minimized so as to place minimal restrictions upon the astronaut. This minimal number of restraint tethers can best be determined through satellite servicing simulation testing (i.e., WIF tank).

SECTION 9.0

CREW TRAINING

Crew training for satellite or payload servicing is an extension of crew training for EVA currently in practice. EVA training is currently concerned with three broad areas as follows:

EMU	Pre and post procedures, EVA operation and malfunction procedures.
MMU	Integration and service from FSS, MMU operation and malfunction procedures.
EVA TASKS	Performing contingency tasks identified to date; namely payload bay door closure, payload bay door latching and RMS cradling. Satellite servicing tasks will become additional EVA tasks as they are identified.

Each of these areas may be standardized to an extent where crew training time is reduced due to reduced time required for understanding procedures and specific tasks, creating standardized crew training equipment and flight operations procedures. Although not defined quantitatively, this interpretation leads to cost savings in addition to training standardization.

9.1 TRAINING FACILITIES AND AIDS

Crew traing uses the following facilities and training aids:

Classroom	Hands-on demonstration of EVA equipment.
Workbook	Programmed learning materials to instruct in construction functions and operations of EVA equipment.
Malfunction Simulator	Computerized input to caution and warning systems to communicate simulated problems and problem-management references.
1-g Orbiter Trainer	H-Fi mockup of orbiter cabin and airlock, used for procedure development and walk-thru.

9.1 (Continued)

11 Ft Altitude Chamber	High vacuum chamber for training on use of the EMU.
Weightless Environment Training Facility (WETF)	Water tanks in which payload EVA scenarios are developed and practiced. These will be the major training facilities for payload service EMU tasks for developing both use of support equipment and tools and practicing payload servicing techniques. A WETF located at Johnson Space Center (JSC) contains a full mockup of the Shuttle payload bay. This unit will allow testing and training for donning and doffing of the MMU, and will simulate the use of EVA handrails and work platforms.
Communication Facsimile	A hardline version of the EMU radio to permit 2-way communication between training direction and EVA subject.
MMU Simulator	A 3-axis, 6 degree of freedom simulator located at Martin Marietta Corporation, Denver which simulated hands-on flying of the MMU. The facility simulates MMU controls and displays, and physically translates and rotates a suited or unsuited training subject in response to control inputs from the training subject.
MFR-OCP Simulator	Large Amplitude Space Simulator (LASS), a 3-axis, 6 degree of freedom simulator located at Grumman Aerospace Corporation, which simulates the dynamic motion of the RMS on orbit and the foot restraints and operational servicing procedures involving the MFR and the OCP.

9.1 (Continued)

K-Bird	A Boeing KC-135 aircraft, based at Ellington Air Force Base, Texas used to fly 0-g parabolic flights. These are used to verify EMU don and doff procedures and to train for 0-g don and doff, which cannot be done in the WETF.
ETA Altitude Chamber	A vacuum simulator of the orbiter cabin and air-lock for training in cabin and airlock procedure at equivalent flight altitudes.

9.2 TRAINING TIME

The crewmember will already be trained in the use of the EMU, and will be trained in use of the MMU if the MMU is required for the payload service scenario. Payload service equipment of complexity comparable to the EVA contingency tools will require approximately the same number of total hours for training. Complex payload service equipment is expected to require several rounds of WETF use and approximately double the workbook and classroom time as the sequences shown below:

1.	Workbook on payload service equipment	2 hrs*
2.	Workbook on payload service procedure	2 hrs*
3.	Classroom on service procedure and equipment	3 hrs
4.	WETF run using scuba gear to practice procedure and use of tools	2 hrs*
5.	WETF familiarizations run using EMU to practice procedure	3 hrs*
6.	WETF run using EMU to practice 1-man contingency procedures	4 hrs
7.	WETF run using EMU to practice 2-man contingency procedures	4 hrs
8.	WETF payload EVA to practice payload service	4 hrs*
9.	WETF payload EVA to practice payload service	4 hrs
	Minimum estimated training time, exclusive of pre and post overhead per EVA crewmember for payload servicing	28 hrs

* Times expected to increase for complex servicing.

9.2 (Continued)

These estimated training times are those felt to be minimal for the simplest of servicing efforts. As specific servicing missions become better defined and simulations take place, a more specific estimate of individual training time can be made. It is recommended that "training records" be kept of these activities to establish baselines for estimating future servicing needs. However, due to the standardization of tasks involved in the satellite servicing scenarios (i.e., redundancy of common steps), successive crew training required for accomplishing the service scenarios will likely be minimized. A review of the satellite servicing scenarios detailed in the appendices of this study illustrates the repetition of tasks involved.

SECTION 10.0

EVA BENEFITS ASSOCIATED WITH THE EMU

Apollo and Skylab missions have demonstrated that EVA can be used as an effective technique for performing tasks associated with repair, maintenance and construction. Modifications to the EMU and support equipment that will benefit satellite servicing are described in the following:

Extravehicular Mobility Unit

8 PSI EMU - By increasing the suit internal pressure from 4 psi to 8 psi the requirement for prebreathing will no longer exist, thereby saving over 3 hours of crew time for each EVA sortie.

Non-Venting Thermal Control Subsystem - Eliminating the venting of consumables (specifically water vapor) will allow the crewmember to service contamination sensitive payloads. This expands the scope of satellite servicing to include all types of LEO satellites.

Automatic Visor - Consider a scenario in which a crewmember performs satellite servicing in an environment which constantly places the astronaut in varying illumination.

The necessity of manually flipping the extravehicular visor assembly (EVVA) requires the free use of one hand, in turn disrupting the flow of the satellite servicing mission. Replacing the EVVA with an automatic visor assembly would provide the benefits of continuous satellite servicing capability (i.e., no illumination distraction, continuous two handed operation).

Work Light - The battery operated EVA work lights provide the capability of conducting any task within a 10 ft. (3m radius). Development in technology areas of light amplification devices indicate potential for EVA use. The benefits this creates include removal of the current EVA work light system and eliminating bulky lighting structures currently designed onto such devices as the Open Cherry Picker.

Expanded EMU Computer - Increased computer capability provides the following benefits:

10.0 (Continued)

- Temperature Monitor. This allows the crewmember to know the surface temperature of an object before he touches it, ultimately affecting productivity (time saved due to indecision) and crewmember safety.
- Voice Control. This includes both voice synthesis (preprogrammed allows elimination of visual displays) and voice recognition systems (active - allows voice command and elimination of control mechanisms). Voice control allows the EVA crewmember to control the MMU by voice command and keep his hands free for other purposes. In addition, voice control of the EMU life support system would eliminate the displays and control module (DCM) - providing both a smaller front-to-back EMU dimension (crewmember can increase effective arm reach length) and an instantaneous life support function monitor system. Benefits include time saved by allowing uninterrupted task operations in both crewmember concentration and two-hands capability.
- High Energy Battery. The major benefit provided by increased energy density power sources are in flight weight and volume. A high energy battery would reduce current battery sizes as well as allow more demanding power loads and longer cycle life. This will expand the range of satellite servicing tasks and the range of ancillary equipment for iterative tasks (i.e., removing many bolts, etc.).
- Power Tool. The Space Telescope satellite servicing DDT&E program has demonstrated, among many things, the fatigue level associated with routine removal of spacecraft modules. The results indicate that the crewmember becomes fatigued before task completion to the extent where productivity is adversely affected. The use of a power tool for satellite servicing will allow both quicker replacement of spacecraft modules and reduced crewmember exertion - each increasing crewmember productivity.

10.0 (Continued)

The benefits associated with EMU modifications will become more apparent as satellite servicing tasks expand in frequency and complexity. One point remains clear - each modification has a good potential of increasing effective utilization of EVA timeliness providing subsequent cost savings by (1) allowing more work to be completed within a satellite servicing sortie or by (2) shortening the total mission time.

SECTION 11.0
TECHNOLOGY PLAN

Hardware procurement for EVA capability equipment will require the following steps in general:

- Concept

  Identify requirements
  Identify concepts
  Evaluate and select concept
  Develop technology to support design of selected concept
  Manufacture and evaluate prototype

- DDT&E

  Design
  Develop - hardware, software, interfaces, procedures
  Test
  Evaluate - WIF, Test Chamber, K-Brid, Flight

- Manufacture

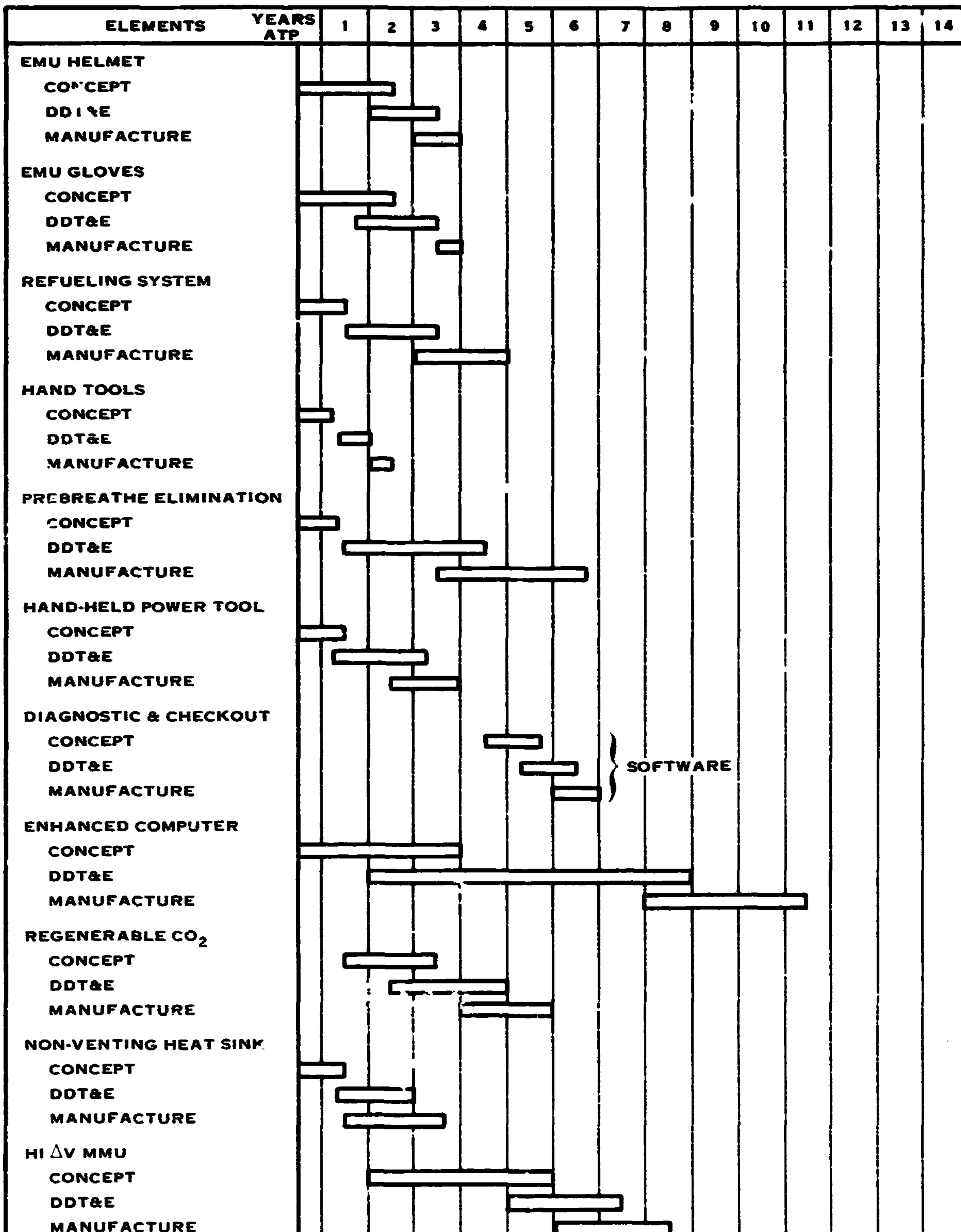
  Fabricate
  Assemble
  Acceptance Test
  Integration into STS operations

- IOC

For a more specific program plan reference Table XI.

UNITED TECHNOLOGIES HAMILTON STANDARD

TABLE XII DEVELOPMENT SCHEDULE*



*ASSUMES IMMEDIATE PROGRAM FUNDING AND INITIATION

SECTION 12.0

CONCLUSIONS AND RECOMMENDATIONS

The Extravehicular Mobility Unit (EMU), currently available and capable for routine satellite servicing, remains a major factor in planning future satellite servicing missions. Results from this study indicate that satellite servicing can be performed within the present EMU EVA time capability and that future EMU modifications could enhance satellite servicing, in turn providing greater benefits to both the NASA and satellite users. Previous Gemini, Apollo and Skylab missions have demonstrated EVA effectiveness, while Water Immersion Facility (WIF) testing has demonstrated that projected satellite servicing operatioins can be conducted successfully.

The study identified current EMU capabilities which in turn affect equipment and satellite design. Although presently capable of satisfying projected satellite servicing time lines and basic equipment interface requirements, some EMU modifications are desirable to enhance future satellite servicing capabilities.

One such modification includes the development of a non-venting heat sink to permit servicing of contamination sensitive satellites. Other modifications include development of an 8-psi space suit (versus current 4.0-psi suit) to eliminate prebreathing, universal power tool (reduces crewmember fatigue, increases number of possible servicing operations), light amplification devices (allows two-handed operating during rapid light variation), and lithium batteries (provide power for advanced EMU and ancillary equipment).

This study's time line analyses indicate that tasks may be standardized. The time required to complete even the most complex Grumman scenario remains well within the EVA capability of the EMU. In addition, standardization of both equipment and tasks will reduce the time required for crew training as well as providing distribution of equipment cost over a multitude of functions.

UNITED TECHNOLOGIES HAMILTON STANDARD

APPENDIX A

UNITED TECHNOLOGIES HAMILTON STANDARD

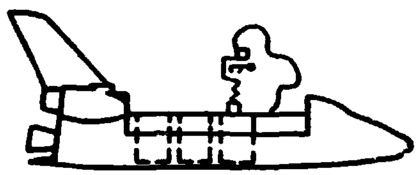
Hamilton Standard examined the following Grumman Aerospace Corporation scenarios in order to establish a comprehensive data base:

D4	Initial Launch	Payload Deployment
D4	Initial Launch	Backup for Retention Latch Hangup
D4	Initial Launch	Backup for Appendage Hangup
D6	Initial Launch	Payload Deployment
D6	Initial Launch	Backup for Retention Latch Hangup
D6	Initial Launch	Backup for Appendage Hangup
R2	Revisit	MTV Deploy/Payload Exam; Retrieval/Servicing; Payload Deployment
R2	Revisit	Backup for Tilt Table Hangup
R2	Revisit	Backup for Appendage Hangup
R4	Revisit	MTV Deploy/Payload Exam; Retrieval/Servicing Payload Deployment
R4	Revisit	Backup for Retention Latch Hangup
R4	Revisit	Backup for Appendage Hangup
ER4	Earth Return	MTV Deploy/Payload Retrieval
ER4	Earth Return	Backup for Retention Latch Hangup
ER4	Earth Return	Backup for Appendage Hangup
ER5	Earth Return	POM-MMU/WRU Deployment/Payload Retrieval
ER5	Earth Return	Backup for Retention Latch Hangup
ER5	Earth Return	Backup for Appendage Hangup
ER6	Earth Return	Manned POM Deploy/Payload Retrieval
ER6	Earth Return	Backup for Retention Latch Hangup
ER6	Earth Return	Backup for Appendage Hangup
ER8	Earth Return	POM/MTV Deploy/Payload Retrieval
ER8	Earth Return	Backup for Retention Latch Hangup
ER8	Earth Return	Backup for Appendage Hangup

UNITED TECHNOLOGIES
HAMILTON STANDARD

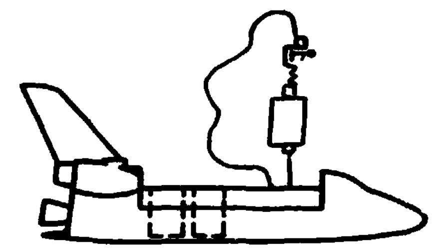
PAYLOAD DEPLOYMENT

(1)



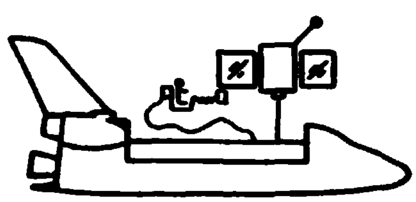
- SATELLITES STOWED IN RETENTION STRUCTURES
- STATUS/HEALTH CHECKS VIA UMBILICAL IN RETENTION STRUCTURE (COMM VIA ORBITER S-BAND)
- MMU/WRU WITH RMS END-EFFECTOR ATTACHES TO SATELLITE

(2)



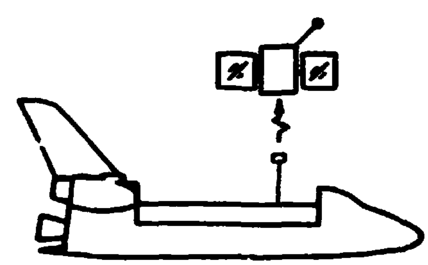
- RETENTION SYSTEM LATCHES/UMBILICAL RELEASED
- MMU/WRU TRANSLATES SATELLITE AND BERTHS TO HPA
- ACTIVATION OF SELECTED SATELLITE SUB-SYSTEMS VIA GROUND LINK (COMM VIA SATELLITE)

(3)



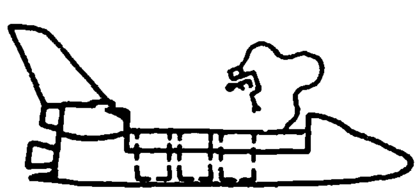
- SATELLITE APPENDAGES DEPLOYED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- STATE VECTOR TRANSFER
- TRANSFER PAYLOAD TO INTERNAL POWER
- FINAL STATUS/HEALTH CHECK PRIOR TO DEPLOYMENT (COMM VIA SATELLITE)

(4)



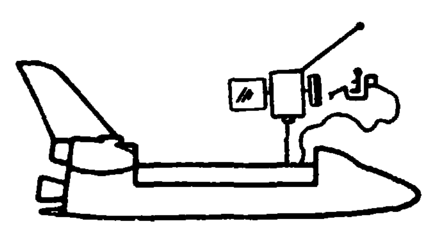
- HPA RELEASES SATELLITE IN PREFERRED ATTITUDE AT ~ 1 FT/SEC VELOCITY
- SATELLITE ACTIVATION OF RCS AT > 200 FT

BACKUP FOR RETENTION LATCH HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE
  OR
  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL ASSIST
  OR
  WORK STATION ON HPA IS UTILIZED

D4 RMS INOPERATIVE DEPLOYMENT SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - MULTIPLE PAYLOADS - HPA USAGE

Initial Launch

D4 RMS Inoperative Deployment Sequence

Payload Deployment

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Airlock	1	1
2.	Translate to Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate to MMU Lock into MMU	2	9
5.	Translate to WRU Lock into WRU	1	10
6.	Translate MMU/WRU to Satellite Storage Area	14	24
7.	Attach MMU/WRU to Satellite	2	26
8.	Translate Satellite to HPA	14	40
9.	Berth Satellite to HPA	5	45
10.	Detach MMU/WRU from Satellite	2	47
11.	Translate Away from Satellite	7	54
12.	Standby (Deploy Satellite Appendages)	10	64
	(Final Satellite Status/Health Checks)	5	69
	(Release Satellite from HPA)	2	71
13.	Translate MMU/WRU to PLB AESA	14	85
14.	Unlock from MMU/WRU	1	86
15.	Configure MMU and WRU for Re-entry	34	120
16.	Translate to Tool Storage	1	121
17.	Return Equipment	5	126
18.	Translate to Airlock	1	127
19.	Enter Airlock	1	128

Scenario assumes WRU is equipped with RMS type end effector.

UNITED TECHNOLOGIES HAMILTON STANDARD

Initial Launch

D4 RMS Inoperative Deployment Sequence

Backup for Retention Latch Hangup

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Airlock	1	1
2.	Translate to Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate to MMU	2	9
	Lock into MMU		
5.	Translate to WRU	1	10
	Lock into WRU		
6.	Translate MMU/WRU to Retention Latch	14	24
7.	Manually Release Retention Latch	10	34
8.	Translate MMU/WRU to Satellite Stowage Area	3	37
9.	Attach MMU/WRU to Satellite	2	39
10.	Translate Satellite to HPA	14	53
11.	Berth Satellite to HPA	5	58
12.	Detach MMU/WRU from Satellite	2	60
13.	Translate Away from Satellite	7	67
14.	Standby (Deploy Satellite Appendages)	10	77
	(Final Satellite Status/Health Checks)	5	82
	(Release Satellite from HPA)	2	84
15.	Translate MMU/WRU to PLB AESA	14	98
16.	Unlock from MMU/WRU	1	99
17.	Configure MMU and WRU for Re-entry	34	133
18.	Translate to Tool Storage	1	134
19.	Return Equipment	5	139
20.	Translate to Tool Storage	1	140
21.	Enter Airlock	1	141

Scenario assumes WRU is equipped with RMS type end effector, and stabilizer.

Initial Launch

D4 RMS Inoperative Deployment Sequence

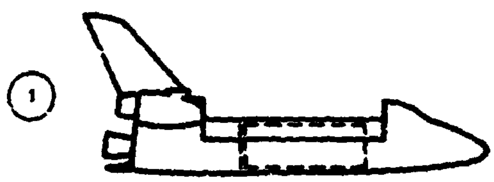
<u>Backup for Appendage Hangup</u>

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Airlock	1	1
2.	Translate to Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate to MMU	2	9
	Lock into MMU		
5.	Translate to WRU	1	10
	Lock into WRU		
6	Translate MMU/WRU to Satellite Storage Area	14	24
7.	Attach MMU/WRU to Satellite	2	26
8.	Translate Satellite to HPA	14	40
9.	Berth Satellite to HPA	5	45
10.	Detach MMU/WRU from Satellite	2	47
11.	Translate MMU/WRU away from Satellite	7	54
12.	Standby (Deploy Satellite Appendages)	10	64
13.	Translate MMU/WRU to Appendage Malfunction	7	71
14.	Repair Appendage Malfunction	10	81
15.	Translate MMU/WRU away from Satellite	7	88
16.	Standby (Final Satellite Status/Health Checks)	5	93
	(Release Satellite from HPA)	2	95
17.	Translate MMU/WRU to PLB AESA	14	109
18.	Unlock from MMU/WRU	1	110
19.	Configure MMU and WRU for Re-entry	34	144
20.	Translate to Tool Storage	1	145
21.	Return Equipment	5	150
22.	Translate to Airlock	1	151
23.	Enter Airlock	1	152

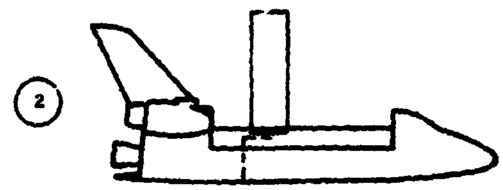
Scenario assumes WRU is equipped with RMS type end effector.

UNITED TECHNOLOGIES
HAMILTON STANDARD

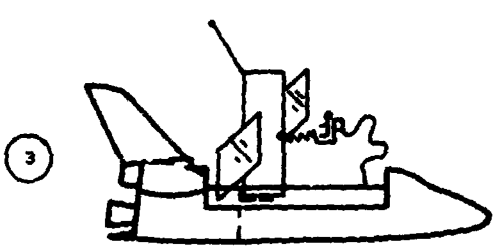
PAYLOAD DEPLOYMENT



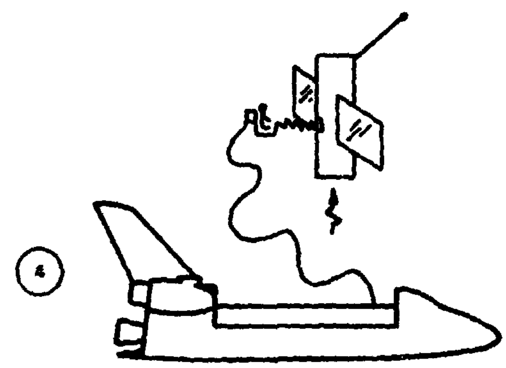
- SATELLITE STOWED IN CARGO BAY
- STATUS/HEALTH CHECKS VIA UMBILICAL IN TILT TABLE (COMM VIA ORBITER S-BAND)



- RETENTION LATCHES RELEASED
- SATELLITE ROTATED OUT OF PAYLOAD BAY VIA TILT TABLE
- ACTIVATION OF SELECTED SATELLITE SUBSYSTEMS VIA GROUND LINK (COMM VIA SATELLITE)

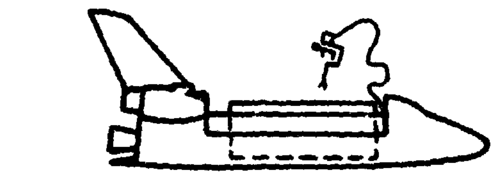


- SATELLITE APPENDAGES DEPLOYED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- STATE VECTOR TRANSFER
- TRANSFER PAYLOAD TO INTERNAL POWER
- FINAL STATUS/HEALTH CHECK PRIOR TO DEPLOYMENT (COMM VIA SATELLITE)
- MMU/WRU WITH RMS END EFFECTOR ATTACHES TO SATELLITE
- SATELLITE RELEASED FROM TILT TABLE/ UMBILICAL



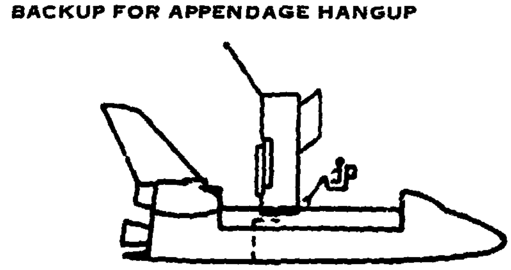
- MMU/WRU RELEASES SATELLITE IN PREFERRED ATTITUDE AT ~ 1 FT/SEC VELOCITY
- SATELLITE ACTIVATION OF RCS AT > 200 FT

BACKUP FOR RETENTION LATCH HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE
  OR
  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE
  OR
  WORK STATION ON TILT TABLE IS UTILIZED

D6 RMS INOPERATIVE DEPLOYMENT SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - LARGE PAYLOADS - TILT TABLE USAGE

Initial Launch

D6 RMS Inoperative Deployment Sequence

Payload Deployment

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Airlock	1	1
2.	Translate to Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate to MMU	2	9
	Lock into MMU		
5.	Tranlate to WRU	1	10
	Lock into WRU		
6.	Translate MMU/WRU to Satellite	14	24
7.	Attach MMU/WRU to Satellite	2	26
8.	Release Satellite from Tilt Table/Umbilical	2	28
9.	Translate Satellite to Deployment Area	14	42
10.	Release Satellite from MMU/WRU	2	44
11.	Translate MMU/WRU to PLB AESA	14	58
12.	Unlock from MMU/WRU	1	59
13.	Configure MMU and WRU for Re-entry	34	93
14.	Translate to Tool Storage	1	94
15.	Return Equipment	5	99
16.	Translate to Airlock	1	100
17.	Enter Airlock	1	101

Scenario assumes WRU is equipped with RMS type end effector.

UNITED TECHNOLOGIES HAMILTON STANDARD

Initial Launch

D6 RMS Inoperative Deployment Sequence

Backup for Retention Latch Hangup

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Airlock	1	1
2.	Translate to Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate to MMU	2	9
	Lock into MMU		
5.	Translate to WRU	1	10
	Lock into WRU		
6.	Translate MMU/WRU to Retention Latch	14	24
7.	Manually Release Retention Latch	10	34
8.	Translate away from Satellite	7	41
9.	Standby (Rotate Satellite Out of Payload Bay)	2	43
	(Activate Satellite Subsystems)	2	45
	(Deploy Satellite Appendages)	10	55
	(Final Satellite Status/Health Checks)	10	65
10.	Translate MMU/WRU to Satellite	7	72
11.	Attach MMU/WRU to Satellite	2	74
12.	Release Satellite from Tilt Table/Umbilical	2	76
13.	Translate Satellite to Deployment Area	14	90
14.	Release Satellite from MMU/WRU	2	92
15.	Translate MMU/WRU to PLB AESA	14	106
16.	Unlock from MMU/WRU	1	107
17.	Configure MMU and WRU for Re-entry	34	141
18.	Translate to Tool Storage	1	142
19.	Return Equipment	5	147
20.	Translate to Airlock	1	148
21.	Enter Airlock	1	149

Scenario assumes WRU is equipped with RMS type end effector, and stabilizer.

Initial Launch

D6 RMS Inoperative Deployment Sequence

Backup for Appendage Hangup

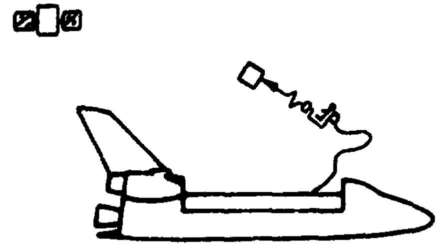
		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Airlock	1	1
2.	Translate to Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate to MMU	2	9
	Lock into MMU		
5.	Translate to WRU	1	10
	Lock into WRU		
6.	Translate MMU/WRU to Appendage Hangup	14	24
7.	Repair Appendage Malfunction	10	34
8.	Translate Away from Satellite	7	41
9.	Standby (Final Satellite Status/Health Checks)	10	51
10.	Translate MMU/WRU to Satellite	7	58
11.	Attach MMU/WRU to Satellite	2	60
12.	Release Satellite from Tilt Table/Umbilical	2	62
13.	Translate Satellite to Deployment Area	14	76
14.	Release Satellite from MMU/WRU	2	78
15.	Translate MMU/WRU to PLB AESA	14	92
16.	Unlock from MMU/WRU	1	93
17.	Configure MMU and WRU for Re-entry	34	127
18.	Translate to Tool Storage	1	128
19.	Return Equipment	5	133
20.	Translate to Airlock	1	134
21.	Enter Airlock	1	135

Scenario assumes WRU is equipped with RMS type end effector, and stabilizer.

FOLDOUT FRAME 1

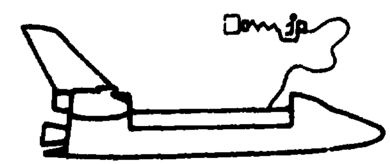
MTV DEPLOYMENT/PAYLOAD EXAMINATION

1



- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN ~ 1000 FT SEPARATION DISTANCE
- MTV IS DEPLOYED BY MMU/WRU WITH RMS END-EFFECTOR TO EXAMINE SATELLITE

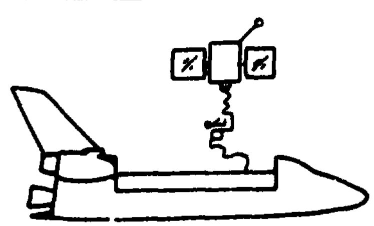
2



- ORBITER/MTV RENDEZVOUS
- MTV RETRIEVED BY MMU/WRU AND STOWED IN PAYLOAD BAY

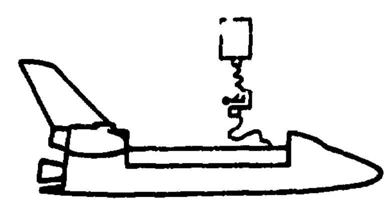
RETRIEVAL/SERVICING

3



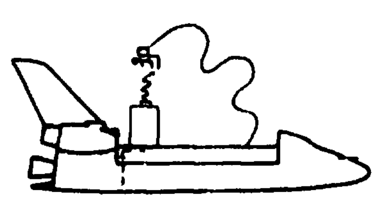
- SATELLITE SAFING, PROPELLANT VENTING, PREPARATIONS FOR RENDEZVOUS
- SATELLITE ACS IS ACTIVE TO MAINTAIN STABILITY
- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS, SATELLITE EXAMINED VIA MMU/WRU OR VISUAL CREW OBSERVATION
- MMU/WRU WITH RMS END EFFECTOR ATTACHES TO SATELLITE

4



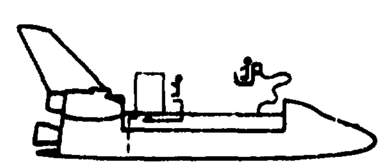
- SATELLITE APPENDAGES RETRACTED
- DEACTIVATE SATELLITE BY GROUND COMMAND

5



- SATELLITE BERTHED TO PAYLOAD BAY TILT TABLE AND UMBILICAL CONNECTIONS VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

6



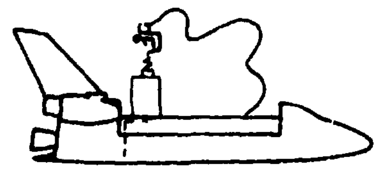
- CHECKOUT STATUS/HEALTH VIA UMBILICAL IN TILT TABLE (COMM VIA SATELLITE)
- IMPLEMENT SERVICING FUNCTIONS VIA OCP/WORK STATION ON TILT TABLE
  EXAMINE, REPAIR, MAINTENANCE, RESUPPLY, RECONFIGURE
- TR T P CK GES TO WORK STATION VIA

- SATELLITE BERTHED TO PAYLOAD BAY TIL. . A. L A UMBILICAL CONNECTIONS VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

- [illegible] (COMM VIA SATELLITE)
- IMPLEMENT SERVICING FUNCTIONS VIA OCP/WORK STATION ON TILT TABLE
  EXAMINE, REPAIR, MAINTENANCE, RESUPPLY, RECONFIGURE
- TRANSPORT PACKAGES TO WORK STATION VIA MMU/WRU WITH PAYLOAD HANDLING CAPABILITY
- CHECKOUT/VERIFY STATUS OF ON-ORBIT SERVICES PERFORMED (COMM VIA SATELLITE)

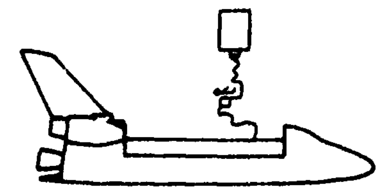
PAYLOAD DEPLOYMENT

(7)



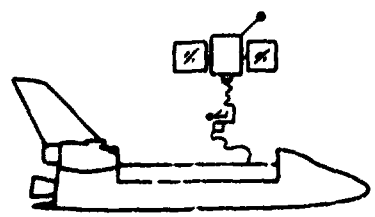
- MMU/WRU ATTACHES TO SATELLITE
- STATE VECTOR TRANSFER
- TRANSFER SATELLITE TO INTERNAL POWER

(8)



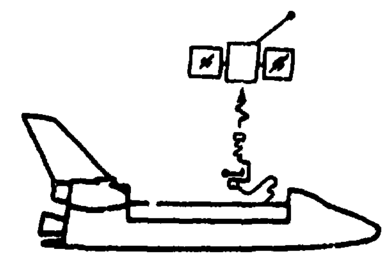
- TILT TABLE LATCHES/UMBILICALS RELEASED
- MMU/WRU ELEVATES PAYLOAD WITHIN VIEW OF AFD AND PAYLOAD BAY TV CAMERAS
- ACTIVATION OF SELECTED SUBSYSTEMS VIA GROUND LINK (COMM VIA SATELLITE)

(9)



- SATELLITE APPENDAGES DEPLOYED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- FINAL STATUS/HEALTH CHECK PRIOR TO DEPLOYMENT (COMM VIA SATELLITE)

(10)

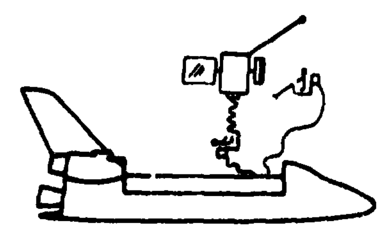


- MMU/WRU RELEASES SATELLITE IN NOMINALLY PREFERRED ATTITUDE AT ~ 1 FT/SEC VELOCITY
- SATELLITE ACTIVATION OF RCS AT > 200 FT

BACKUP FOR TILT TABLE HANGUP

- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE OR EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- FIRST MMU/WRU MAINTAINS STABILITY/POSITION OF SATELLITE
- SECOND MMU WITH STABILIZER DEPLOYED FOR MANUAL ASSIST

R2 NOMINAL REVISIT SEQUENCE - RMS INOPERATIVE - DIRECT DELIVERY PAYLOAD CLASS - MMS-TYPE SATELLITES - TILT TABLE USAGE

FOLDOUT FRAME 2

Revisit

R2 Nominal Revisit Sequence, RMS Inoperative

MTV Deployment/Payload Examination; Retrieval/Servicing; Payload Redeployment

	MMU/WRU	OCP/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To MTV Stowage Area		14	24
7.	Attach MMU/WRU To MTV		2	26
8.	Translate MTV To Deployment Area		14	40
9.	Release MTV From MMU/WRU		2	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Stowage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite	Leave Air Lock	2/1	82
17.	Retract Satellite Appendages	Translate To Tool Storage	10/1	92
18.	Deactivate Satellite ACS	Obtain Equipment	-/5	-
19.	Satellite Berthing To Tilt Table	Translate To OCP/Work Station	5/1	97
20.	Verify Umbilical Connections	Lock Into OCP	2/1	99
21.	Transfer Satellite To Orbiter Power	Translate To Satellite Maintenance Position	2/2	101
22.	Transport Servicing Equipment As Required	Implement Satellite Servicing Functions	45***	146
23.	Translate MMU/WRU To Satellite	Translate To OCP Storage Position	-/2	148
24.	Attach MMU/WRU To Satellite	Unlock From OCP	2/1	150
25.	Transfer Satellite To Internal Power	Standby	2/-	152
26.	Detach Umbilical Connections		2	154
27.	Release Satellite From Tilt Table		2	156
28.	Translate Satellite To Deployment Area		14	170
29.	Deploy Satellite Appendages		10	180
30.	Final Satellite Status/Health Checks		10	190
31.	Release Satellite From MMU/WRU	Translate To Tool Storage	2/1	192
32.	Translate MMU/WRU TO PLB AESA	Return Equipment	14/5	206
33.	Unlock From MMU/WRU	Translate To MMU/WRU	1/1	207
34.	Configure MMU And WRU For Re-entry	Obtain Equipment	34/5	241
35.		Translate To Tool Storage	-/1	-
36.		Return Equipment	-/5	-
37.	Translate To Air Lock	Translate To Air Lock	1/1	242
38.	Enter Air Lock	Enter Air Lock	1/1	243

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

*** May Be Increased (As Required) Within EMU EVA Limitations (400 Minutes)

UNITED TECHNOLOGIES HAMILTON STANDARD

Revisit

R2 Nominal Revisit Sequence, RMS Inoperative

Backup For Tilt Table Hangup

	MMU/WRU	OCP/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU	Leave Air Lock	1/1	10
6.	Translate MMU/WRU To MTV Stowage Area	Translate To Tool Storage	14/1	24
7.	Attach MMU/WRU To MTV	Obtain Equipment	2/5	26
8.	Translate MTV To Deployment Area	Translate To Tilt Table	14/1	40
9.	Release MTV From MMU/WRU	Repair Tilt Table Malfunction	2/10	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Stowage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite		2	82
17.	Retract Satellite Appendages		10	92
18.	Deactivate Satellite ACS		-	-
19.	Satellite Berthing To Tilt Table	Translate To OCP/Work Station	5/1	97
20.	Verify Umbilical Connections	Lock Into OCP	2/1	99
21.	Transfer Satellite To Orbiter Power	Translate To Satellite Maintenance Position	2/2	101
22.	Transfer Servicing Equipment As Required	Implement Satellite Servicing Functions	45***	146
23.	Translate MMU/WRU To Satellite	Translate To OCP Storage Position	-/2	148
24.	Attach MMU/WRU To Satellite	Unlock From OCP	2/1	150
25.	Transfer Satellite To Internal Power	Standby	2/-	152
26.	Detach Umbilical Connections		2	154
27.	Release Satellite From Tilt Table		2	156
28.	Translate Satellite To Deployment Area		14	170
29.	Deploy Satellite Appendages		10	180
30.	Final Satellite Status/Health Checks		10	190
31.	Release Satellite From MMU/WRU	Translate To Tool Storage	2/1	192
32.	Translate MMU/WRU To PLB AESA	Return Equipment	14/5	206
23.	Unlock From MMU/WRU	Translate To MMU/WRU	1/1	207
34.	Configure MMU And WRU For Re-entry	Obtain Equipment	34/5	241
35.		Translate To Tool Storage	-/1	-
36.		Return Equipment	-/5	-
37.	Translate To Air Lock	Translate To Air Lock	1/1	242
38.	Enter Air Lock	Enter Air Lock	1/1	243

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

*** May Be Increased (As Required) Within EMU EVA Limitations (400 Minutes)

Revisit

R2 Nominal Revisit Sequence, RMS Inoperative

Backup For Appendage Hangup

	MMU/WRU	OCP/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To MTV Stowage Area		14	24
7.	Attach MMU/WRU To MTV		2	26
8.	Translate MTV To Deployment Area		14	40
9.	Release MTV From MMU/WRU		2	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Stowage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite	Leave Air Lock	2/1	82
17.	Retract Satellite Appendages	Translate To Tool Storage	10/1	92
18.	Deactivate Satellite ACS	Obtain Equipment	-/5	-
19.	Satellite Berthing To Tilt Table	Translate To OCP Work Station	5/1	97
20.	Verify Umbilical Connections	Lock Into OCP	2/1	99
21.	Transfer Satellite To Orbiter Power	Transfer To Satellite Maintenance Position	2/2	101
22.	Transport Servicing Equipment As Required	Implement Satellite Servicing Functions	45***	146
23.	Translate MMU/WRU To Satellite	Translate To OCP Storage Position	-/2	148
24.	Attach MMU/WRU To Satellite	Unlock From OCP	2/1	150
25.	Transfer Satellite To Internal Power	Standby	2/-	152
26.	Detach Umbilical Connections		2	154
27.	Release Satellite From Tilt Table		2	156
28.	Translate Satellite To Deployment Area		14	170
29.	Deploy Satellite Appendages		10	180
30.	Standby	Translate To MMU Lock Into MMU	1	181
31.		Translate To WRU Lock Into WRU	1	182
32.		Translate MMU/WRU To Appendage	14	196
33.		Repair Appendage Malfunction	10	206
34.		Translate Away From Satellite	14	220
35.	Final Satellite Status/Health Checks	Standby	10	230
36.	Release Satellite From MMU/WRU		2	232
37.	Translate MMU/WRU To PLB AESA	Translate MMU/WRU To PLB AESA	14/14	246
38.	Unlock From MMU/WRU	Unlock From MMU/WRU	1/1	247
39.	Configure MMU And WRU For Re-entry	Configure MMU And WRU For Re-entry	34/34	281
40.	Translate To Tool Storage	Translate To Tool Storage	1/1	282
41.	Return Equipment	Return Equipment	5/5	287
42.	Translate To Air Lock	Translate To Air Lock	1/1	288
43.	Enter Air Lock	Enter Air Lock	1/1	289

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

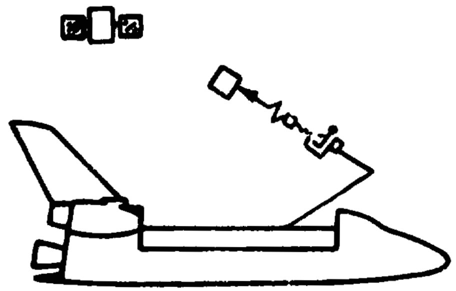
** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

*** May Be Increased (As Required) Within EMU EVA Limitations (400 Minutes)

UNITED TECHNOLOGIES
HAMILTON STANDARD

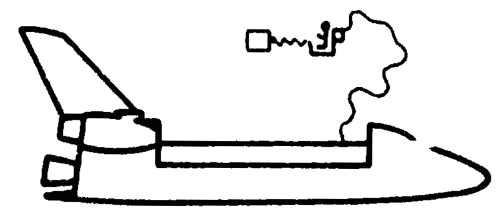
MTV DEPLOYMENT/PAYLOAD EXAMINATION

1



- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN ~1000 FT SEPARATION DISTANCE
- MTV IS DEPLOYED BY MMU/WRU (WITH RMS END-EFFECTOR) TO EXAMINE SATELLITE

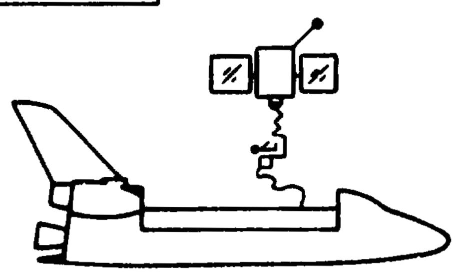
2



- ORBITER/MTV RENDEZVOUS
- MTV RETRIEVED BY MMU/WRU AND STOWED IN PAYLOAD BAY

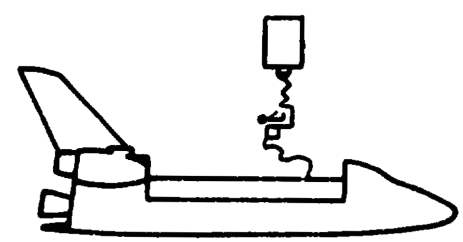
RETRIEVAL/SERVICING

3



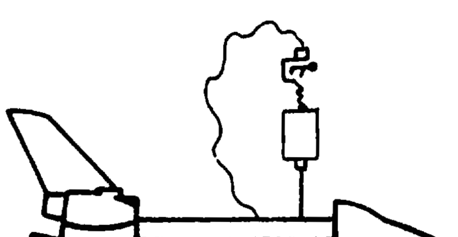
- SATELLITE SAFING, PROPELLANT VENTING, PREPARATIONS FOR RENDEZVOUS
- SATELLITE ACS IS ACTIVE TO MAINTAIN STABILITY
- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS, SATELLITE EXAMINED VIA MMU/WRU OR VISUAL CREW OBSERVATION
- MMU/WRU (WITH RMS END-EFFECTOR) ATTACHES TO SATELLITE

4



- SATELLITE APPENDAGES RETRACTED
- DEACTIVATE SATELLITE BY GROUND COMMAND

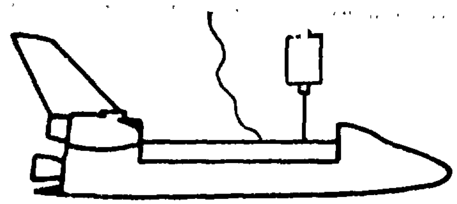
5



6

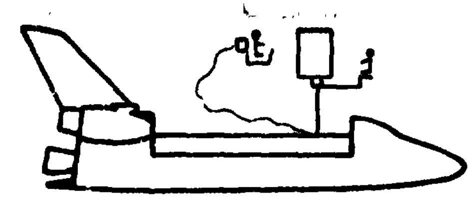
FOLDOUT FRAME 1

5



- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTIONS VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

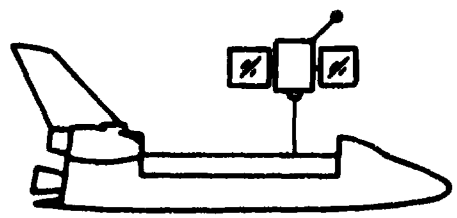
6



- CHECKOUT STATUS/HEALTH VIA UMBILICAL IN HPA (COMM VIA SATELLITE)
- IMPLEMENT SERVICING FUNCTIONS VIA HPA
  EXAMINE, REPAIR, MAINTENANCE, RESUPPLY, RECONFIGURE
- TRANSPORT PACKAGES TO WORK STATION VIA MMU/WRU WITH PAYLOAD HANDLING CAPABILITY
- CHECKOUT/VERIFY STATUS OF ON-ORBIT SERVICES PERFORMED (COMM VIA SATELLITE)
- ACTIVATION OF SELECTED SUBSYSTEMS VIA GROUND LINK

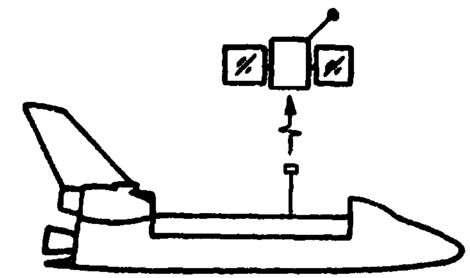
PAYLOAD REDEPLOYMENT

7



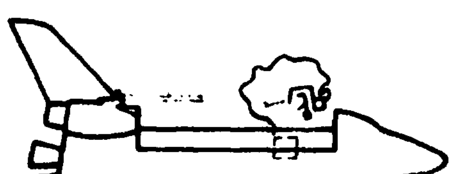
- SATELLITE APPENDAGES DEPLOYED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- STATE VECTOR TRANSFER
- TRANSFER SATELLITE TO INTERNAL POWER
- FINAL STATUS/HEALTH CHECK PRIOR TO DEPLOYMENT (COMM VIA SATELLITE)

8



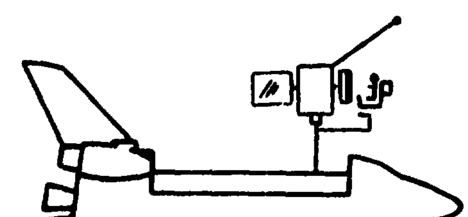
- HPA RELEASES SATELLITE AT ~ 1 FT/SEC VELOCITY
- SATELLITE ACTIVATION OF RCS AT > 200 FT SEPARATION

BACKUP FOR RETENTION LATCH HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE
  OR
  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- WORK STATION ON HPA IS UTILIZED

R4 ALTERNATE NO. 1 REVISIT SEQUENCE - RMS INOPERATIVE - DIRECT DELIVERY PAYLOAD CLASS - MMS-TYPE SATELLITES - HPA USAGE

Revisit

R4 Alternate No. 1 Revisit Sequence, RMS Inoperative

MTV Deployment/Payload Examination; Retrieval/Servicing; Payload Deployment

	MMU/WRU	HPA/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To MTV Stowage Area		14	24
7.	Attach MMU/WRU To MTV		2	26
8.	Translate MTV To Deployment Area		14	40
9.	Release MTV From MMU/WRU		2	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Stowage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite	Leave Air Lock	2/1	82
17.	Retract Satellite Appendages	Translate To Tool Storage	10/1	92
18.	Deactivate Satellite ACS	Obtain Equipment	-/5	-
19.	Satellite Berthing To HPA	Translate To OCP/Work Station	5/1	97
20.	Verify Umibilical Connections	Lock Into OCP	2/1	99
21.	Transfer Satellite To Orbiter Power	Translate To Satellite Maintenance Position	2/2	101
22.	Transport Servicing Equipment As Required	Implement Satellite Servicing Functions	45***	146
23.	Standby (Transfer Satellite To Internal Power)	Translate To OCP Storage Position	2/2	148
24.	(Detach Umbilical Connections)	Standby	2	150
25.	(Deploy Satellite Appendages)		10	160
26.	(Final Satellite Status/Health Checks)	Unlock From OCP	10/1	170
27.	Release Satellite From HPA	Translate To Tool Storage	2/1	172
28.	Translate MMU/WRU to PLB AESA	Return Equipment	14/5	186
29.	Unlock From MMU/WRU	Translate to MMU/WRU	1/1	187
30.	Configure MMU And WRU For Re-entry	Obtain Equipment	34/5	221
31.		Translate To Tool Storage	-/1	-
32.		Return Equipment	-/5	-
33.	Translate To Air Lock	Translate To Air Lock	1/1	222
34.	Enter Air Lock	Enter Air Lock	1/1	223

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

*** May Be Increased (As Required) Within EMU EVA Limitations (400 Minutes)

Revisit

R4 Alternate No. 1 Revisit Sequence, RMS Inoperative

Backup For Retention Latch Hangup

	MMU/WRU	HPA/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To Retention Latch		14	24
7.	Manually Release Retention Latch		10	34
8.	Attach MMU/WRU To MTV		2	36
9.	Translate MTV To Deployment Area		14	50
10.	Release MTV From MMU/WRU		2	52
11.	Standby		15*	67
12.	MTV Docking With MMU/WRU		2	69
13.	Translate MMU/WRU To MTV Stowage Area		14	83
14.	Stow MTV		5	88
15.	Detach MMU/WRU From MTV		2	90
16.	Translate Satellite Close To Orbiter		(15)**	-
17.	MMU/WRU Docking With Satellite	Leave Air Lock	2/1	92
18.	Retract Satellite Appendages	Translate To Tool Storage	10/1	102
19.	Deactivate Satellite ACS	Obtain Equipment	-/5	-
20.	Satellite Berthing To HPA	Translate To OCP Work Station	5/1	107
21.	Verify Umbilical Connections	Lock Into OCP	2/1	109
22.	Transfer Satellite To Orbiter Power	Translate To Satellite Maintenance Position	2/2	111
23.	Transfer Servicing Equipment As Required	Implement Satellite Servicing Functions	45***	156
24.	Standby (Transfer Satellite To Internal Power)	Translate To OCP Storage Position	2/2	158
25.	(Detach Umbilical Connections)	Standby	2	160
26.	(Deploy Satellite Appendages)		10	170
27.	(Final Satellite Status/Health Checks)	Unlock From OCP	10/1	180
28.	Release Satellite From HPA	Translate To Tool Storage	2/1	182
29.	Translate MMU/WRU To PLB AESA	Return Equipment	14/5	196
30.	Unlock From MMU/WRU	Translate To MMU/WRU	1/1	197
31.	Configure MMU And WRU For Re-entry	Obtain Equipment	34/5	231
32.		Translate To Tool Storage	-/1	-
33.		Return Equipment	-/5	-
34.	Translate To Air Lock	Translate To Air Lock	1/1	232
35.	Enter Air Lock	Enter Air Lock	1/1	233

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

*** May Be Increased (As Required) Within EMU EVA Limitations (400 Minutes)

Revisit

R4 Alternate No. 1 Revisit Sequence, RMS Inoperative

Backup For Appendage Hangup

	MMU/WRU	HPA/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To MTV Stowage Area		14	24
7.	Attach MMU/WRU To MTV		2	26
8.	Translate MTV To Deployment Area		14	40
9.	Release MTV From MMU/WRU		2	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Stowage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite	Leave Air Lock	2/1	82
17.	Retract Satellite Appendages	Translate To Tool Storage	10/1	92
18.	Deactivate Satellite ACS	Obtain Equipment	-/5	-
19.	Satellite Berthing To HPA	Translate To OCP/Work Station	5/1	97
20.	Verify Umbilical Connections	Lock Into OCP	2/1	99
21.	Transfer Satellite To Orbiter Power	Translate To Satellite Maintenance Position	2/2	101
22.	Transport Servicing Equipment As Required	Implement Satellite Servicing Functions	45***	146
23.	Standby (Transfer Satellite To Internal Power)	Translate To OCP Storage Position	2/2	148
24.	(Detach Umbilical Connections)	Standby	2	150
25.	(Deploy Satellite Appendages)	Translate OCP To Appendage	10/2	160
26.		Repair Appendage Malfunction	10	170
27.		Translate To OCP Storage Position	2	172
28.	(Final Satellite Status/Health Checks)	Unlock From OCP	10/1	182
29.	Release Satellite From HPA	Translate To Tool Storage	2/1	184
30.	Translate MMU/WRU To PLB AESA	Return Equipment	14/5	198
31.	Unlock From MMU/WRU	Translate To MMU/WRU	1/1	199
32.	Configure MMU And WRU For Re-entry	Obtain Equipment	34/5	233
33.		Translate To Tool Storage	-/1	-
34.		Return Equipment	-/5	-
35.	Translate To Air Lock	Translate To Air Lock	1/1	234
36.	Enter Air Lock	Enter Air Lock	1/1	235

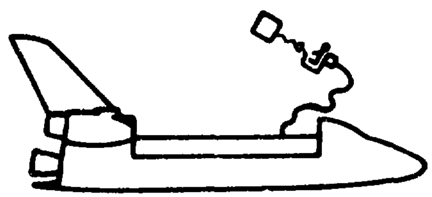
* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

*** May Be Increased (As Required) Within EMU EVA Limitations (400 Minutes)

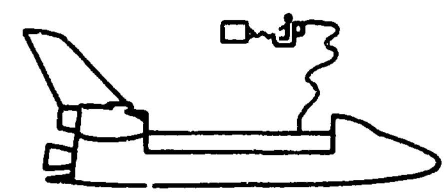
MTV DEPLOYMENT/PAYLOAD EXAMINATION

(1)



- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN ~ 1000 FT SEPARATION DISTANCE
- MTV IS DEPLOYED BY MMU/WRU WITH RMS END EFFECTOR TO EXAMINE SATELLITE

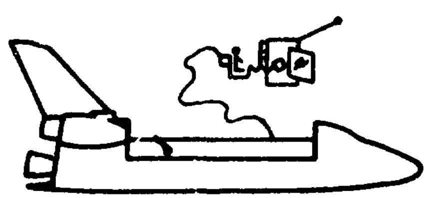
(2)



- ORBITER/MTV RENDEZVOUS (MTV ACTIVE)
- MTV RETRIEVED BY MMU/WRU AND STOWED IN PAYLOAD BAY

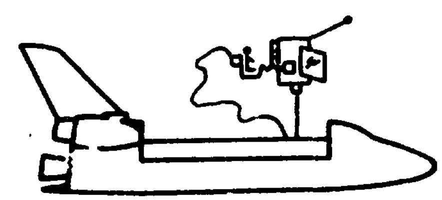
RETRIEVAL/STOWAGE

(3)



- SATELLITE SAFING, PROPELLANT VENTING, PREPARATIONS FOR RENDEZVOUS
- SATELLITE ACS IS ACTIVE TO MAINTAIN STABILITY
- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS. SATELLITE EXAMINED VIA MMU/WRU OR VISUAL CREW OBSERVATION
- MMU/WRU WITH RMS END EFFECTOR ATTACHES TO SATELLITE

(4)



- SATELLITE BERTHED TO HPA

OPTION

- UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

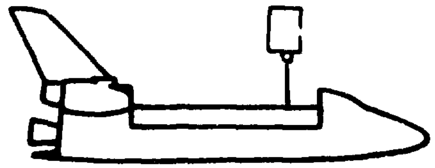
(5)

(6)

OPTION

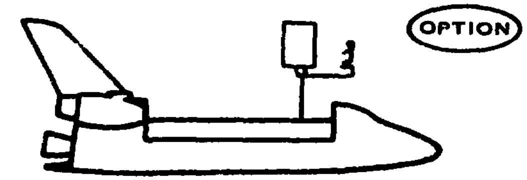
FOLDOUT FRAME

5



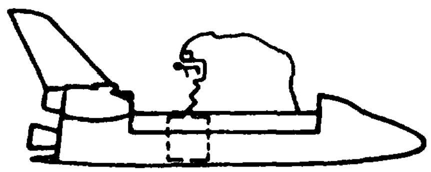
- SATELLITE APPENDAGES RETRACTED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- SATELLITE INACTIVATED BY GROUND COMMAND AND CHECKED-OUT FOR RETURN

6



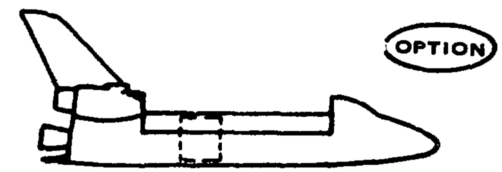
- IMPLEMENT MANUAL REMOVAL/STORAGE OF SELECTED EQUIPMENT VIA HPA WORK STATION, IF REQUIRED

7



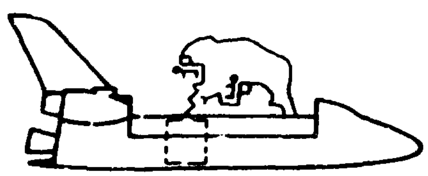
- MMU/WRU TRANSFERS SATELLITE TO RETENTION STRUCTURE
- RETENTION LATCHES LOCKED

8



- UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

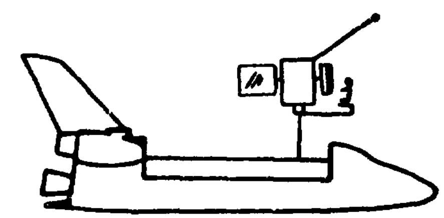
BACKUP FOR RETENTION LATCH HANGUP



- FIRST MMU/WRU MAINTAINS STABILITY/POSITION OF SATELLITE IN PAYLOAD BAY
- SECOND MMU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE OR

  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- WORK STATION ON HPA IS UTILIZED

FOLDOUT FRAME

A-23/A-24

ER4 ALTERNATE NO. 1 EARTH RETURN SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - COOPERATIVE MMS-TYPE SATELLITES - RMS INOPERATIVE - HPA USAGE

UNITED TECHNOLOGIES HAMILTON STANDARD

Earth Return

ER4 Alternate No. 1 Earth Return Sequence

MTV Deployment/Payload Retrieval

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MMU Lock Into MMU	2	9
5.	Translate To WRU Lock ' to WRU	1	10
6.	Translate MMU/WRU To MTV Storage Area	14	24
7.	Attach MMU/WRU To MTV	2	26
8.	Translate MTV To Deployment Area	14	40
9.	Release MTV From MMU/WRU	2	42
10.	Standby	15*	57
11.	MTV Docking With MMU/WRU	2	59
12.	Translate MMU/WRU To MTV Storage Area	14	73
13.	Stow MTV	5	78
14.	Detach MMU/WRU From MTV	2	80
15.	Translate Satellite Close To Orbiter	(15)**	-
16.	MMU/WRU Docking With Satellite	2	82
17.	Berth Satellite To HPA	5	87
18.	Standby (Verify Satellite Umbilical Connection)	2	89
19.	(Transfer Satellite To Orbiter Power)	2	91
20.	(Retract Satellite Appendages)	10	101
21.	(Deactivate Satellite ACS)	-	-
22.	Release Satellite From HPA	2	103
23.	Translate Satellite To Storage Area	14	117
24.	Stow Satellite	5	122
25.	Detach MMU/WRU From Satellite	2	124
26.	Translate MMU/WRU To PLB AESA	14	138
27.	Unlock From MMU/WRU	1	139
28.	Prepare MMU And WRU For Re-entry	34	173
29.	Translate To Tool Storage	1	174
30.	Return Equipment	5	179
31.	Translate To Air Lock	1	180
32.	Enter Air Lock	1	181

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV.

Earth Return

ER4 Alternate No. 1 Earth Return Sequence

Backup For Retention Latch Hangup

	MMU/WRU	MMU/WRU	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To MTV Storage Area		14	24
7.	Attach MMU/WRU To MTV		2	26
8.	Translate MTV To Deployment Area		14	40
9.	Release MTV From MMU/WRU		2	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Storage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite		2	82
17.	Berth Satellite To HPA		5	89
18.	Standby (Verify Satellite Umbilical Connection)		2	87
19.	(Transfer Satellite To Orbiter Power)		2	91
20.	(Retrach Satellite Appendages)		10	101
21.	(Deactivate Satellite ACS)		-	-
22.	Release Satellite From HPA		2	103
23.	Translate Satellite To Storage Area		14	117
24.	Stow Satellite		5	122
25.	Standby	Leave Air Lock	-/1	123
26.		Translate To Tool Storage	1	124
27.		Obtain Equipment	5	129
28.		Translate To MMU Lock Into MMU	2	131
29.		Translate To WRU Lock Into WRU	1	132
30.		Translate MMU/WRU To Retention Latch	14	146
31.		Manually Latch Retention Latch	10	156
32.	Detach MMU/WRU From Satellite	Standby	2	158
33.	Translate MMU/WRU To PLB AESA	Translate MMU/WRU To PLB AESA	14/14	172
34.	Unlock From MMU/WRU	Unlock From MMU/WRU	1/1	173
35.	Prepare MMU And WRU For Re-entry	Prepare MMU And WRU For Re-entry	34/34	207
36.	Translate To Tool Storage	Translate To Tool Storage	1/1	208
37.	Return Equipment	Return Equipment	5/5	213
38.	Translate To Air Lock	Translate To Air Lock	1/1	214
39.	Enter Air Lock	Enter Air Lock	1/1	215

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

Earth Return

ER4 Alternate No. 1 Earth Return Sequence

Backup For Appendage Hangup

	MMU/WRU	OCP/Work Station	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Transfer MMU/WRU To MTV Storage Area		14	24
7.	Attach MMU/WRU To MTV		2	26
8.	Translate MTV To Deployment Area		14	40
9.	Release MTV From MMU/WRU		2	42
10.	Standby		15*	57
11.	MTV Docking With MMU/WRU		2	59
12.	Translate MMU/WRU To MTV Storage Area		14	73
13.	Stow MTV		5	78
14.	Detach MMU/WRU From MTV		2	80
15.	Translate Satellite Close To Orbiter		(15)**	-
16.	MMU/WRU Docking With Satellite		2	82
17.	Berth Satellite To HPA		5	87
18.	Standby (Verify Satellite Umbilical Connection)		2	89
19.	(Transfer Satellite To Orbiter Power)		2	91
20.	(Retract Satellite Appendages)	Leave Air Lock	10/1	101
21.		Translate To Tool Storage	1	102
22.		Obtain Equipment	5	107
23.		Translate To OCP	1	108
24.		Lock Into OCP	1	109
25.		Translate OCP To Appendage Malfunction	2	111
26.		Repair Appendage Malfunction	10	121
27.	(Deactivate Satellite ACS)	Translate OCP To Storage Position	-/2	123
28.	Release Satellite From HPA	Unlock From OCP	2/1	125
29.	Translate Satellite To Storage Area	Standby	14/-	139
30.	Stow Satellite		5	144
31.	Detach MMU/WRU From Satellite		2	146
32.	Translate MMU/WRU To PLB AESA	Translate To Tool Storage	14/1	160
33.		Return Equipment	-/5	-
34.	Unlock From MMU/WRU	Translate To MMU/WRU	1/1	161
35.	Prepare MMU And WRU For Re-entry	Obtain Equipment	34/5	195
36.		Return Equipment	-/5	-
38.	Translate To Air Lock	Translate To Air Lock	1/1	196
39.	Enter Air Lock	Enter Air Lock	1/1	197

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

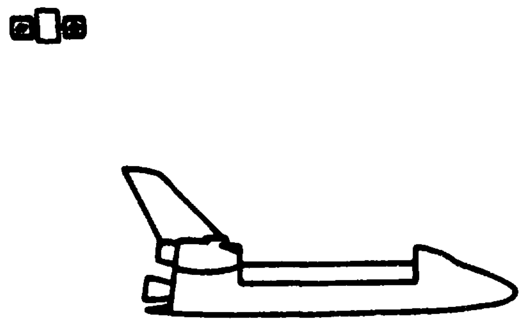
** Not Included In Cumulative Time Since Satellite Translation Will Occur During Stowage Of MTV

UNITED TECHNOLOGIES
HAMILTON STANDARD

FOLDOUT FRAME 1

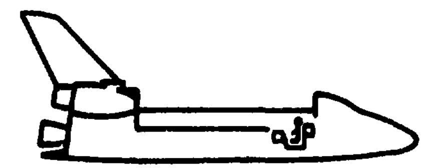
POM-MMU/WRU DEPLOYMENT/PAYLOAD RETRIEVAL

(1)



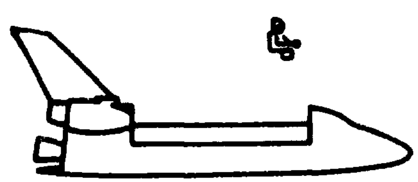
- SATELLITE SAFING, PROPELLANT VENTING, PREPARATIONS FOR RENDEZVOUS
- SATELLITE ACS IS ACTIVE TO MAINTAIN STABILITY
- ORBITER RENDEZVOUS WITH SATELLITE TO WITHIN 1000 FT SEPARATION DISTANCE

(2)



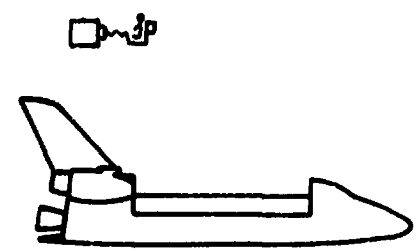
- PROXIMITY OPERATIONS MODULE (POM)-MMU/WRU ADAPTATION STOWED IN RETENTION STRUCTURE (AESA)
- STATUS/HEALTH CHECKS VIA UMBILICAL IN RETENTION STRUCTURE (COMM VIA ORBITER S-BAND)
- EVA CREWMAN MOUNTS POM-MMU/WRU
- ACTIVATION/CHECKOUT OF POM-MMU/WRU

(3)



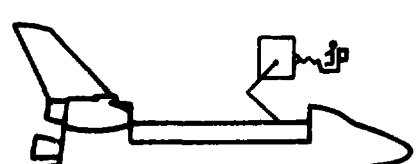
- POM-MMU/WRU RELEASED FROM RETENTION STRUCTURE/ UMBILICAL
- POM-MMU/WRU INITIATES CLOSURE MANEUVER TO EXAMINE AND RETRIEVE SATELLITE

(4)



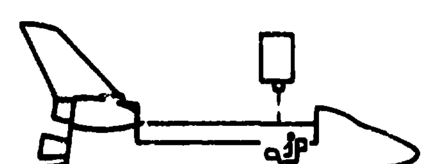
- POM-MMU/WRU DOCKS TO SATELLITE GRAPPLE FITTING
- SATELLITE APPENDAGES RETRACTED
- SATELLITE ACS DEACTIVATED

(5)



- POM-MMU/WRU TRANSPORTS SATELLITE TO ORBITER WITHIN RMS REACH DISTANCE
- RMS ATTACHES TO SATELLITE AND POM (POM ACS

(6)



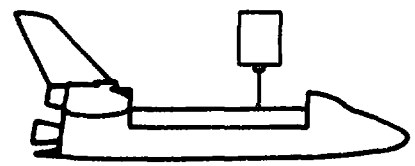
- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN

- POM-MMU/WRU TRANSPORTS SATELLITE TO ORBITER WITHIN RMS REACH DISTANCE
- RMS ATTACHES TO SATELLITE AND POM (POM ACS ACTIVE)
- DEACTIVATE SATELLITE BY GROUND COMMAND POM-MMU/WRU SEPARATES FROM SATELLITE

- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL
- POM-MMU/WRU STOWED IN RETENTION STRUCTURE (AESA), RETENTION LATCHES LOCKED

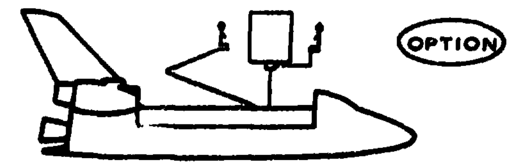
SATELLITE STOWAGE

(7)



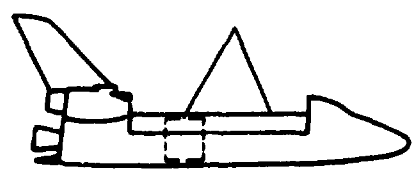
- SATELLITE INACTIVATED BY GROUND COMMAND AND CHECKED-OUT FOR RETURN

(8)



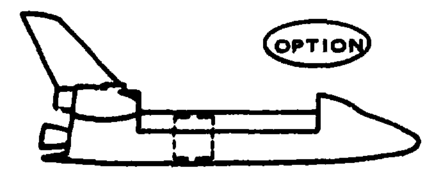
- IMPLEMENT MANUAL REMOVAL/STOWAGE OF SELECTED EQUIPMENT VIA HPA AND RMS/OCP, IF REQUIRED

(9)



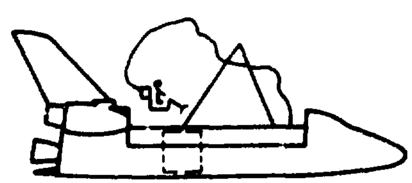
- RMS TRANSFERS SATELLITE TO RETENTION STRUCTURE
- RETENTION LATCHES LOCKED

(10)



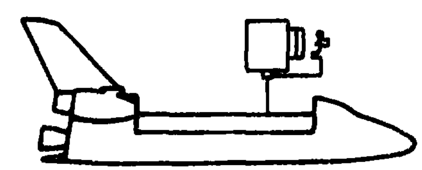
- UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

BACKUP FOR RETENTION LATCH HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL ASSIST
  OR
  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- WORK STATION ON HPA IS UTILIZED
  OR
  MFR/RMS DEPLOYED FOR MANUAL ASSIST

ER5 ALTERNATE NO. 2 EARTH RETURN SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - COOPERATIVE NOMINAL (MMS-TYPE) PAYLOADS - RMS/HPA USAGE - MANNED RETRIEVAL OF SATELLITES AT 1000 FT SEPARATION

Earth Return

ER5 Alternate No. 2 Earth Return Sequence

POM-MMU/WRU Deployment/Payload Retrieval

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MMU	1	8
5.	Final POM Status/Health Checks	5	13
6.	Lock Into MMU	2	15
7.	Translate To POM-WRU	2	17
8.	Lock Into POM-WRU	2	19
9.	Translate Manned POM To Satellite	15*	34
10.	POM Docking With Satellite	2	36
11.	(Retract Satellite Appendages)	10	46
12.	(Deactivate Satellite ACS)	-	-
13.	Translate Satellite Close To Orbiter	15*	61
14.	Attach RMS To Satellite	2	63
15.	Detach POM From Satellite	2	65
16.	(Satellite Berthed To HPA)	5	70
17.	(Transfer Satellite To Orbiter Power)	2	72
18.	(Satellite Inactivated By Ground Command)	2	74
19.	(RMS Translates Satellite To Storage Area)	5	79
20.	Translate POM-MMU/ To PLB AESA	14	93
21.	Unlock From POM-WRU Translate To MMU/RSS	5	98
22.	Unlock From MMU/WRU	1	99
23.	Prepare POM-MMU/WRU For Re-entry	34	133
24.	Translate To Tool Storage	1	134
25.	Return Equipment	5	139
26.	Translate To Air Lock	1	140
27.	Enter Air Lock	1	141

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

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HAMILTON STANDARD

ER5 Alternate No. 2 Earth Return Sequence

Backup For Retention Latch Hangup

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MMU	1	8
5.	Final POM Status/Health Checks	5	13
6.	Lock Into MMU	2	15
7.	Translate To POM-WRU	2	17
8.	Lock Into POM-WRU	2	19
9.	Translate Manned POM To Satellite	15*	34
10.	POM Docking With Satellite	2	36
11.	(Retract Satellite Appendages)	10	46
12.	(Deactivate Satellite ACS)	-	-
13.	Translate Satellite Close To Orbiter	15*	61
14.	Attach RMS To Satellite	2	63
15.	Detach POM From Satellite	2	65
16.	(Satellite Berthed To HPA)	5	70
17.	(Transfer Satellite To Orbiter Power)	2	72
18.	(Satellite Inactivated By Ground Command)	2	74
19.	(RMS Translates To Storage Area)	5	79
20.	(RMS Stows Satellite)	5	84
21.	Translate To Retention Latch	14	98
22.	Manually Latch Retention Latch	10	108
23.	Translate POM-MMU/WRU To PLB AESA	14	122
24.	Unlock From MMU/WRU	1	123
25.	Prepare POM-MMU And WRU For Re-entry	34	157
26.	Translate To Tool Storage	1	158
27.	Return Equipment	5	163
28.	Translate To Air Lock	1	164
29.	Enter Air Lock	1	165

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

Earth Return

ER5 Alternate No. 2 Earth Return Sequence

Backup For Appendage Hangup

		Task Time (Min.)	Cum. Time (Min.
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MMU	1	8
5.	Final POM Status/Health Checks	5	13
6.	Lock Into MMU	2	15
7.	Translate To POM-WRU	2	17
8.	Lock Into POM-WRU	2	19
9.	Translate Manned POM To Satellite	15*	34
10.	POM Docking With Satellite	2	36
11.	(Retract Satellite Appendages)	10	46
12.	(Deactivate Satellite ACS)	-	-
13.	Translate Satellite Close To Orbiter	15*	61
14.	Attach RMS To Satellite	2	63
15.	Detach POM From Satellite	2	65
16.	(Satellite Berthed To HPA)	5	70
17.	(Transfer Satellite To Orbiter Power)	2	72
18.	Translate POM-MMU/WRU To PLB AESA	14	86
19.	Unlock From MMU/WRU	1	87
20.	Translate To OCP/Work Station	1	88
21.	Lock Into OCP	1	89
22.	Translate OCP To Appendage	2	91
23.	Repair Appendage Malfunction	10	101
24.	Translate OCP To Storage Position	2	103
25.	(Satellite Inactivated By Ground Command)	(2)**	-
26.	(RMS Translates Satellite To Stowage Area)	(5)**	-
27.	(RMS Stows Satellite)	(5)**	-
28.	Unlock From OCP	1	104
29.	Translate To PLB AESA	1	105
30.	Prepare POM-MMU/WRU For Re-entry	34	139
31.	Translate To Tool Storage	1	140
32.	Return Equipment	5	145
33.	Translate To Air Lock	1	146
34.	Enter Air Lock	1	147

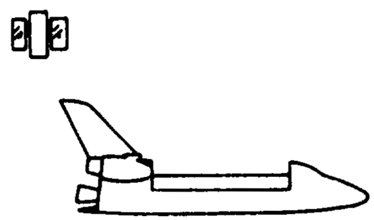
* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Not Included In Cumulative Time Since Operation Will Occur Simultaneously With EVA Activities

UNITED TECHNOLOGIES
HAMILTON STANDARD

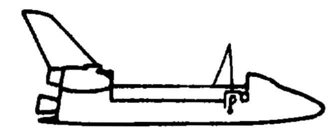
FOLDOUT FRAME 1

MANNED-POM DEPLOYMENT/PAYLOAD RETRIEVAL



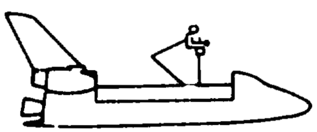
(1)

- SATELLITE SAFING, PROPELLANT VENTING, PREPARATIONS FOR RENDEZVOUS
- SATELLITE ACS IS ACTIVE TO MAINTAIN STABILITY
- ORBITER RENDEZVOUS WITH SATELLITE TO 1000 FT SEPARATION DISTANCE



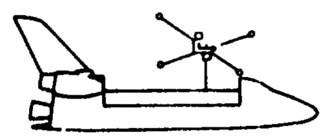
(2)

- PROXIMITY OPERATIONS MODULE (POM), MANNED VERSION, STOWED IN RETENTION STRUCTURE
- STATUS/HEALTH CHECKS VIA UMBILICAL IN RETENTION STRUCTURE (COMM VIA ORBITER S-BAND)
- EVA CREWMAN MOUNTS POM-MANNED VERSION
- RMS ATTACHES TO POM MANNED VERSION



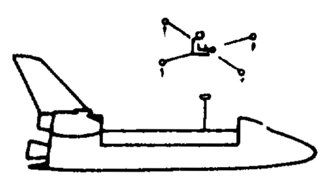
(3)

- POM RELEASED FROM RETENTION STRUCTURE/UMBILICAL
- RMS BERTHS POM TO HPA AND UMBILICALS VERIFIED
- TRANSFER POM TO ORBITER POWER TO MAINTAIN THERMAL CONTROL



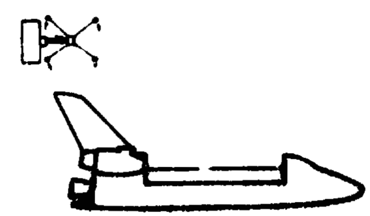
(4)

- ACTIVATION OF POM SUBSYSTEMS VIA ORBITER COMMAND (COMM VIA ORBITER)
- POM APPENDAGES DEPLOYED BY ORBITER COMMAND AND VERIFIED BY ORBITER CREW
- FINAL STATUS/HEALTH CHECKS PRIOR TO DEPLOYMENT (COMM VIA ORBITER)



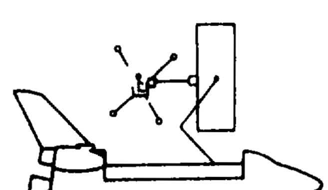
(5)

- TRANSFER POM TO INTERNAL POWER
- HPA RELEASES MANNED POM TO EXAMINE AND RETRIEVE SATELLITE
- POM INITIATES CLOSURE MANEUVER



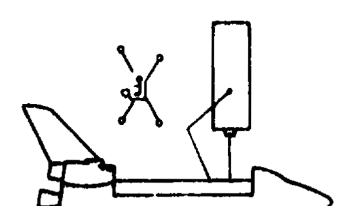
(6)

- POM DOCKS TO SATELLITE GRAPPLE FITTING
- SATELLITE APPENDAGES RETRACTED
- SATELLITE ACS INACTIVATED



(7)

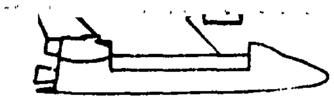
- MANNED POM TRANSPORTS SATELLITE TO ORBITER



(8)

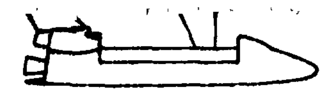
- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTIONS VERIFI

7



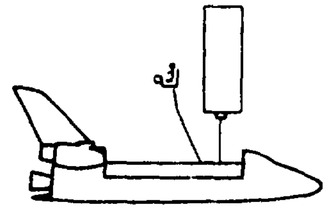
- MANNED POM TRANSPORTS SATELLITE TO ORBITER WITHIN RMS REACH DISTANCE
- RMS ATTACHES TO SATELLITE (POM ACS ACTIVE)
- DEACTIVE SATELLITE BY GROUND COMMAND
- POM SEPARATES FROM SATELLITE

8



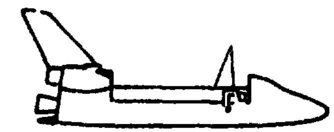
- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTIONS VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

9



- RMS ATTACHES TO MANNED POM AND ELEVATED WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS
- POM APPENDAGES RETRACTED
- POM INACTIVATED, CHECKED OUT FOR STOWAGE AND RETURN

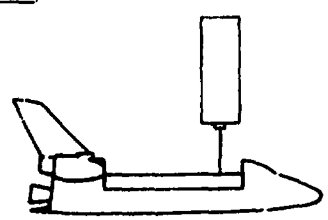
10



- POM STOWED IN RETENTION STRUCTURE, RETENTION LATCHES LOCKED

SATELLITE STOWAGE

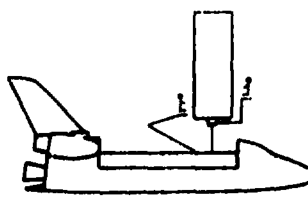
11



- SATELLITE INACTIVATED BY GROUND COMMAND AND CHECKED-OUT FOR RETURN

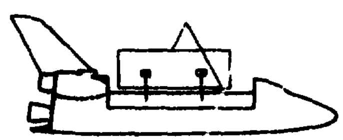
12

OPTION



- IMPLEMENT MANUAL REMOVAL/STOWAGE OF SELECTED EQUIPMENT VIA HPA AND RMS/OCP IF REQUIRED

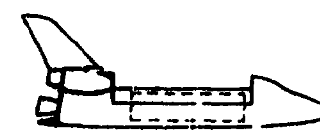
13



- RMS TRANSFERS SATELLITE TO PIDA
- PIDA LOWERS SATELLITE IN RETENTION STRUCTURE
- RETENTION LATCHES LOCKED

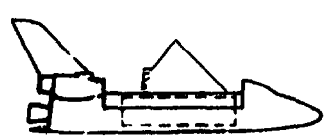
14

OPTION



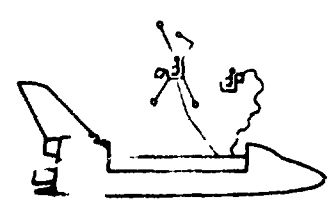
- UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

BACKUP FOR RETENTION LATCH HANGUP



- MFR/RMS DEPLOYED FOR MANUAL ASSIST
  OR
  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- MMU/WRU WITH STABILIZER DEPLOYED FOR MANUAL ASSIST

ER6 ALTERNATE NO. 2 EARTH RETURN SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - COOPERATIVE LARGE SATELLITES - RMS/HPA USAGE - MANNED RETRIEVAL OF SATELLITES AT 1000 FT. SEPARATION

FOLDOUT FRAME 2

UNITED TECHNOLOGIES
HAMILTON STANDARD

Earth Return

ER6 Alternate No. 2 Earth Return Sequence

Manned POM Deployment/Payload Retrieval

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To OM	1	8
5.	Final POM Status/Health Checks	5	13
6.	Lock Into POM	2	15
7.	RMS Attaches To POM	2	17
8.	Release POM From Retention Structure Umbilical	2	19
9.	RMS Berths POM To HPA	5	24
10.	Transfer POM To Orbiter Power	2	26
11.	Activate POM Subsystems	2	28
12.	Deploy POM Appendages	10	38
13.	Final POM Status/Health Checks	5	43
14.	Transfer POM To Internal Power	2	45
15.	HPA Release Of Manned POM	2	47
16.	Translate Manned POM To Satellite	15*	62
17.	POM Docking With Satellite	2	64
18.	(Retract Satellite Appendages)	10	74
19.	(Deactivate Satellite ACS)	-	-
20.	Translate Satellite Close To Orbiter	15*	89
21.	Attach RMS To Satellite	2	91
22.	Separate POM From Satellite	2	93
23.	Standby (Satellite Berthed To HPA)	5	98
24.	Attach RMS To POM	2	100
25.	Retract POM Appendages	10	110
26.	Inactivate POM Subsystems	2	112
27.	Final POM Stowage Status/Health Checks	5	117
28.	Translate POM To Storage Position	5	122
29.	Stow POM	5	127
30.	(Detach RMS From POM)	2	129
31.	Unlock From POM	1	130
32.	Standby		
33.	(RMS Attaches To Satellite)	2	132
34.	(RMS Transfers Satellite To PIDA)	5	137
35.	(PIDA Lowers Satellite Into Structure)	5	142
36.	(Retention Latches Locked)	-	-
37.	Translate To Tool Storage	1	143
38.	Return Equipment	5	148
39.	Translate To Air Lock	1	149
40.	Enter Air Lock	1	150

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

UNITED TECHNOLOGIES HAMILTON STANDARD

Earth Return

ER6 Alternate No. 2 Earth Return Sequence

Backup For Retention Latch Hangup

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To POM	1	8
5.	Final POM Status/Health Checks	5	13
6.	Lock Into POM	2	15
7.	RMS Attaches To POM	2	17
8.	Release POM From Retention Structure Umbilical	2	19
9.	RMS Berths POM To HPA	5	24
10.	Transfer POM To Orbiter Power	2	26
11.	Activate POM Subsystems	2	28
12.	Deploy POM Appendages	10	38
13.	Final POM Status/Health Checks	5	43
14.	Transfer POM To Internal Power	2	45
15.	HPA Release Of Manned POM	2	47
16.	Translate Manned POM To Satellite	15*	62
17.	POM Docking With Satellite	2	64
18.	(Retract Satellite Appendages)	10	74
19.	(Deactivate Satellite ACS)	-	-
20.	Translate Satellite Close To Orbiter	15*	89
21.	Attach RMS To Satellite	2	91
22.	Separate POM From Satellite	2	93
23.	Standby (Satellite Berthed To HPA)	5	98
24.	Attach RMS To POM	2	100
25.	Retract POM Appendages	10	110
26.	Inactivate POM Subsystems	2	112
27.	Final POM Stowage Status/Health Checks	5	117
28.	Translate POM To Storage Position	5	122
29.	Stow POM	5	127
30.	(Detach RMS From POM)	2	129
31.	Unlock From POM	1	130
32.	Standby		
33.	(RMS Attaches To Satellite)	2	132
34.	(RMS Transfers Satellite To PIDA)	5	137
35.	(PIDA Lowers Satellite Into Structure)	5	142
36.	(Retention Latch Problem Identified)	-	-
37.	Translate To MFR/RMS	1	143
38.	Attach MFR Into RMS End Effector	.5	143.5
39.	Lock Into MFR	.5	144
40.	Translate RMS To Retention Latch	1.5**	145.5
41.	Manually Latch Retention Latch	10	155.5
42.	Translate RMS To Storage Position	1.5**	157
43.	Unlock From MFR	.5	157.5
44.	Detach MFR From RMS End Effector	.5	158
45.	Translate To Tool Storage	1	159
46.	Return Equipment	5	164
47.	Translate To Air Lock	1	165
48.	Enter Air Lock	1	166

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

** Time Line Approximates 1.5 Minutes With Computer Control Of RMS

Earth Return

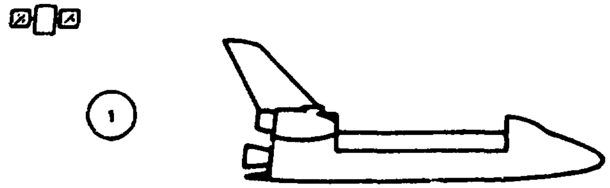
ER6 Alternate No. 2 Earth Return Sequence

Backup For Appendage Hangup

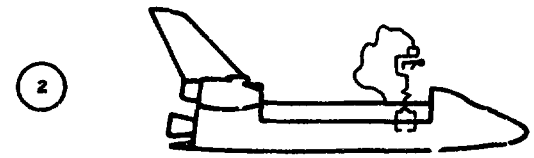
	POM	MMU/WRU	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To POM		1	8
5.	Final POM Status/Health Checks		5	13
6.	Lock Into POM		2	15
7.	RMS Attaches To POM		2	17
8.	Release POM From Retention Structure Umbilical		2	19
9.	RMS Berths POM To HPA		5	24
10.	Transfer POM To Orbiter Power		2	26
11.	Activate POM Subsystems		2	28
12.	Deploy POM Appendages		10	38
13.	Final POM Status/Health Checks		5	43
14.	Transfer POM To Internal Power		2	45
15.	HPA Release Of Manned POM		2	47
16.	Translate Manned POM To Satellite		15*	62
17.	POM Docking With Satellite		2	64
18.	Retract Satellite Appendages		10	74
19.	Deactivate Satellite ACS		-	-
20.	Translate Satellite Close To Orbiter		15*	89
21.	Attach RMS To Satellite		2	91
22.	Separate POM From Satellite		2	93
23.	(Satellite Berthed To HPA)		5	98
24.	Attach RMS To POM		2	100
25.	Retract POM Appendages	Leave Air Lock	10/1	110
26.		Translate To Tool Storage	1	111
27.		Obtain Equipment	5	116
28.		Translate To MMU Lock Into MMU	2	118
29.		Translate To WRU Lock Into WRU	1	119
30.		Translate To POM Appendage	14	133
31.		Repair POM Appendage	10	143
32.	Inactivate POM Subsystems	Standby	2/-	145
33.	Final POM Stowage Status/Health Checks		5	150
34.	Translate POM To Storage Position		5	155
35.	Stow POM		5	160
36.	(Detach RMS From POM)		2	162
37.	Unlock From POM		1	163
38.	Standby		-	-
39.	(RMS Attaches To Satellite)		2	165
40.	(RMS Transfers Satellite To PIDA)	Translate MMU/WRU To PLB AESA	5/14	179
41.	(PIDA Lowers Satellite Into Structure)	Unlock From [illegible]/WRU	5/1	180
42.	(Retention Latches Locked)	Configure M[illegible]d WRU For Re-entry	-/34	214
43.	Translate To Tool Storage	Translate To Tool Storage	1/[illegible]	215
44.	Return Equipment	Return Equipment	5/5	220
45.	Translate To Air Lock	Translate To Air Lock	1/1	221
46.	Enter Air Lock	Enter Air Lock	1/1	[illegible]2

* Time Line Approximates 15 Minutes Depending Upon Satellite Distance From Orbiter

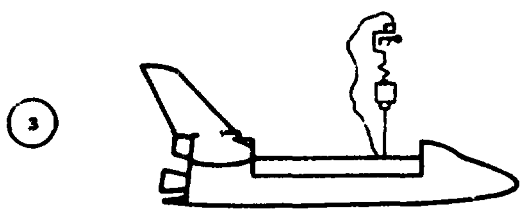
POM-MTV DEPLOYMENT/PAYLOAD RETRIEVAL



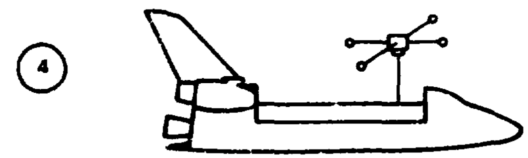
- SATELLITE SAFING, PROPELLANT VENTING, PREPARATIONS FOR RENDEZVOUS
- SATELLITE ACS IS ACTIVE TO MAINTAIN STABILITY
- ORBITER RENDEZVOUS WITH SATELLITE TO 1000 FT SEPARATION DISTANCE



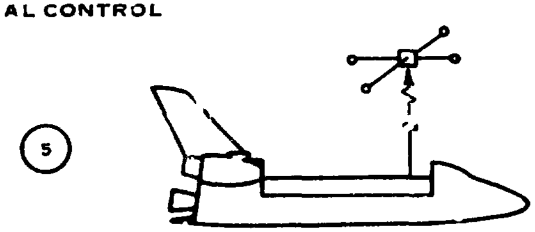
- PROXIMITY OPERATIONS MODULE – MTV ADAPTATION (POM-MTV) STOWED IN RETENTION STRUCTURE
- STATUS/HEALTH CHECKS VIA UMBILICAL IN RETENTION STRUCTURE (COMM VIA ORBITER S-BAND)
- MMU/WRU WITH RMS END-EFFECTOR ATTACHES TO POM-MTV



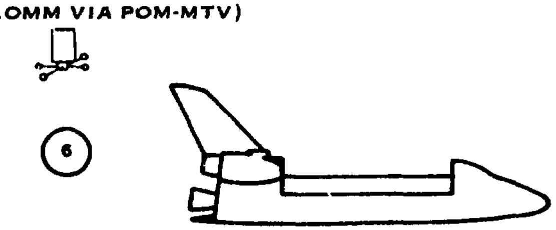
- POM-MTV RELEASED FROM RETENTION STRUCTURE/ UMBILICAL
- MMU/WRU BERTHS POM-MTV TO HPA AND UMBILICAL VERIFIED
- TRANSFER POM-MTV TO ORBITER POWER TO MAINTAIN THERMAL CONTROL



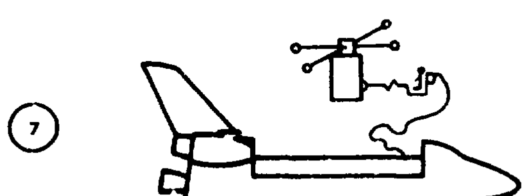
- ACTIVATION OF SELECTED POM-MTV SUBSYSTEMS VIA GROUND LINK (COMM VIA POM-MTV)
- POM-MTV APPENDAGES DEPLOYED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- FINAL STATUS/HEALTH CHECKS PRIOR TO DEPLOYMENT (COMM VIA POM-MTV)



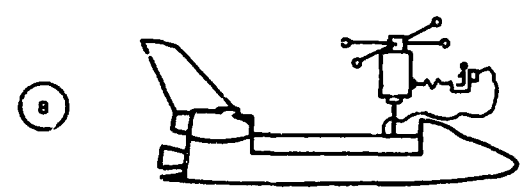
- TRANSFER POM-MTV TO INTERNAL POWER
- HPA RELEASES POM-MTV AT ~ 1 FT/SEC VELOCITY TO EXAMINE AND RETRIEVE SATELLITE (MMU/WRU MANNED POM DEPLOYMENT IS ALTERNATE)



- POM-MTV DOCKS TO SATELLITE GRAPPLE FITTING
- SATELLITE APPENDAGES RETRACTED
- SATELLITE ACS INACTIVATED



- POM-MTV TRANSPORTS SATELLITE TO ORBITER WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS
- MMU/WRU ATTACHES TO SATELLITE (POM ACS ACTIVE)
- DEACTIVATE SATELLITE BY GROUND COMMAND

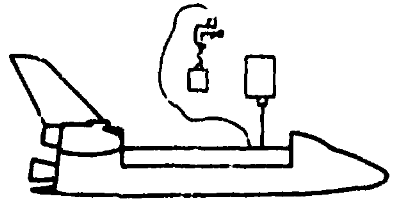


- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTIONS VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL
- ACTIVATE ORBITER'S NON-CONTAMINATING ACS PACKAGE

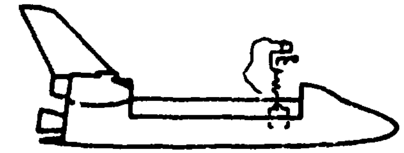
- POM-MTV TRANSPORTS SATELLITE TO ORBITER WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS
- MMU/WRU ATTACHES TO SATELLITE (*POM ACS ACTIVE*)
- DEACTIVATE SATELLITE BY GROUND COMMAND

- SATELLITE BERTHED TO HPA AND UMBILICAL CONNECTIONS VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL
- ACTIVATE ORBITER'S NON-CONTAMINATING ACS PACKAGE OR PLACE ORBITER IN FREE DRIFT

(9)



(10)

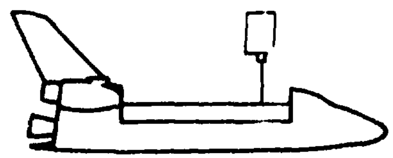


- MMU/WRU ATTACHES TO POM-MTV, RELEASES FROM SATELLITE AND ELEVATES WITHIN VIEW OF AFD/PAYLOAD BAY TV CAMERAS
- POM-MTV APPENDAGES RETRACTED
- POM-MTV INACTIVATED, CHECKED OUT FOR STOWAGE AND RETURN

- POM-MTV STOWED IN RETENTION STRUCTURE, RETENTION LATCHES LOCKED

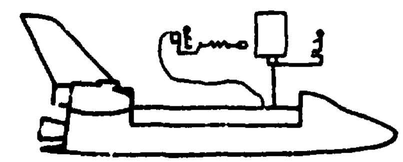
SATELLITE STOWAGE

(11)



OPTION

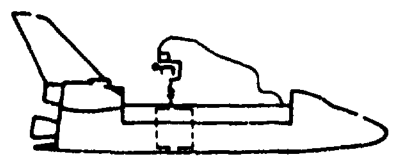
(12)



- SATELLITE INACTIVATED BY GROUND COMMAND AND CHECKED-OUT FOR RETURN

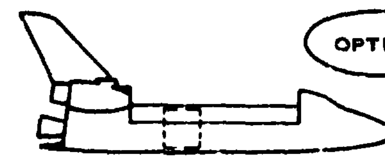
- IMPLEMENT MANUAL REMOVAL/STOWAGE OF SELECTED EQUIPMENTS VIA HPA, IF REQUIRED

(13)



OPTION

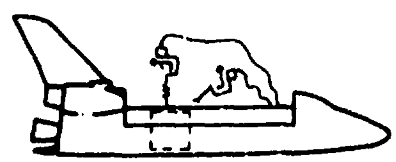
(14)



- MMU/WRU TRANSFERS SATELLITE TO RETENTION STRUCTURE
- RETENTION LATCHES LOCKED

- UMBILICAL CONNECTION VERIFIED
- TRANSFER SATELLITE TO ORBITER POWER TO MAINTAIN THERMAL CONTROL

BACKUP FOR RETENTION LATCH HANGUP

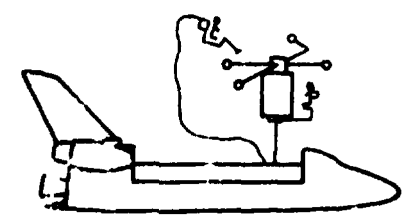


- FIRST MMU/WRU MAINTAINS STABILITY/POSITION OF SATELLITE IN PAYLOAD BAY
- SECOND MMU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE

  OR

  EVA VIA HANDRAILS EMPLOYED

BACKUP FOR APPENDAGE HANGUP



- WORK STATION ON HPA IS UTILIZED

  OR

  MMU WITH STABILIZER DEPLOYED FOR MANUAL RELEASE

ER8 ALTERNATE NO. 3 EARTH RETURN SEQUENCE - DIRECT DELIVERY PAYLOAD CLASS - COOPERATIVE CONTAMINATION SENSITIVE SATELLITE - HPA USAGE - RMS INOPERATIVE - UNMANNED RETRIEVAL OF SATELLITES AT 1000 FT. SEPARATION

FOLDOUT FRAME 2

UNITED TECHNOLOGIES
HAMILTON STANDARD

Earth Return

ER8 Alternate No. 3 Earth Return Sequence

POM-MTV Deployment/Payload Retrieval

		Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock	1	1
2.	Translate To Tool Storage	1	2
3.	Obtain Equipment	5	7
4.	Translate To MMU Lock Into MMU	2	9
5.	Translate To WRU Lock Into WRU	1	10
6.	Translate MMU/WRU To POM-MTV Stowage Area	14	24
7.	Attach MMU/WRU To POM-MTV	2	26
8.	Translate POM-MTV To HPA	14	40
9.	MMU/WRU Berths POM-MTV To HPA	5	45
10.	Transfer POM-MTV To Orbiter Power	2	47
11.	Translate Away From POM-MTV	7	54
12.	Standby	20*	74
13.	Translate MMU/WRU To POM-MTV Satellite	7	81
14.	MMU/WRU Docking With Satellite	2	83
15.	Translate Satellite To HPA	14	97
16.	MMU/WRU Berths Satellite To HPA	5	102
17.	Translate MMU/WRU To POM-MTV	7	109
18.	Attach MMU/WRU To POM-MTV	2	111
19.	Translate POM-MTV Away From Satellite	7	118
20.	Retract POM Appendages	10	128
21.	Inactivate POM Subsystems	2	130
22.	Final POM Stowage Status/Health Checks	5	135
23.	Translate POM To Storage Position	14	149
24.	Stow POM/MTV	5	154
25.	Translate MMU/WRU To Satellite	14	168
26.	Attach MMU/WRU To Satellite	2	170
27.	Release Satellite From HPA	2	172
28.	Translate Satellite To Stowage Area	14	186
29.	Stow Satellite	5	191
30.	Translate MMU/WRU To PLB AESA	14	205
31.	Unlock From MMU/WRU	1	206
32.	Prepare MMU And WRU For Re-entry	34	240
33.	Translate To Tool Storage	1	241
34.	Return Equipment	5	246
25.	Tranlsate To Air Lock	1	247
36.	Enter Air Lock	1	248

* Time Line Approximates 20 Minutes Depending Upon Satellite Distance From Orbiter

Earth Return

ER8 Alternate No. 3 Earth Return Sequence

Backup For Retention Latch Hangup

	MMU/WRU	MMU/WRU	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To POM-MTV Stowage Area		14	24
7.	Attach MMU/WRU To POM-MTV		2	26
8.	Translate POM-MTV To HPA		14	40
9.	MMU/WRU Berths POM-MTV To HPA		5	45
10.	Transfer POM-MTV To Orbiter Power		2	47
11.	Translate Away From POM-MTV		7	54
12.	Standby		20*	74
13.	Translate MMU/WRU To POM-MTV-Satellite		7	81
14.	MMU/WRU Docking With Satellite		2	83
15.	Translate Satellite To HPA		14	97
16.	MMU/WRU Berths Satellite To HPA		5	102
17.	Translate MMU/WRU To POM-MTV		7	109
18.	Attach MMU/WRU To POM-MTV		2	111
19.	Translate POM-MTV Away From Satellite		7	118
20.	Retract POM Appendages		10	128
21.	Inactivate POM Subsystems		2	130
22.	Final POM Stowage Status/Health Checks		5	135
23.	Translate POM To Storage Area		14	149
24.	Stow POM/MTV		5	154
25.	Translate MMU/WRU To Satellite		14	168
26.	Attach MMU/WRU To Satellite		2	170
27.	Release Satellite From HPA		2	172
28.	Translate Satellite To Stowage Area		14	186
29.	Stow Satellite	Leave Air Lock	5/1	191
30.		Translate To Tool Storage	1	192
31.		Obtain Equipment	5	197
32.		Translate To MMU Lock Into MMU	2	199
33.		Translate To WRU Lock Into WRU	1	200
34.		Translate MMU/WRU To Retention Latch	14	214
35.		Manually Latch Retention Latch	10	224
36.	Translate MMU/WRU To PLB AESA	Translate MMU/WRU To PLB AESA	14/14	238
37.	Unlock From MMU/WRU	Unlock From MMU/WRU	1/1	239
38.	Prepare MMU And WRU For Re-entry	Prepare MMU And WRU For Re-entry	34/34	273
39.	Translate To Tool Storage	Translate To Tool Storage	1/1	274
40.	Return Equipment	Return Equipment	5/5	279
41.	Translate To Air Lock	Translate To Air Lock	1/1	280
42.	Enter Air Lock	Enter Air Lock	1/1	281

* Time Line Approximates 20 Minutes Depending Upon Satellite Distance From Orbiter

Earth Return

ER8 Alternate No. 3 Earth Return Sequence

Backup For Appendage Hangup

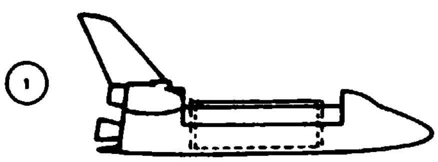
	MMU/WRU	MMU/WRU	Task Time (Min.)	Cum. Time (Min.)
1.	Leave Air Lock		1	1
2.	Translate To Tool Storage		1	2
3.	Obtain Equipment		5	7
4.	Translate To MMU Lock Into MMU		2	9
5.	Translate To WRU Lock Into WRU		1	10
6.	Translate MMU/WRU To POM-MTV Stowage Area		14	24
7.	Attach MMU/WRU To POM-MTV		2	26
8.	Translate POM-MTV To HPA		14	40
9.	MMU/WRU Berths POM-MTV To HPA		5	45
10.	Transfer POM-MTV To Orbiter Power		2	47
11.	Translate Away From POM-MTV		7	54
12.	Standby		20*	74
13.	Translate MMU/WRU To POM-MTV-Satellite		7	81
14.	MMU/WRU Docking With Satellite		2	83
15.	Translate Satellite To HPA		14	97
16.	MMU/WRU Berths Satellite To HPA		5	102
17.	Translate MMU/WRU To POM-MTV		7	109
18.	Attach MMU/WRU To POM-MTV		2	111
19.	Translate POM-MTV Away From Satellite		7	118
20.	Retract POM Appendages	Leave Air Lock	10/1	128
21.		Translate To Tool Storage	1	129
22.		Obtain Equipment	5	134
23.		Translate To MMU Lock Into MMU	2	136
24.		Translate To WRU Lock Into WRU	1	137
25.		Translate MMU/WRU To Appendage	14	151
26.		Repair Appendage Malfunction	10	161
27.		Translate Away From POM	7	168
28.		Standby	-	-
29.	Inactivate POM Subsystems		2	170
30.	Final POM Stowage Status/Health Checks		5	175
31.	Translate POM To Storage Position		14	189
32.	Stow POM-MTV		5	194
33.	Translate MMU/WRU To Satellite		14	208
34.	Attach MMU/WRU To Satellite		2	210
35.	Release Satellite From HPA		2	212
36.	Translate Satellite To Stowage Area		14	226
37.	Stow Satellite		5	231
38.	Translate MMU/WRU To PLB AESA	Translate MMU/WRU To PLB AESA	14/14	245
39.	Unlock From MMU/WRU	Unlock From MMU/WRU	1/1	246
40.	Prepare MMU And WRU For Re-entry	Prepare MMU And WRU For Re-entry	34/34	280
41.	Transfer To Tool Storage	Translate To Tool Storage	1/1	281
42.	Return Equipment	Return Equipment	5/5	286
43.	Translate To Air Lock	Translate To Air Lock	1/1	287
44.	Enter Air Lock	Enter Air Lock	1/1	208

* Time Line Approximates 20 Minutss Depending Upon Satellite Distance From Orbiter

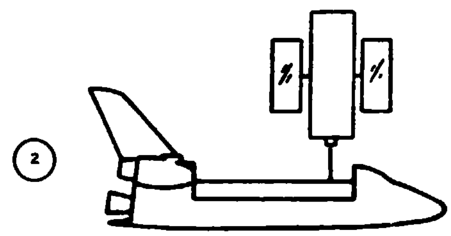
UNITED TECHNOLOGIES
HAMILTON STANDARD

APPENDIX B

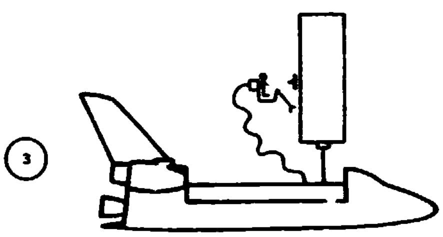
Although not considered a prime EVA operation, an orbital storage timeline analysis was incorporated for completeness of task coverage.



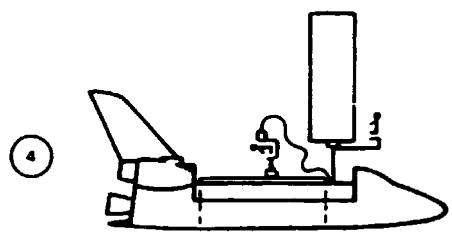
- PAYLOAD STOWED IN THERMAL ENCLOSURE ON ORBIT



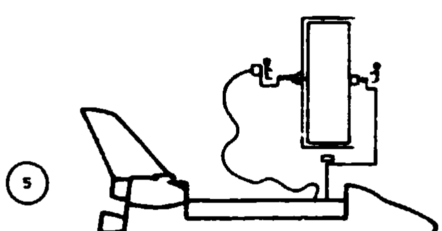
- CHECKOUT/PREPARATION FOR DEPLOYMENT INDICATES MALFUNCTION PRECLUDING OPERATIONAL DEPLOYMENT
- PREPARE SPACECRAFT FOR ORBITAL STORAGE
- SATELLITE ON ORBITER POWER TO MAINTAIN THERMAL CONTROL



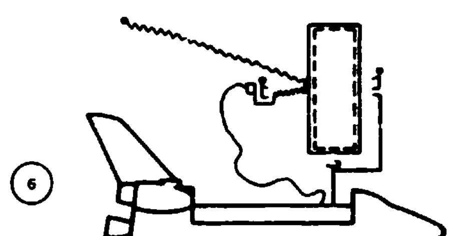
- SATELLITE APPENDAGES RETRACTED BY GROUND COMMAND AND VERIFIED BY ORBITER CREW
- MMU/WRU WITH STABILIZER DEPLOYED TO ATTACH ADDITIONAL GRAPPLE FIXTURE



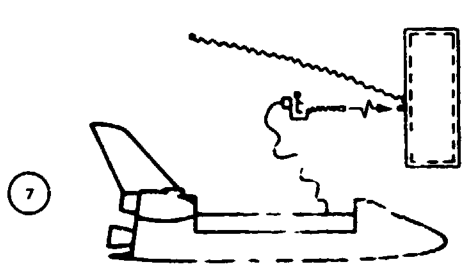
- SATELLITE INACTIVATED BY GROUND COMMAND AND CHECKED OUT FOR STORAGE
- MMU/WRU WITH RMS END EFFECTOR ATTACHES TO THERMAL ENCLOSURE



- HPA WORK PLATFORM'S RMS END EFFECTOR ATTACHED TO SATELLITE GRAPPLE FIXTURE
- SATELLITE RELEASED FROM HPA
- HPA WORK PLATFORM (VIA GRAPPLE ATTACHMENT) ELEVATES SATELLITE
- THERMAL ENCLOSURE RETENTION LATCHES RELEASED
- MMU/WRU TRANSFERS THERMAL ENCLOSURE OVER SATELLITE AND ATTACHES TO GRAPPLE FIXTURE



- THERMAL ENCLOSURE ACTIVATES TO ENVELOP SATELLITE
- GRAVITY STABILIZATION BOOM DEPLOYED FROM THERMAL ENCLOSURE



- MMU WRU RELEASES SATELLITE AT ~ 1 FT SEC VELOCITY

OS4 ORBITAL STORAGE OPTION - HPA USAGE - RMS INOPERATIVE - SATELLITES > 15 FT. LENGTH

UNITED TECHNOLOGIES HAMILTON STANDARD

ORBITAL STORAGE

OS4 ORBITAL STORAGE OPTION

HPA USAGE, RMS INOPERATIVE

MMU/WRU	HPA/WORK STATION	TASK TIME (MIN.)	CUM. TIME (MIN.)
1 LEAVE AIR LOCK	LEAVE AIR LOCK	1/1	1
2. TRANSLATE TO TOOL STORAGE	TRANSLATE TO TOOL STORAGE	1/1	2
3. OBTAIN EQUIPMENT	OBTAIN EQUIPMENT	5/5	7
4. TRANSLATE TO MMU LOCK INTO MMU	TRANSLATE TO HPA/WORK STATION	2/1	9
5. TRANSLATE TO WRU LOCK INTO WRU	LOCK INTO OCP	1/1	10
6. TRANSLATE MMU/WRU TO SATELLITE	TRANSLATE OCP TO SATELLITE GRAPPLE FIXTURE	14/2	24
7. ATTACH GRAPPLE FIXTURE TO SATELLITE	ATTACH HPA END EFFECTOR TO SATELLITE	10/2	34
8. TRANSLATE MMU/WRU TO THERMAL ENCLOSURE	RELEASE SATELLITE FROM HPA	14/2	48
9 ATTACH MMU/WRU TO THERMAL ENCLOSURE	ELEVATE SATELLITE (VIA HPA END EFFECTOR)	2/2	50
10. TRANSLATE THERMAL ENCLOSURE TO SATELLITE	STANDBY	14/–	64
11. MANEUVER THERMAL ENCLOSURE OVER SATELLITE		5/–	69
12. ATTACH THERMAL ENCLOSURE TO GRAPPLE FIXTURE		2/–	71
13. STANDBY	RELEASE SATELLITE FROM HPA END EFFECTOR	–/2	73
14.	TRANSLATE HPA AWAY FROM SATELLITE	–/1	74
15. ACTIVATE THERMAL ENCLOSURE TO ENVELOPE SATELLITE	STANDBY	5/–	79
16. DEPLOY GRAVITY STABILIZATION BOOM		2/–	81
17. STANDBY	TRANSLATE OCP TO STORAGE POSITION	–/2	83
18. TRANSLATE SATELLITE TO DEPLOYMENT AREA	UNLOCK FROM OCP	14/1	97
19. RELEASE SATELLITE FROM MMU/WRU	TRANSLATE TO TOOL STORAGE	2/1	99
20. TRANSLATE MMU/WRU TO PLB AESA	RETURN EQUIPMENT	14/5	113
21. UNLOCK FROM MMU/WRU	TRANSLATE TO MMU/WRU	1/1	114
22. CONFIGURE MMU AND WRU FOR RE-ENTRY	OBTAIN EQUIPMENT	34/5	148
23.	TRANSLATE TO TOOL STORAGE	–/1	—
24.	RETURN EQUIPMENT	–/5	—
25 TRANSLATE TO AIR LOCK	TRANSLATE TO AIR LOCK	1/1	149
26. ENTER AIR LOCK	ENTER AIR LOCK	1/1	150

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