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EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

FINAL REPORT VOLUME SATELLITE SERVICE

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EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

FINAL REPORT
VOLUME 3
SATELLITE SERVICE

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July 1980

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FOREWORD

The Extravehicular Crewman Work System is a study of manned extravehicular activity centering about construction and satellite servicing in Earth orbit.

This report is divided into four volumes:

Volume 1	Executive Summary
Volume 2	Construction
Volume 3	Satellite Service
Volume 4	Program Evolution

This volume, Volume 3, Satellite Service, provides an overview of the work performed in the study.

This study program has been performed under contract by Hamilton Standard for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center over a period from April 1977 to June 1980.

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EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 3, Satellite Service

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The study was conducted at Hamilton Standard with significant contributions made by Dr. Harrison Griswold. We wish to acknowledge valuable comments and input from Mr. William Smith at NASA Headquarters and from Messrs. James Gibson, Alva Hardy, Vernon Bailey, Robert Spann and Manuel Rodriguez of NASA JSC, as well as Dr. Karl Pfitzer of McDonnell Douglas Aeronautics, Messrs. John Scheibel and Kenneth Lambson of ILC-Dover and Mr. William Elkins of Acurex Aerotherm.

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 3, Satellite Service

- **Introduction**
- Satellite Characteristics
- Service Task Requirements
- Service Equipment Concepts
- Service Capability Packages
- Appendices

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INTRODUCTION

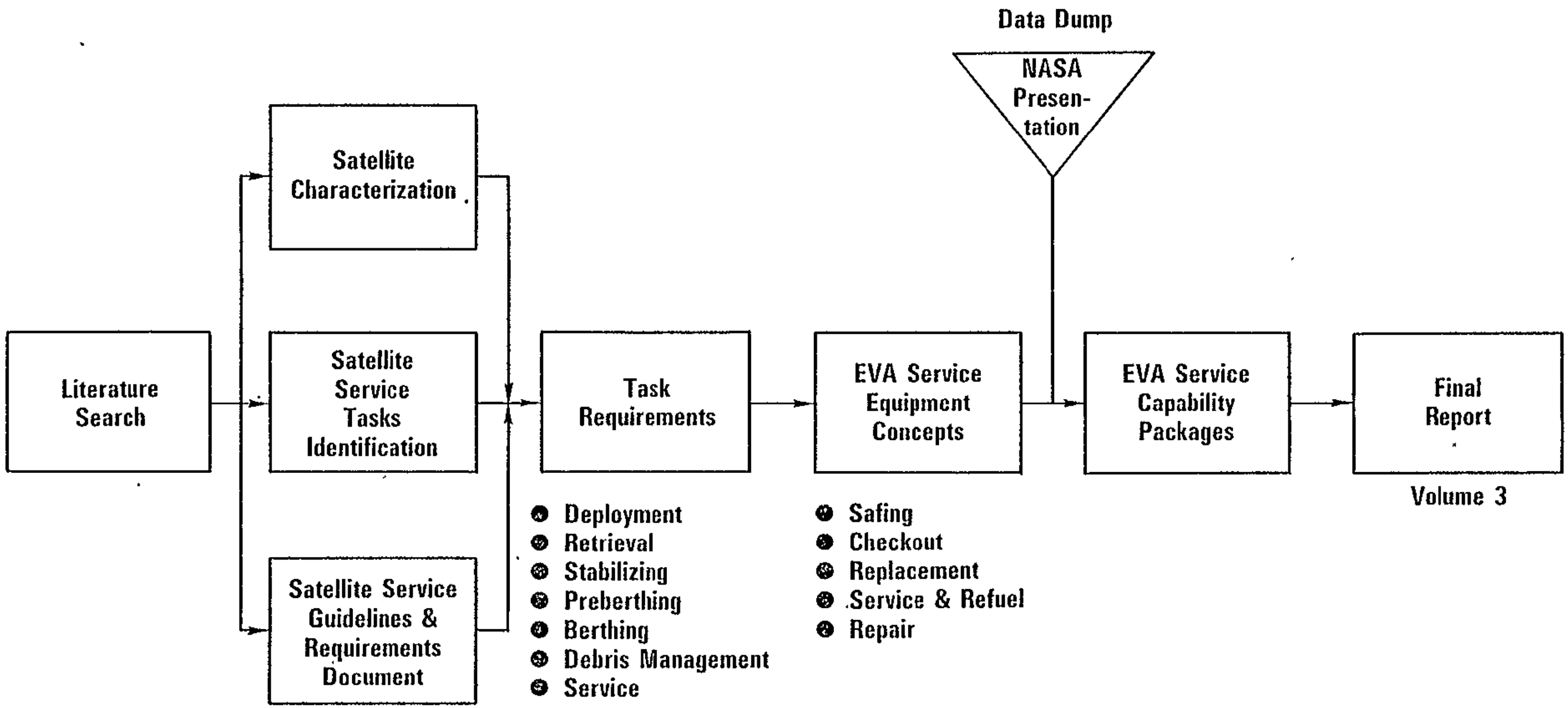
The objective of the satellite service portion of the Extravehicular Crewman Work System (ECWS) Study program is to define requirements and service equipment concepts for performing EVA satellite service from the Space Shuttle Orbiter.

The following conclusions were drawn from this study:

- EVA will be required to support both normal and contingency orbital satellite service.
- Service oriented satellite design practices will be required to provide for on-orbit satellite service capability for the wide variety of satellites at the subsystem level.
- Development of additional Satellite Service equipment is required. The existing Space Transportation System (STS) provides a limited capability for performing satellite service tasks in the Shuttle payload bay area.

The accompanying illustration shows the structure of the satellite service portion of the ECWS study.

ECWS SATELLITE SERVICE STUDY FLOW



ECWS SATELLITE SERVICE REPORT

The ECWS Satellite Service Report covers the following set of program tasks:

- Identify satellite characteristics.
- Identify Satellite Service tasks.
- Define Satellite Service Guideline and Requirements.
- Define task requirements.
- Define EVA Service Equipment Concepts.
- Define Incremental Service Capability Packages.

A literature search preceded the study effort. The following background information was reviewed:

- Satellite population, subsystems and operational characteristics data (period: 1965-1990).
- Shuttle Orbiter subsystems and operational characteristics data.
- Shuttle EMU subsystems and operational characteristics data.
- Technical reports applicable to space-environment EVA.

This material is referenced in Section 7 of this volume.

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 3, Satellite Service

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SATELLITE CHARACTERISTICS

EVA satellite service is based upon considerations involving both the Orbiter and the satellites. The orbiter is the service base and delivers the satellite service supplies and equipment to orbit. The satellite characteristics define what service may be required and the likelihood of being able to perform the service objectives. This report section discusses the following considerations that satellite service:

- Operational capability of EVA.
- Service support capabilities of the Orbiter.
- Satellite population characteristics.
- Examples of representative satellites.

OPERATIONAL CAPABILITY OF EVA

United States Manned Space Flight Programs have accepted EVA as an operational capability for performing mission operations outside spacecraft in earth orbit and in deep space. Examples of man's capability to perform useful EVA tasks in the hostile environment of space are found in past manned space programs such as Gemini, Apollo and Skylab. Using EVA techniques and equipment developed for the Apollo Lunar Program, the $2.5 billion Skylab Program was saved through contingency EVA action performed to repair spacecraft damage sustained during launch. In addition, scheduled EVA was the baseline mode for meeting many scientific experiment objectives of Skylab and Apollo. The Skylab program provides a dramatic example of EVA as a cost-effective, quick-response, adaptable operational technique for accomplishing both scheduled and contingency tasks in space. Man's diagnostic, decision-making, and adaptive capabilities underscore EVA as a powerful operational capability.

The Space Shuttle is ushering in a new era in space exploration and utilization. With the projected high frequency of Shuttle launches as well as the complexity of Shuttle and payload systems, the need for EVA capability to insure mission success is an expected certainty. While EVA will be particularly important in accomplishing orbital tasks associated with Shuttle mission contingencies, it should prove equally important as a capability for performing scheduled tasks associated with Shuttle payloads.

Looking ahead to Shuttle space programs it appears certain that increasing dependence will be made upon EVA as an operational capability to insure mission success. Establishment of EVA's role is required to guide technology planning and development for the next generation of EVA equipment.

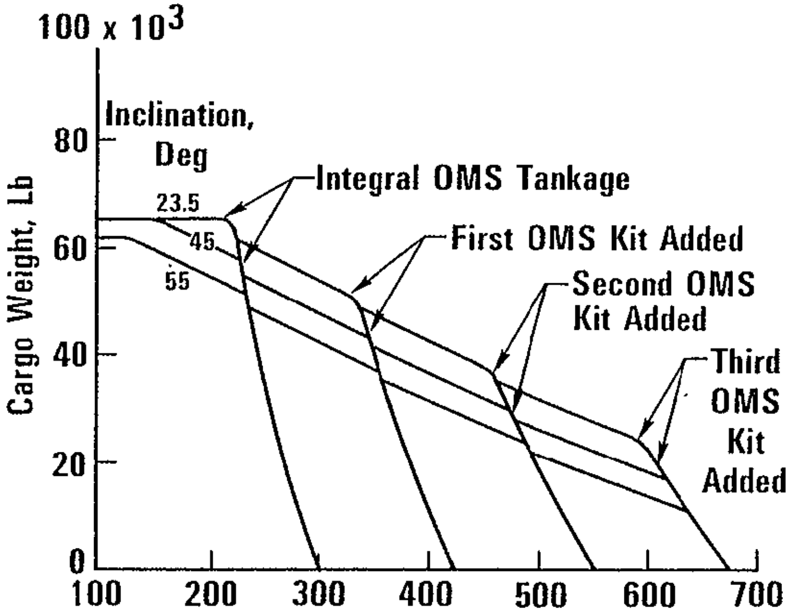
SERVICE SUPPORT CAPABILITIES OF THE SHUTTLE

Limits on Space Shuttle launch capability are imposed by the Shuttle operational envelopes as presented in the accompanying figures for launches from Kennedy Space Center. The figures, which define Shuttle payload delivery and rendezvous capability as functions of altitude and orbital inclination, indicate that the Shuttle is capable of delivery/retrieval of payloads up to an altitude of approximately 600 nautical miles. To reach the higher altitudes (above 200 nautical miles) additional propulsion kits (OMS) will need to be carried aboard the Shuttle, which reflects in the decreased maximum delivery payload with altitude. Similar operational envelope curves exist for Shuttle launches.

Only those spacecraft currently in-orbit or scheduled for delivery whose orbits fall within the Shuttle operational envelope are considered in this study. It is recognized, however, that the effective Shuttle satellite delivery/retrieval operational envelope may be increased substantially through future development of IUS or Teleoperator propulsion modules to be used for payload transport to other low earth orbits, or for transit between LEO and GEO.

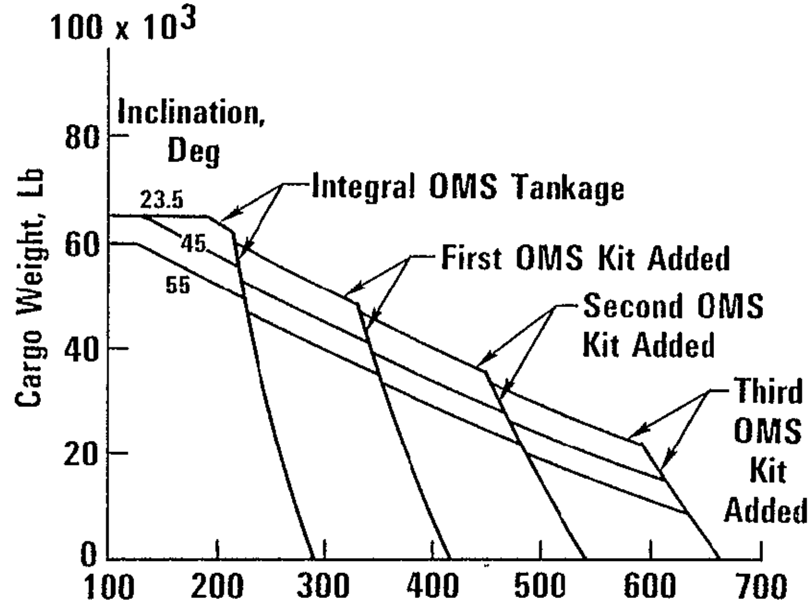
SHUTTLE LAUNCH CAPABILITY

Delivery Only



Maximum Cargo Weights at Various Circular Orbital Altitudes for Flights with Delivery Only

Delivery and Rendezvous



Maximum Cargo Weights for Delivery and Rendezvous Flights in Circular Orbit

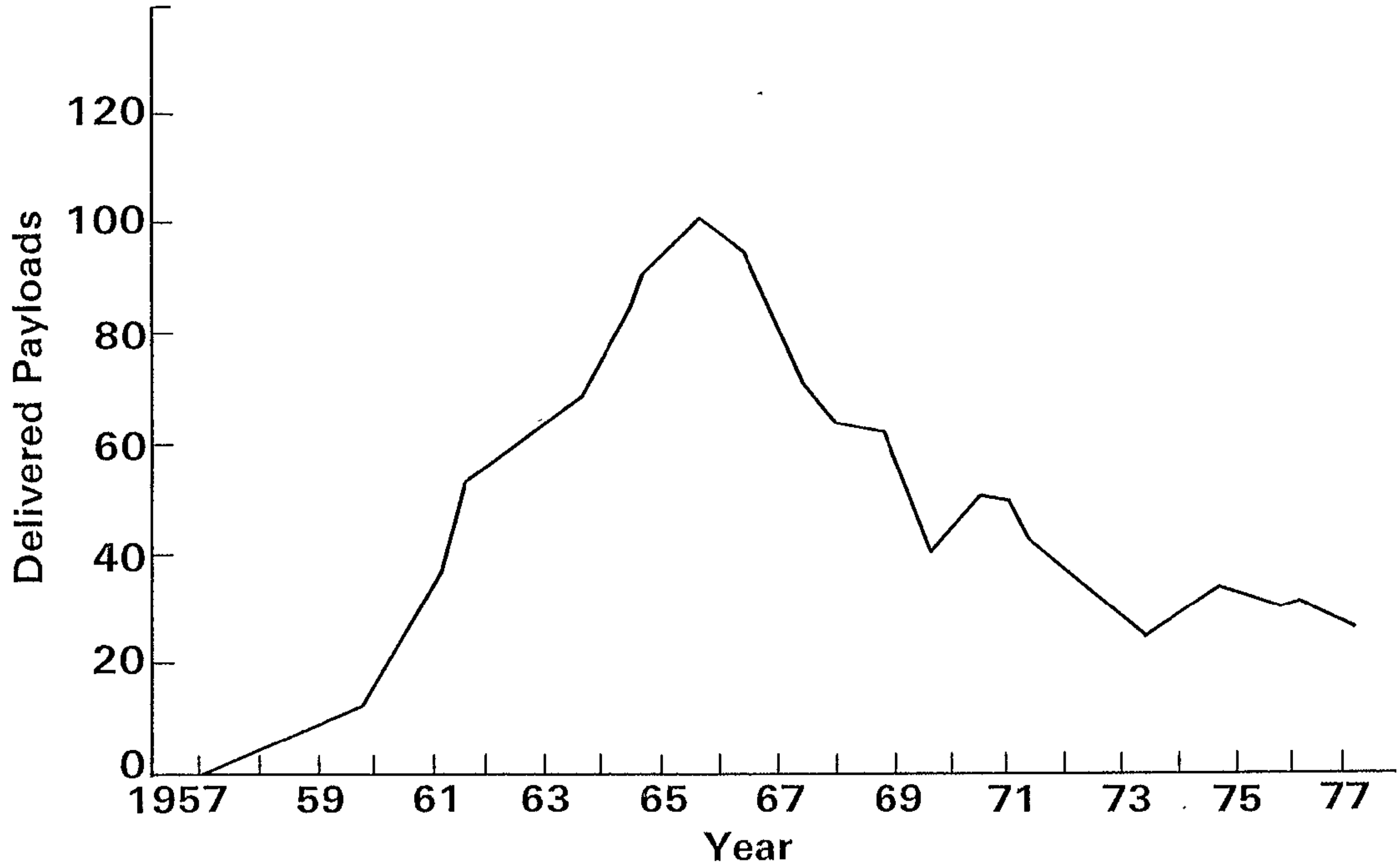
(Figures taken from "Space Transportation System", NASA Report, June 1977)

The use of space by the United States has increased rapidly since 1957 resulting in a concentration of orbital objects with orbital inclinations in the 20°-100° range.

The approximate frequency distribution of U.S. payloads delivered to earth orbit over 20-years is shown in the accompanying figure. It can be noted that the number of payloads delivered to orbit has stabilized in recent years to about 25 spacecraft per year. It is estimated that 70 percent of the spacecraft delivered to orbit to date have approximately circular orbits with an altitude ranging between 100 and 1500 mi.

At the end of 1977 there were about 200 U.S. non-military spacecraft in Earth orbit with 40 percent of these within range of the Shuttle (OMS kits required to reach some spacecraft).

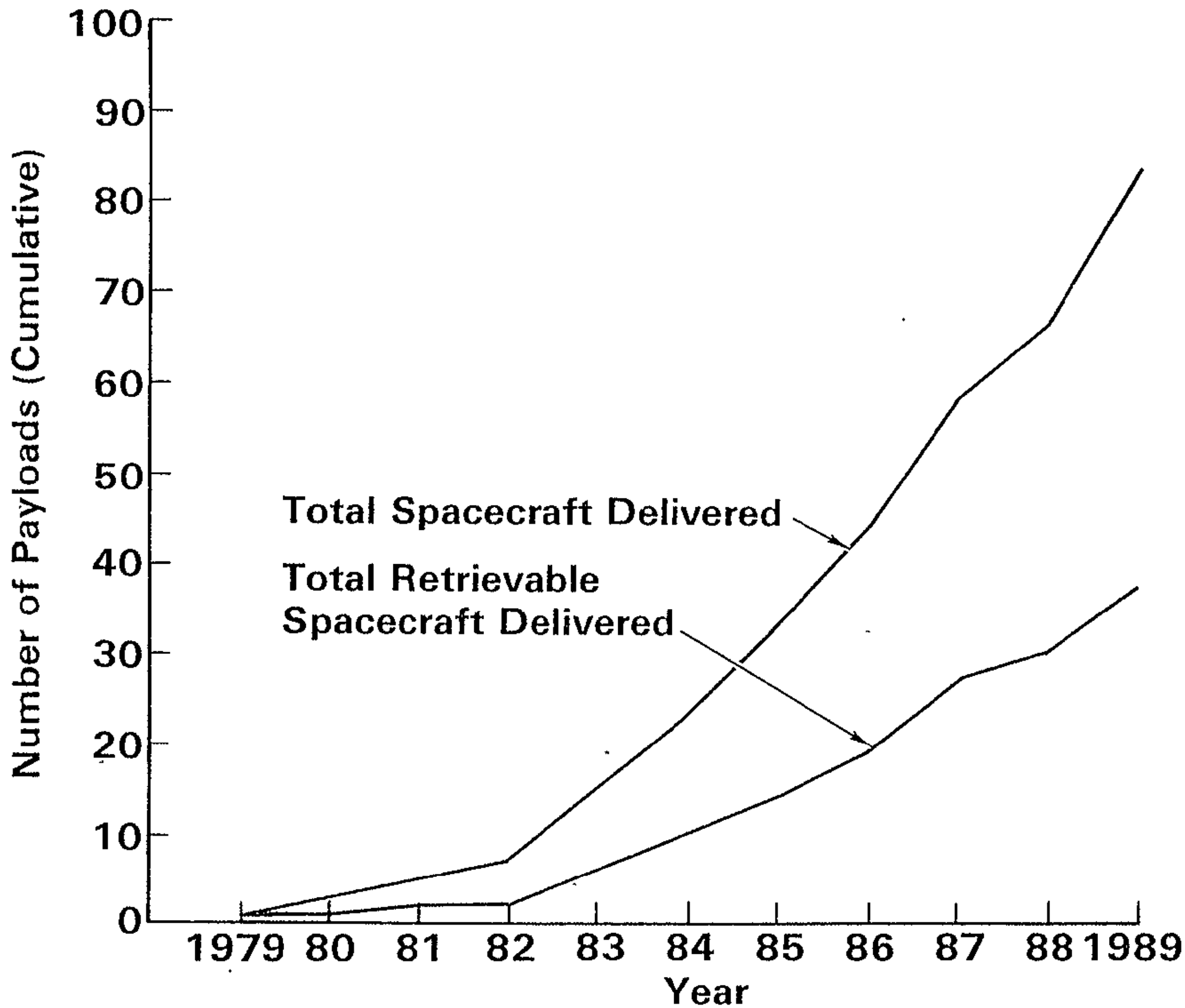
UNITED STATES PAYLOAD LAUNCH DISTRIBUTION



PROJECTED FUTURE PAYLOAD LAUNCHES

Population estimates for new spacecraft to be delivered to orbit, within the Shuttle Operational envelope, have been made for the next decade based on current program projections. One such estimate indicates 90 such spacecraft will be launched in the next decade with approximately one third of those scheduled for a least one Shuttle mission revisit. Satellites making up this estimate are listed by name in Appendix 1 together with program sponsor and satellite operational/hardware characteristics. The proposed delivery schedule of spacecraft listed in Appendix 1 is depicted graphically in the accompanying figure. The upper curve estimates the cumulative number of payloads to be delivered to Low Earth Orbit while the lower curve represents the cumulative number of spacecraft for which Shuttle revisit missions are planned. Some of these revisits will be for satellite retrieval and return-to-earth. As orbital satellite service capability is added to the existing baseline Shuttle work system, it can be expected that the percentage of delivered spacecraft for which Shuttle revisits will be scheduled will increase substantially.

PROJECTED CUMULATIVE PAYLOADS DELIVERED TO LEO DURING 1980'S



(Figure taken from "Low-Energy Mission Propulsion Requirements", Battelle Lab Report, February 1979)

SATELLITE CHARACTERISTICS

Until the Space Transportation System (STS) becomes operational, satellites will be launched using expendable rocket boosters. The expendable boosters have imposed constraints on satellite size, weight and geometry. Satellites launched to date have not embodied orbital service or resupply capability, and each must be considered individually for on-orbit service from the Space Shuttle. It may be desirable to retrieve, repair, replenish or reboost some of these satellites using the Shuttle, and so these satellites will be included in this satellite characterization discussion.

Future satellites, required for Shuttle launch, are also potentially serviceable from Shuttle. The characteristics of these proposed satellites are very important for identifying and defining requirements for satellite servicing. However, future satellite programs are still evolving and Shuttle mission planning is not yet firm, so that identifying characteristics of future satellites is somewhat speculative. Appendix 1 contains the results of a recent study of proposed satellite launches to LEO during the 1980's and a recent projected Shuttle cargo manifest for the early 1980's. These are indicative of plans being made, and can serve to broadly characterize future satellites.

Serviceability On-Orbit - It has been estimated that within three years of launch, many satellites will be either out-of-date or have suffered random equipment failure. Component wear-out appears to be rare. Although preliminary cost studies indicate that returning satellites to earth for repair and updating, followed by relaunch, will not prove to be cost effective. There are indications that certain types of service, refurbishment and updating, performed in orbit, will be cost effective in extending the useful life of satellites.

At the present time the multi-mission satellite (MMS) concept, under consideration by NASA, represents the first step towards a standardized satellite design emphasizing orbital serviceability and reusability of satellite subsystems. The long duration exposure facility (LDEF) is being concepted for return to earth as well as for on-orbit servicing, and the space telescope (ST) has been concepted for on-orbit servicing via EVA.

Weight - Most current and projected satellites weigh in excess of 2,000 lbs. The majority weigh over 5,000 lbs. A few projected satellites, such as the space telescope, weigh in excess of 20,000 lbs. The maximum weight limit is approximately 65,000 lbs. for a single payload launched by Shuttle.

Size - Deployed satellites are characterized by two principal dimensions, a main body diameter, ranging from 5 to 15 feet, and the length or diameter of a deployed appendage or array. Such dimensions generally exceed 15 feet.

Geometry - The accompanying illustration typifies shapes of satellites launched to date. Geometry is important in identifying potential EVA service access corridors and establishing mass nunents and products of inertia.

Orbital Dynamics - It has been determined (2) that unstable, passive satellites typically possess only one simple tumble motion generally less than 10 RPM, and that for low earth orbits nutational and precession motions dump out quickly, perhaps in as little as one day. This relatively simple satellite motion suggest that it should be possible to develop techniques for retrieving passive, unstable satellites. However, it should be noted that complex motions could be induced by retrieval activities.

CHARACTERISTIC SATELLITE SHAPES

Cylindrical:

Polygonal:

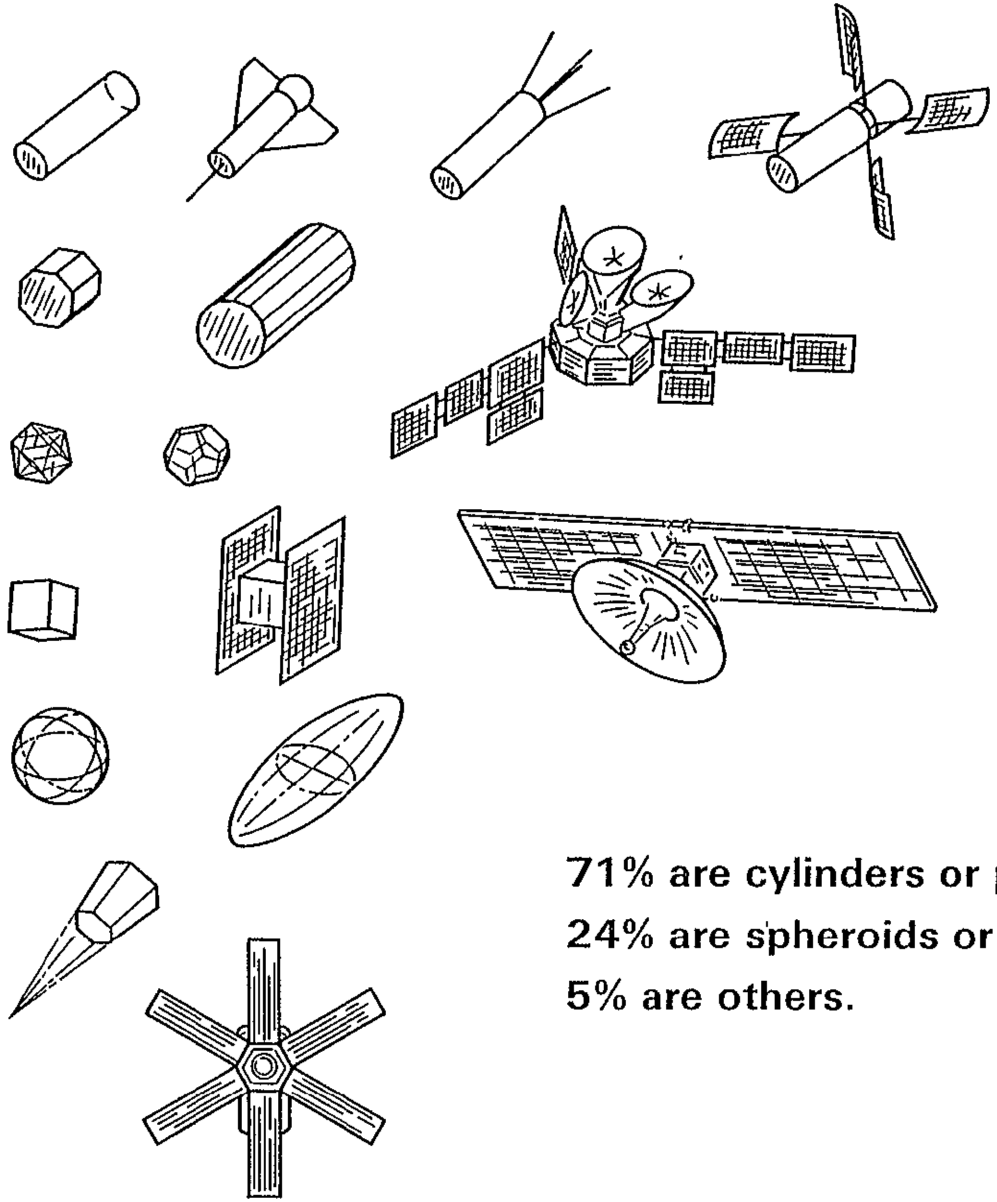
Polyhedral:

Box:

Spheroidal:

Frustum:

Windmill:



71% are cylinders or polygons.

24% are spheroids or polyhedrons.

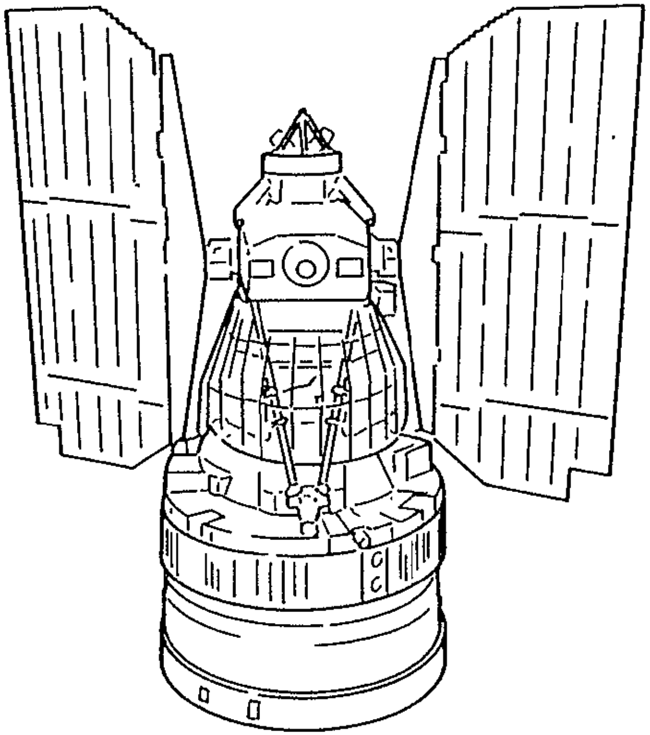
5% are others.

REPRESENTATIVE SATELLITES

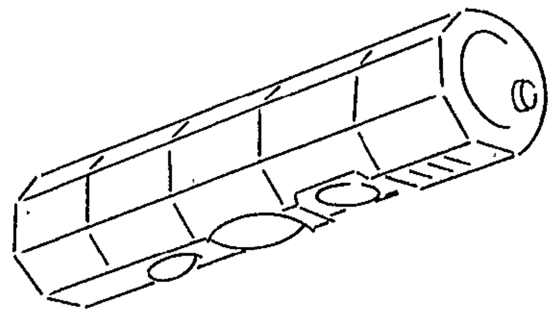
The following tabulation highlights characteristics of several satellites launched during the 1970's and projected for launch during the early 1980's. These satellites are illustrated on the following pages.

Satellite	Launch year	Orbit n.mi	Geometry	Length ft	Diameter ft	Weight lb	Payload	Mission
Landsat	1972-77	560	cylinder	10	4	2,000	Photo-graphy	Earth resources study
HEAO	1974	340	Octagonal cylinder	19	9	10,000	x-ray & gamma ray sensors	High energy astronomy
Seasat	1978	430	cylinder	35	6	4,000	Active & passive radar, IR	Ocean study & weather
LDEF	Early 1980's	300	12 sided cylindrical frame	30	14	User - depend-ent	Experi-ment trays	Exposure to space environ-ment
Space Telescope	Mid 1980's	270	cylinder	42	15	21,000	Optical telescope	Visible light astronomy
25 KW Power System	Mid 1980's	200-250	Box	34	10	28,000	Solar panels	Power for extended orbiter missions
MMS	Mid-late 1980's	270-864	Triangular Box	5 + payload	6	10,000	User - depend-ent	Multi-mission modular concept

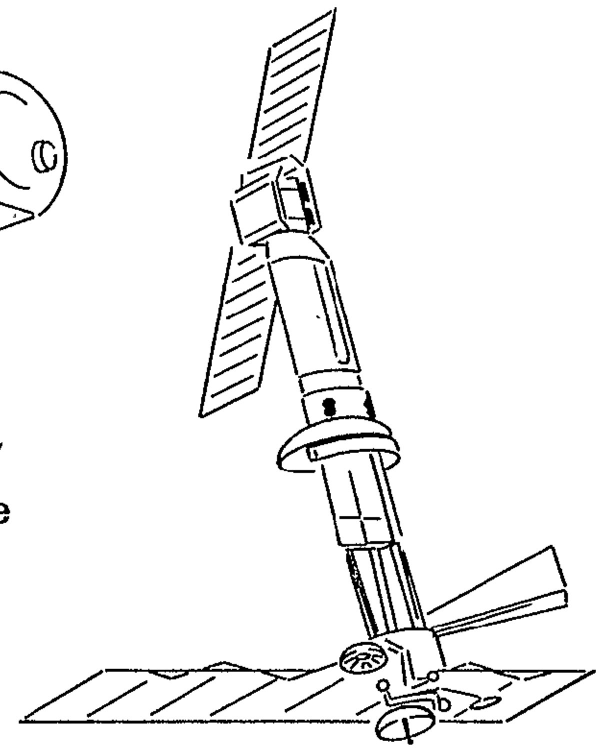
REPRESENTATIVE SATELLITES



LANDSAT-1 Earth Resources
Technology Satellite

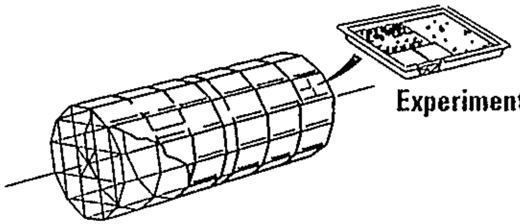


HEAO High Energy
Astronomy Satellite

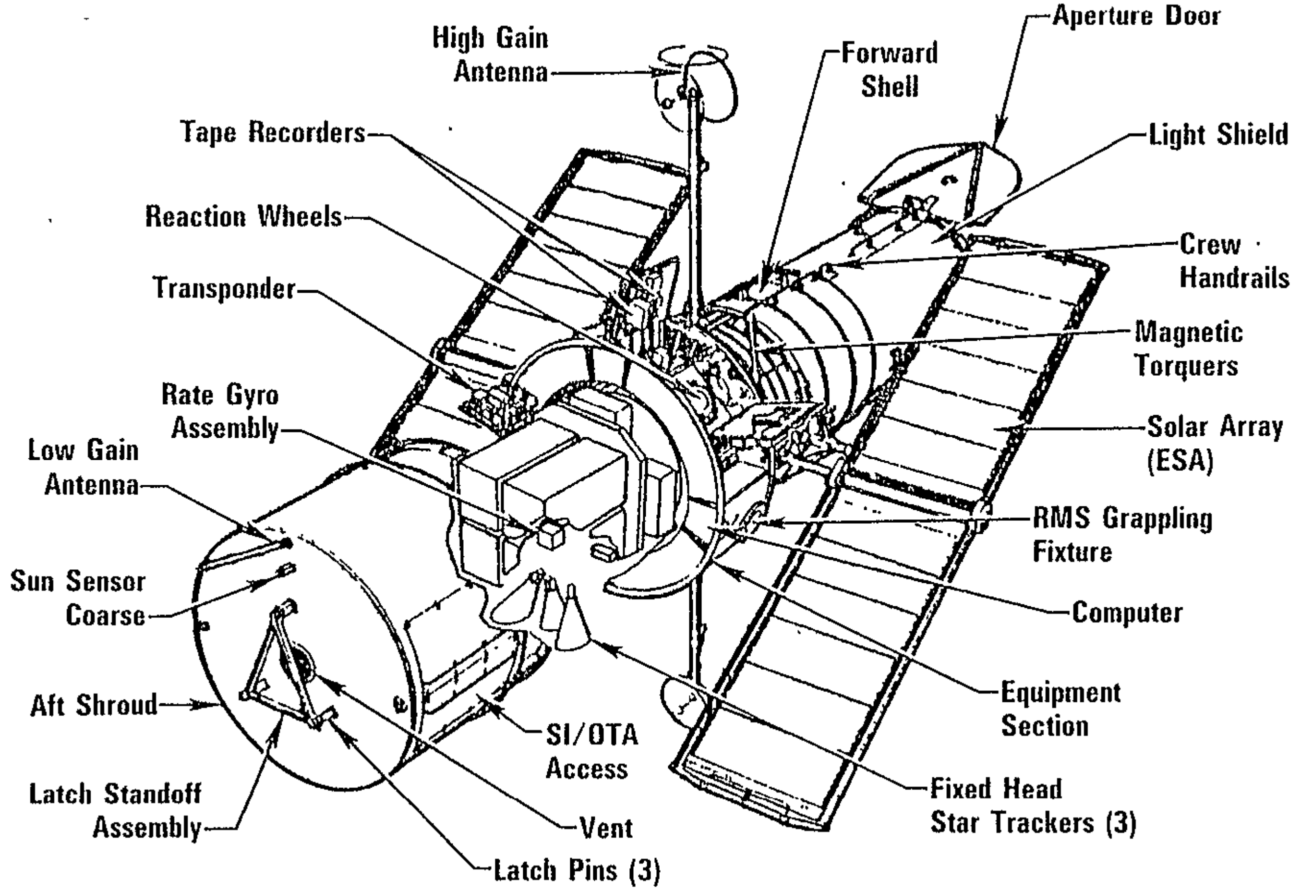


SEASAT-A Ocean Observation
Satellite

REPRESENTATIVE SATELLITES (CONTINUED)

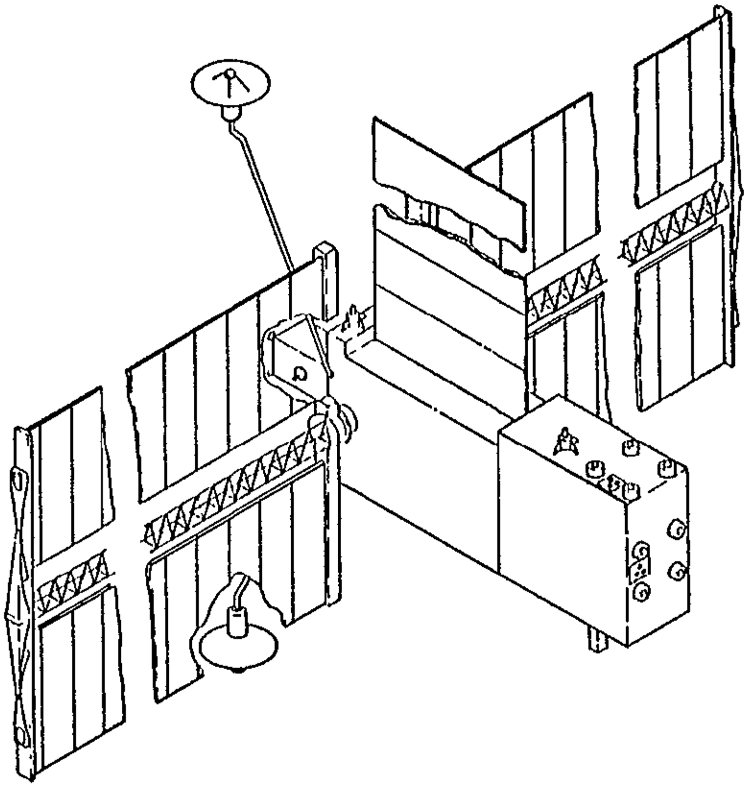


Long Duration
Exposure Facility

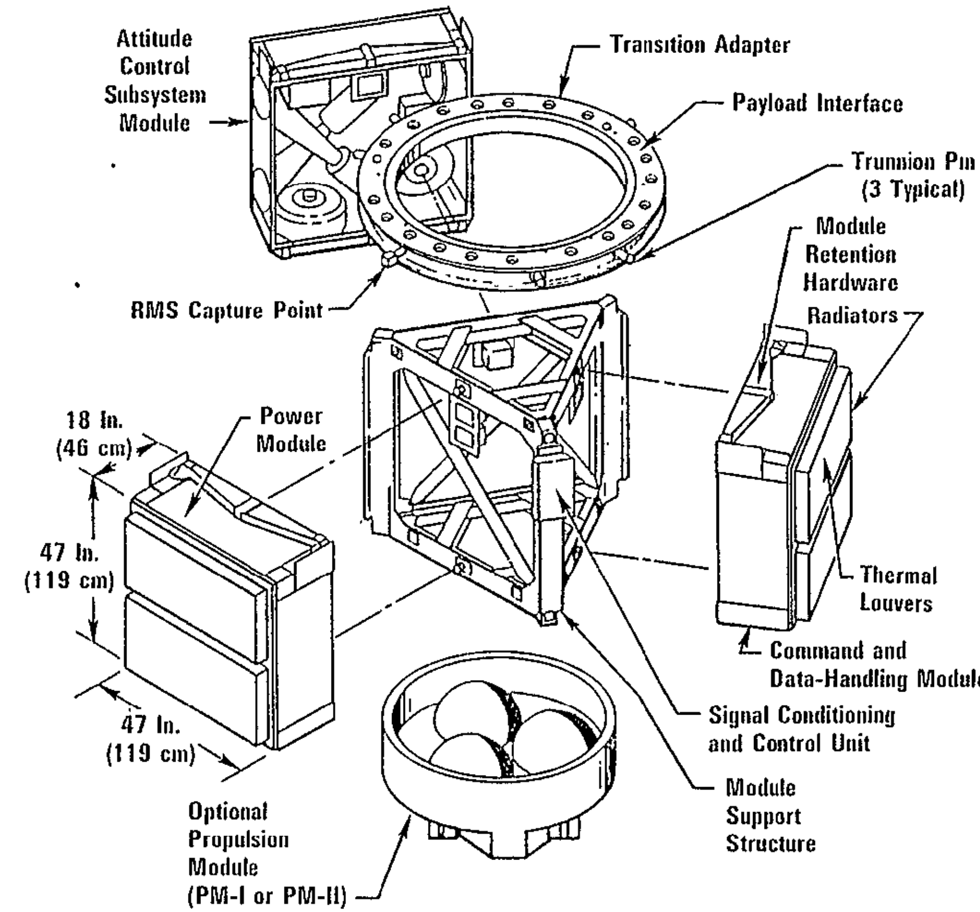


Space Telescope

REPRESENTATIVE SATELLITES (CONTINUED)



25 kW Power System (Concept)



MMS Multi-Mission Satellite (Concept)

Satellite Subsystems - Satellites typically consist of the following subsystems, although subsystem designs and construction are highly mission dependent and vary between manufacturers.

- Power Subsystem

  Power source (solar array, batteries, nuclear)
  Power conditioning

- Attitude Control Subsystem

  Thrusters
  Tankage

- Command and Data Handling Subsystem

  Attitude control sensor (star tracker, gyro)
  Subsystems control
  Signal conditioning
  Data telemetry

- Heat Rejection Subsystem (radiators, loovers, passive cooling)

- Orbit Insertion Propulsion Subsystem

- Structure

  Subsystem support
  Payload interface
  Launch vehicle interface

- Payload

  Sensors
  Experiments

Design Considerations for On-Orbit Serviceability - The accompanying list summarizes satellite design characteristics to enhance on-orbit serviceability. Implementation of such guidelines would lead to a new generation of satellites with provision for safe EVA access to satellite subsystems, crewman restraint anchors at anticipated service sites and modular replacement of subsystems requiring a minimum of EVA tools and equipment.

SATELLITE DESIGN CONSIDERATIONS FOR ON-ORBIT SERVICEABILITY

- Deployment and Retrieval Loads
- Safe Surfaces & Edges
- Accessable Maintenance Areas
- Subsystem Deactivation, Disarming and Safetying
- Replaceable Subsystem Modules
- Fail-Safe Pressure Vessels
- Fluid System Servicing

    Circuit Isolation
    Leak Detection
    Refueling
    Safety Venting
    Module Replacement

- Standard Interfaces

    Diagnostic & checkout Connector
    Disconnects/Fittings/Fasteners
    RMS Snaring Adapter
    Crewman Restraints or Attachment Points
    Equipment Tether Points Launch Vehicle Mounts

- Diagnostics & Checkout Software

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SERVICE TASK REQUIREMENTS

The general meaning of the term "satellite service" covers all Shuttle mission operations in orbit associated with satellites. In this report satellite service activity is partitioned into three classes of operations:

- Deployment - activation and release from Orbiter
- Retrieval - return to orbiter or vicinity
- Service - resupply and/or recondition

As discussed subsequently in this report, each class of operation consists of many specified tasks, performed by the Shuttle crew either by EVA or by IVA. Two premises underly the discussion to follow:

1. EVA is required for satellite operations - Present planning calls for IVA support of payload deployment and retrieval as the baseline approach to payloads in general. EVA has been identified as the baseline only in support of payload activities associated with the 25 kW Power System, LDEF, Space Telescope and Spacelab. NASA and user community payload service thinking is still in the formative stages. However, studies have showed that EVA satellite service is cost-effective. Hence it is expected that EVA will become the baseline service mode once the STS becomes operational. It is likely that EVA will be utilized to support satellite retrieval with the RMS, perform service operations on retrieved satellites and deal with payload service contingencies.

2. RMS orbiter system has limitations for satellite operations - Within the 50 foot reach of the RMS, orbiter thruster plumes may impinge on satellites, making it difficult to null relative velocities between the Orbiter and satellite. Since the maximum speed of the RMS end effector is 2 ft/sec, relative velocities will have to be small for the RMS to effect capture. Intricate closing manuevers may be required of the Orbiter to approach a satellite within the RMS capture envelope. In addition the RMS can be backdriven by forces in excess of 23 lbs. and it has limited damping capability. Therefore, EVA may be required to assist the RMS in snaring a satellite, positioning a satellite and damping unwanted motions.

Deployment Operations - Shuttle deployment operations are expected to consist of multiple launching of small satellites, positioning of individual payloads to be assembled into large satellites in earth orbit, and re-boosting satellites from decayed orbit.

- Normal Deployment - Normal deployment is expected to be automated, with all crew activity being IVA. The satellite is elevated in the payload bay by the Flight Support System (FSS) platform, and the satellite antennas and solar panels are self-deployed. The platform can also impart spin to the satellite prior to release, if required. While on vehicle power the satellite is checked out and subsequently released by "soft" springs. Following release, satellite is remotely checked out using satellite power, prior to automatic sequence initiation that culminates in propelling the satellite to its prescribed orbit.

Contingency Deployment - Contingencies may alter normal deployment at any deployment step. For example, present planning is for the RMS to release a stuck panel, using EVA as backup. However, EVA can also support inspection and evaluation of anomalies, both prior to and following satellite release from the Orbiter. In addition, EVA can be used to assemble arrays or antennas that are too large to reliably self-deploy.

- Reboost - For reboosting satellites from a decayed orbit, it is anticipated that a propulsion module, delivered to orbit by the Shuttle, could be attached to the satellite to reboost the satellite to its operational orbit.

Retrieval Operations - Retrieval operations will be required to support Shuttle mission objectives ranging from film pack retrieval and space debris collection to returning satellites to the payload bay for servicing or (as with the LDEF) return to Earth.

- Normal Retrieval - Normal satellite retrieval presently requies flying the satellite, under active control, to within the capture envelope of the RMS, snaring the satellite with the RMS, and birthing the satellite in the payload bay. This sequence is intended to require crew IVA only. However, two situations could arise to prevent executing this sequence as planned, namely:

    - Difficulty in flying the satellite from the Orbiter to bring it within the 50 foot capture envelope of the RMS.

    - Nulling residual satellite velocities sufficiently to permit snaring with the RMS, whose maximum end effects velocity in 2 ft/sec.

  EVA can alleviate these problems by helping to position the satellite within the reach of the RMS and by nulling excessive residual velocities to permit the RMS to snare the satellite.

  Contingency Retrieval - Retrieval of satellites without fly-to-orbiter capability is not presently considered to be a baseline capability. EVA would make this a baseline capability, by delivering a retrieval propulsion kit to the satellite and assisting with snaring the satellite using the RMS after the satellite is flow back.

  Stabilization - Satellites that are spinning or tumbling out of control are not presently considered retrievable. EVA techniques appear to be feasible to approach and stabilize a satellite, using stabilization it hardware. Once stabilized a retrieval propulsion kit could be used to maneuver the satellite within the capture envelope of the RMS.

SERVICE TASK REQUIREMENTS (continued)

- Preberthing - Normal preberthing activities include safetying satellite subsystems to protect against inadverted thruster firing, depressurizing tankage, and folding or jettisoning appendages to permit the satellite to fit in the payload bay. These activities are expected to require EVA because satellites are not expected to be self-safetying or self-folding.

  Contingency preberthing activities might involve cutting stuck or damaged appendages away, or inactivating thrusters by antenna removal, pressurant release or mechanically baffling thruster nozzles. In addition, EVA may be required to defuel the satellite, attach an FSS adapter if one does not exist on the satellite, and trim away and collect debris from the satellite.

- Berthing - Normal berthing of the satellite to the FSS is expected to be performed with the RMS and FSS platform by an IV crew.

  Contingencies can alter the berthing sequence at any step, with EVA assistance most likely required during final positioning of the satellite on the FSS platform.

- Debris Management - Debris management includes collecting orbital debris, collecting damaged satellite elements removed during preberthing operations, transporting debris to the Orbiter, and stowing debris in the payload bay for return-to-Earth. Stabilization and retrieval operational steps described above may be required in the debris management of large objects such as rocket bodies.

Service Operations - Experience gained in on-orbit satellite deployment will lead the way to servicing payloads, satellites and contingency repair of the Orbiter itself. Certain resupply and refurbishing tasks on satellites are expected to be cost-effective, including refueling, sensor replacement, experiment change out, and solar panel and antenna replacement.

- Inspection - Satellite inspection is expected to include remote visual assessment of satellite condition prior to preberthing, as well as diagnostic checkout of satellite systems prior to service to preidentify the service operations required.

- Service, Orbiter Vicinity - Service in the near vincinity of the Orbiter (up to 100 meters away) consists of simple, routine tasks, such as experiment retrieval or film pack replacement. These tasks can be performed by EVA on a satellite that is performing normally. More distant EVA up to 10 km is also considered feasible using uprated EVA equipment, as discussed in subsequent sections of this report.

- Service, RMS - Some service is expected to be performed on satellites while docked to the RMS. Tasks include instrument service, subsystem module replacement and refueling. These are routine service tasks for which it may not be necessary to berth the satellite in the payload bay.

- Service, Payload Bay - Service in the payload bay includes all satellite service operations plus more extensive subsystem checkout, repair and replacement of large/modules, such as solar arrays, antennas and propulsion modules.

SATELLITE SERVICE TASKS

Defining satellite characteristics and service operations establishes the framework for identifying specific satellite resupply and refurbishing tasks. Because service equipment or supplies are needed to perform most tasks, it is useful to define the applicability of service tasks to the satellite subsystems. The relative applicability, or "leverage", is an indication of the amount of satellite service capability achieved if specific service equipment or supplies are available. High leverage serves to establish service capability development priorities.

The study methodology to identify service tasks and leverage was as follows:

Service Tasks - The following broad classes of satellite service tasks were identified:

- Safetying
- Checkout
- Refuel and Refurbish
- Hardware Replacement
- Hardware Repair

Each satellite subsystem was analyzed to identify applicable specific service tasks. This analysis is contained in Appendix 2 of this volume.

Summarize Service Tasks - Appendix 2 is summarized on the accompanying table.

Leverage - Leverage is expressed on the accompanying table as the number of subsystems for which a particular service task can be performed. As the table indicates, the highly leveraged tasks are:

- Mate and demate electrical connectors
- Tether unsupported items
- Install & remove mechanical fasteners
- Visual inspection
- Install and remove modular equipment
- Check electrical continuity
- Actuate switches and breakers
- Check item performance
- Straighten deformed material
- Replace damaged mechanical fasteners
- Repair damaged electrical connectors

Groundrules for this analysis are as follows:

- Satellite is serviceable while in orbit
- Satellite is stable if free-flying. Otherwise satellite is attached to RMS or is in Shuttle payload bay.
- EVA crewman has restraint provisions at service sites.

SATELLITE SERVICE TASKS

LEVERAGE	SERVICE TASK	ATTITUDE CONTROL	TANKAGE	POWER CONDITIONING	POWER SOURCE	SOLAR CELL	BATTERY	FUEL CELL	NUCLEAR	COMMAND & CONTROL	DATA HANDLING & SIG. COND.	HEAT REJECTION	PAYLOADS	PASSIVE EXPOSURE	PASSIVE SENSOR	ACTIVE RF	BIOLOGICAL	STRUCTURE
	SAFETYING																	
11	MATE & DEMATE ELECTRICAL CONNECTORS			X		X	X	X	X	X	X	X			X	X	X	
12	ACTUATE SWITCH/BREAKER	X		X		X	X	X	X	X	X	X			X	X	X	
1	REMOVE ANTENNA									X								
1	SHIELD JAGGED/SHARP EDGES																	X
1	INSTALL & REMOVE THRUSTER BAFFLES	X																
1	SHIELD RADIATION SOURCES								X									
2	ISOLATE FLUIDS		X									X						
3	VENT PRESSURE VESSELS		X					X				X						
2	SHIELD PRESSURE VESSELS		X					X										
	CHECKOUT																	
3	CHECK FLUID LEAKAGE	X	X									X						
13	CHECK ELECTRICAL CONTINUITY	X	X	X		X	X	X	X	X	X	X			X	X	X	
12	CHECK ITEM PERFORMANCE/CONDITION	X		X		X	X	X	X	X	X	X			X	X	X	
14	VISUAL INSPECTION	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X
2	GAUGE FLUID QUANTITIES		X									X						
1	MEASURE LENGTH & STRAIGHTNESS																	X
	REPLACEMENT																	
6	MATE & DEMATE FLUID CONNECTIONS	X	X					X	X			X						
14	MATE & DEMATE ELECTRICAL CONNECTORS	X	X	X		X	X	X	X	X	X	X		X	X	X	X	
15	ACTUATE/INSTALL & REMOVE MECH. FASTENERS	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X
14	INSTALL & REMOVE ITEM	X	X	X		X	X	X	X	X	X	X		X	X	X	X	
15	TETHER & RELEASE UNSUPPORTED ITEMS	X	X	X		X	X	X	X	X	X	X		X	X	X	X	
2	DECONTAMINATE REMOVED HARDWARE	X	X															
	SERVICE & REFUEL																	
1	GAUGE FLUID QUANTITIES		X															
1	MATE & DEMATE FLUID CONNECTIONS		X															
1	DISTRIBUTE FLUIDS BETWEEN TANKS		X															
1	VENT PRESSURE VESSELS		X															
2	REFURBISH PASSIVE SURFACES					X						X						
1	CLEAN LENS/SENSOR HEAD														X			
3	CALIBRATE SENSORS										X				X		X	
	REFURBISH & REPAIR																	
11	STRAIGHTEN DEFORMED MATERIAL	X	X	X		X	X	X	X	X	X	X						X
3	REPAIR DAMAGED FLUID LEAKAGE AT FITTINGS	X	X					X				X						
4	ISOLATE/REPLACE DAMAGED TUBING		X					X				X						
10	REPAIR DAMAGED ELECTRICAL CONNECTORS	X	X	X		X	X	X	X	X	X	X						
4	REPAIR/REPLACE DAMAGED ELECTRICAL HARNESSES			X						X	X	X						
11	REPLACE MECHANICAL FASTENERS	X	X	X		X	X	X	X	X	X	X						X
2	TRIM AWAY DAMAGED MATERIAL					X												X
1	MEASURE LENGTH & STRAIGHTNESS																	X
1	SMOOTH ROUGH/JAGGED EDGES																	X
1	MAKE FASTENER HOLES																	X
1	FABRICATE REPAIR SECTIONS																	X
1	BOND/WELD REPAIR SECTION																	X
1	REFILL FLUID SYSTEM											X						

EQUIPMENT REQUIRED TO SUPPORT SATELLITE SERVICE TASKS

A study of the service tasks provides an indication of the level of equipment required to support a particular satellite service task. Some tasks such as visual inspection require no tools. Other tasks require supplies such as wipers, replenishment materials or bulk repair materials. Still other tasks require tools and equipment of varying complexity. The accompanying table lists the complexity of equipment required to support each satellite service task.

REQUIRED SATELLITE SERVICE TASK EQUIPMENT

SERVICE TASK	NO TOOLS	SUPPLIES	SHIELDS OR BAFFLES	SIMPLE HAND TOOLS	HAND HELD POWER TOOLS	FLIGHT SERVICE EQUIPMENT
						SERVICE TASK EQUIPMENT
MATE & DEMATE ELECTRICAL CONNECTORS	X					
ACTUATE SWITCH/BREAKER	X					
VISUAL INSPECTION	X					
CLEAN LENS/SENSOR HEAD	X	X			X	
INSTALL & REMOVE ITEM	X			X		
SHIELD JAGGED/SHARP EDGES	X	X				
SHIELD PRESSURE VESSELS	X		X			
INSTALL & REMOVE THRUSTER BAFFLES	X		X			
SHIELD RADIATION SOURCES	X		X			
MATE/DEMATE FLUID CONNECTIONS	X			X		
ACTUATE/INSTALL & REMOVE MECH. FASTENERS	X			X	X	
REFURBISH PASSIVE SURFACES		X		X		
TETHER & RELEASE UNSUPPORTED ITEMS	X	X				
REMOVE ANTENNA				X	X	
TRIM AWAY DAMAGED MATERIAL				X	X	
SMOOTHE ROUGH/JAGGED EDGES				X	X	
MAKE FASTENER HOLES				X	X	
REPLACE MECHANICAL FASTENERS	X	X		X		
FABRICATE REPAIR SECTIONS		X		X	X	
BOND/WELD REPAIR SECTIONS		X			X	
STRAIGHTEN DEFORMED METAL				X	X	
MEASURE LENGTH & STRAIGHTNESS				X		
REPAIR FLUID LEAKAGE AT FITTINGS		X		X		
REPAIR DAMAGED FLUID FITTINGS/TUBING						X
REPLACE DAMAGED TUBING		X		X	X	
REPAIR DAMAGED ELECTRICAL CONNECTORS		X		X		
REPAIR DAMAGED ELECTRICAL HARNESSES		X		X		
REPLACE DAMAGED ELECTRICAL HARNESSES				X		
CHECK ELECTRICAL CONTINUITY				X		
ISOLATE FLUIDS		X				X
VENT PRESSURE VESSELS						X
CHECK FLUID LEAKAGE		X				X
CHECK ITEM PERFORMANCE/CONDITION						X
GAGE FLUID QUANTITIES						X
DECONTAMINATE REMOVED HARDWARE						X
DISTRIBUTE FLUIDS BETWEEN TANKS						X
REFILL FLUID SYSTEM		X				X
CALIBRATE SENSORS						X

SATELLITE SERVICE TASK REQUIREMENTS

The practicality of performing the satellite service tasks depends on the capability of the crewman performing the task, the difficulty of the task and the complexity of the equipment required to support the task. The accompanying tables combine leverage with these three considerations to highlight whether significant service equipment development is required or not, and the relative applicability of the service capability, once developed. The following definitions are used in the accompanying tables:

General Equipment - Consists of simple adaptation of common, 1-g hand tools and hand-held power tools. Limited DDT&E would be required to adapt the tool concept to to space use.

Special Equipment - Consists of equipment embodying new concepts or representing zero-g adaptation of specialized aerospace or electronic test sets and service facilities. Significant DDT&E work would be required to qualify the equipment for space use.

Simple Task - Defined as an uncomplicated service task with low risk of damage to satellite or service equipment. Low crewman dexterity and visual perceptual levels required.

Complex Task - Defined as complicated service task with some risk of damage to satellite or service equipment. High dexterity and visual perception may be required of the crewmember.

SIMPLE TASKS REQUIRING GENERAL SERVICE EQUIPMENT

	Leverage	Task
1.	25	Mate & demate electrical connectors.
	5	Mate & demate fluid connectors
2.	15	Actuate/install & remove mechanical fasteners
3.	15	Tether & release unsupported item
4.	14	Visual inspection
5.	14	Install & remove item
6.	13	Check electrical continuity
7.	12	Actuate switch/breaker
8.	11	Replace mechanical fasteners
9.	11	Straighten deformed material
10.	4	Replace damaged electrical harness
11.	2	Refurbish passive surfaces
12.	2	Shield pressure vessels
13.	2	Measure length & straightness
14.	1	Clean lens/sensor head
15.	1	Smooth rough/jagged edges
16.	1	Install & remote thruster baffle
17.	1	Shield radiation sources
18.	1	Shield radiation sources
19.	1	Make fastener holes
20.	1	Shield jagged/sharp edges
21.	1	Remove antenna

COMPLEX TASKS REQUIRING GENERAL SERVICE EQUIPMENT

	Leverage	Task
1.	1	Repair damaged electrical connectors
2.	4	Repair damaged electrical harnesses
3.	3	Replace damaged tubing
4.	3	Repair fluid leakage at fittings
5.	2	Trim away damaged material
6.	1	Fabricate repair sections

COMPLEX TASKS REQUIRING SPECIAL SERVICE EQUIPMENT

	Leverage	Task
1.	12	Check item performance/condition
2.	7	Repair damaged fluid fittings/tubing
3.	4	Vent pressure vessels
4.	3	Gage fluid quantities
5.	3	Check fluid leakage
6.	3	Calibrate sensors
7.	3	Isolate fluids
8.	2	Decontaminate removed hardware
9.	1	Bond/weld repair sections
10.	1	Refill fluid system
11.	1	Distribute fluids between tanks

SERVICE CAPABILITY DEVELOPMENT

All satellite service tasks listed in the tables on the previous page require detail study and evaluation to develop procedures, constraints, time lines, tools and supporting equipment. However, service tasks requiring specialized equipment warrant additional consideration, because all of these tasks are complex, and the equipment development requirements are significant. As the accompanying table shows, these tasks are concerned with fueling, repairing fluid systems, maintaining electronics and performing some types of structural repair. These are important in keeping major satellites, such as the space telescope, operational for a long time.

It is recommended, therefore, that primary satellite service task development effort concentrate on the service tasks requiring special equipment. Secondary effort, emphasizing training, should be devoted to developing the service tasks requiring only general equipment.

SERVICE TASKS REQUIRING SIGNIFICANT SPECIAL EQUIPMENT DEVELOPMENT

Fluids

Check fluid leakage
Isolate fluids
Repair damaged fluid fittings/tubing
Refill fluid systems
Decontaminate removed hardware

Fueling

Gage fluid quantities
Vent pressure vessels
Distribute fluids between tanks

Electronics

Check item performance/condition
Calibrate sensors

Structural Repair

Bond/weld repair sections

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 3, Satellite Service

Introduction

Satellite Characteristics

Service Task Requirements

Service Equipment Concepts

Service Capability Packages

Appendices

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SERVICE EQUIPMENT CONCEPTS

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

EVA's role in supporting nominal and contingency operations was defined, and specific resupply and reconditioning tasks were identified. This section identifies some EVA techniques and equipment for supporting deployment, retrieval and service operations, and disucsses them as required to clarify the concepts. While all of the concepts presented are believed to be feasible and some of these are believed to be unique, none have been optimized in this study. Discussion of tool and equipment requirements is beyond the scope of this study.

DEPLOYMENT EQUIPMENT

Deployment Operation	Representative Service Equipment Required
Normal Deployment	Flight Service System (FFS) Remote Manupulator System (RMS)
Contingency Deployment	FSS, RMS, Hand Tools, Tram Line Extravehicular Mobility Unit (EMU) Manned Remote Work System (MRWS)
Satellite Boost	RMS, Propulsion Module

Normal Deployment - Normal deployment is expected to be automated, with all crew activity being IVA. The satellite is elevated in the payload bay by the Flight Support System (FSS) platform, and the satellite antennas and solar panels are self-deployed. The platform can impart a spin to the satellite prior to release, if required. While on vehicle power the satellite is checked out followed by soft spring/launch. Following release, the satellite goes through a final checkout under remote control using satellite power, prior to automatic sequence initiation that culminates in propelling the satellite to its prescribed orbit. In certain cases large solar panels or antennas may be deployed by the RMS under IV control.

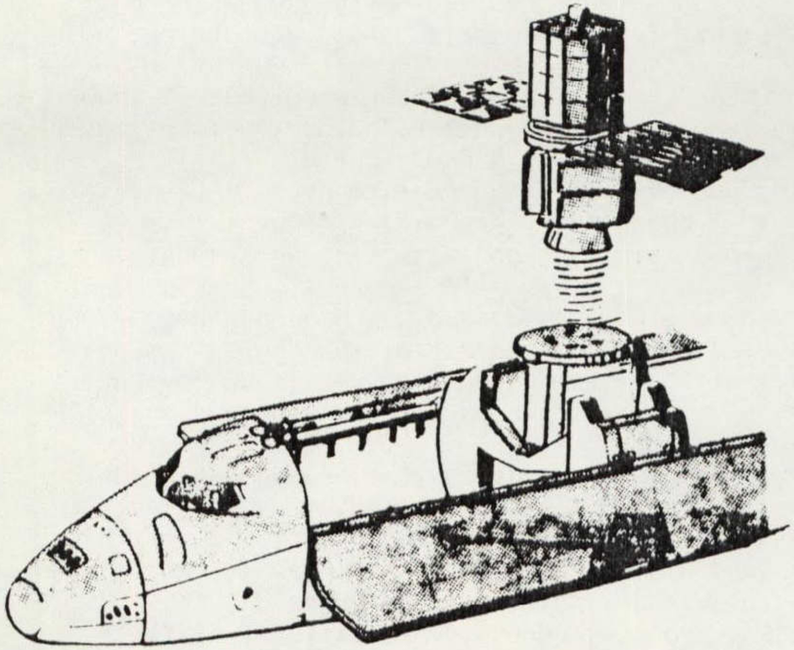
In the accompanying figure a satellite is shown moving off deployment FSS platform following soft spring launch. An alternative deployment mode is also shown in which the satellite is activated and checked out on the RMS using vehicle power. Following release from the RMS the satellite is checked out on-board power, and then flown to its prescribed orbit.

Contingency Deployment - Contingencies could alter normal deployment at any step. For example, while the RMS is intended to release a stuck panel, EVA may be required as backup. EVA could support inspection and evaluation of anomalies, both prior to and following release from the Orbiter, as well as support repair activities. In addition, EVA can be used for final assembly of arrays or antennas that are too large to self-deploy for specialized checkout of selected satellite subsystems, and for repair to the RMS or replacement of the RMS end-effector.

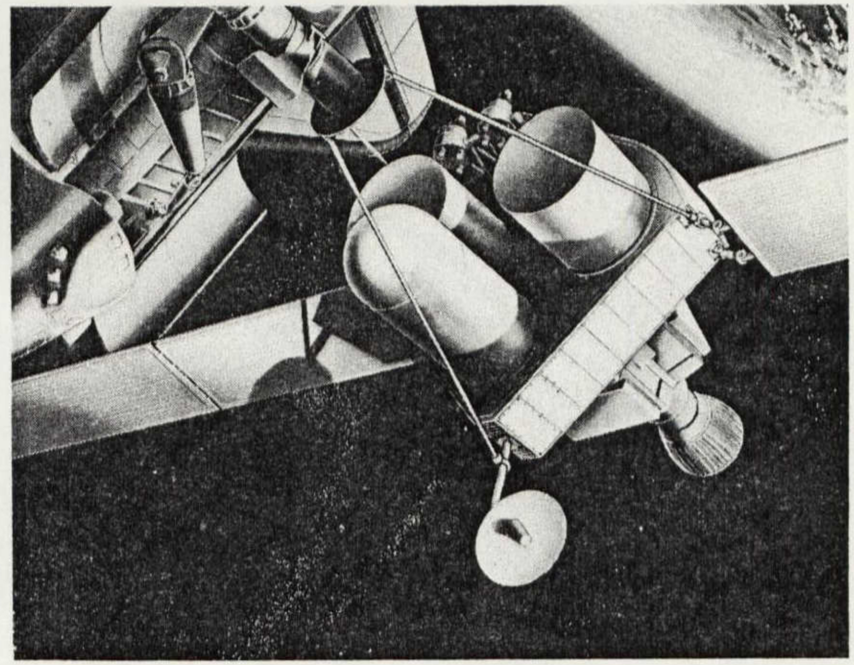
In the accompanying illustration (a) EVA is shown supporting final assembly and checkout using a tram line to tether and move large panel sections. The accompanying illustration (b) shows EVA supporting payload damage repair prior to release.

Satellite Boost - Certain satellites may be retrieved in orbit to be boosted back from decayed orbits to prescribed orbits or boosted to new orbits altogether. Normal reboost is expected to be by IVA, using a Shuttle vehicle equipped with two RMS arms. One RMS would hold the satellite while the second RMS positioned a propulsion module. EVA assistance would be required to attach the propulsion module to the satellite.

NORMAL DEPLOYMENT

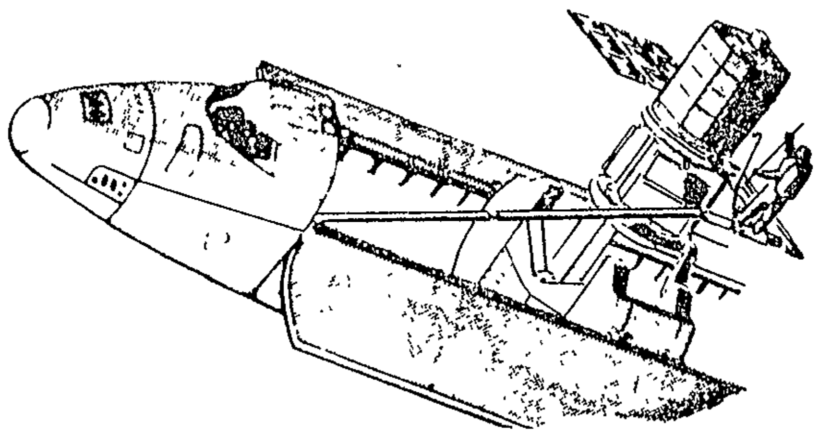


DEPLOYMENT — SPRING RELEASE

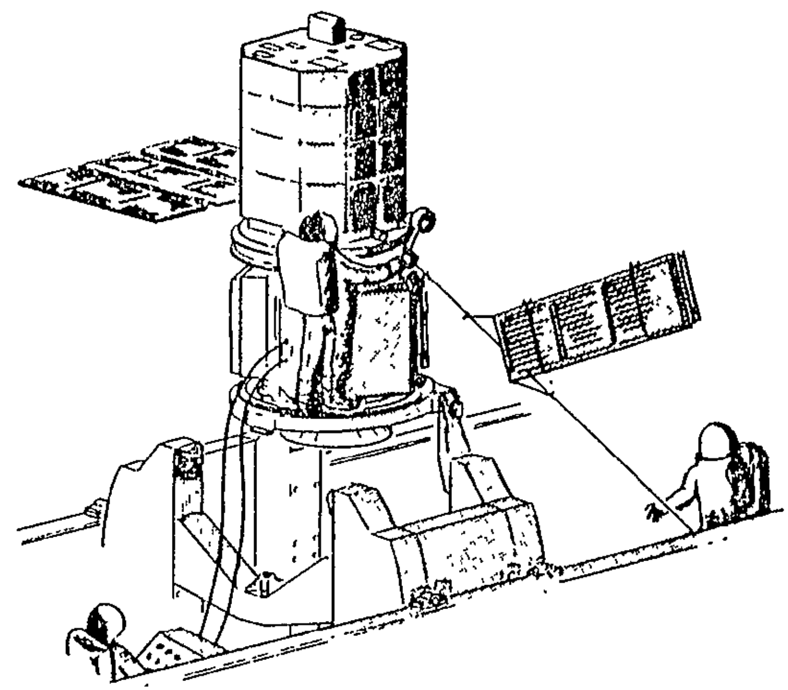


DEPLOYMENT — RMS RELEASE

CONTINGENCY DEPLOYMENT



(a) PAYLOAD DAMAGE-CONTINGENCY



(b) FINAL ASSEMBLY/CHECKOUT

RETRIEVAL EQUIPMENT

Retrieval Operation	Representative Service Equipment Required
1. Satellite Retrieval	Retrieval kit, EMU, MMU, Remote Electronic Controller
2. Satellite Stabilization	Stabilization kit, EMU Manned Maneuvering Unit (MMU)
3. Preberthing	
Subsystem Safetying	Subsystem safetying kit
Vent pressure vessels	Fluid service facility
Fold or trim deployed appendages	Cutters
Decontaminate EMU	Air-Lock decontamination unit
4. Berthing Assist	MMU, RMS
5. Debris Management	Debris Management Kit

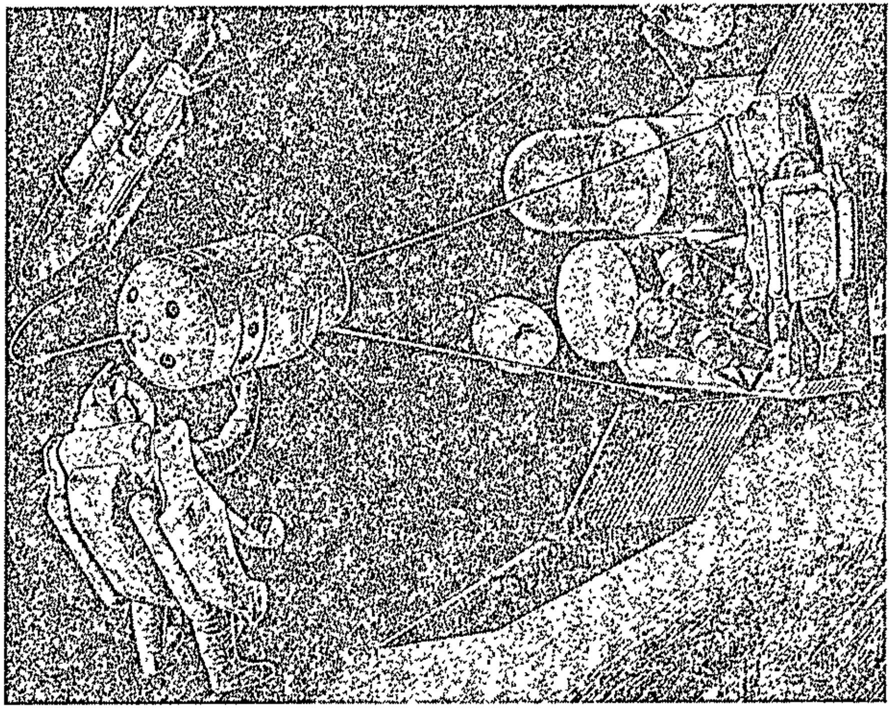
Retrieval - Retrieval is concerned with passive satellites having no fly-to-Orbiter capability. A typical retrieval would involve use of a retrieval kit to bring the unpowered satellite within the snaring envelope of the RMS.

- Thruster Pack - A "smart" thruster pack with RMS coupler is delivered to the satellite and attached by EVA. The pack remains attached to a light line from a take-up reel mounted in the Orbiter payload bay.

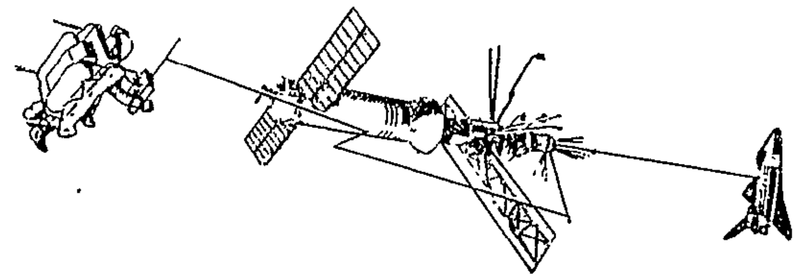
- Line Reel - The line reel, under IV operator control reels the line in, pulling the satellite towards the Orbiter.

In operation, the reel exerts a retrieval force on the satellite to move it towards the Orbiter. As the line reduces the distance between the satellite and the Orbiter, the satellite will accelerate due to the line force and orbital mechanics. The "smart" feature of the thruster pack senses the direction of the line pull and fires small directional thrusters in the proper direction to keep the satellite pointing towards the Orbiter and keeping the line taut. Firing of small retro thrusters, under command of the EVA crewman using a remote electronic controller, maintains line tension. Periodic thruster correction will keep the satellite moving in a controlled fashion along the desired trajectory towards the Orbiter.

SATELLITE RETRIEVAL



THRUSTER PACK ATTACHMENT
(a)



THRUSTER OPERATION
(b)

RETRIEVAL EQUIPMENT (Continued)

In illustration (a) two EVA crewmen are shown attaching the thruster pack to a satellite via a collapsable tripod, whose interface is compatible with the satellite. This illustrates the case where the satellite does not have integral provisions for docking with the Orbiter. The "smart" feature of the thruster pack is illustrated also. The line attachment to the thruster pack is made via a rod. Sensors in the pack generated the signals when the rod is deflected off-axis with respect to the major axis of the pack. Directional thrusters, responding to the sensor signals, null the direction error, thus keeping the satellite aimed towards the Orbiter.

The illustration (b) shows the retro thruster being fired by remote command from the EVA crewman, and a directional thruster firing to maintain the proper trajectory back to the Orbiter.

An alternative retrieval approach is to use a teleoperator thruster pack which would be flown out to a satellite under IV control, dock itself to the satellite, and fly the satellite back to the Shuttle within range of the RMS. This approach would require that the satellite be dynamically stable, so that proper approach corridors exist for the thruster pack to move in and attach itself to the satellite.

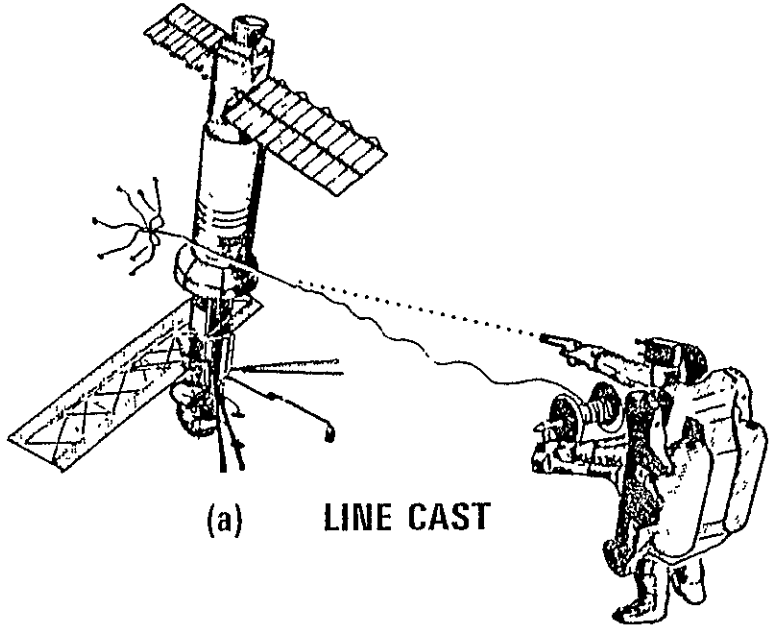
Stabilization - Stabilization is concerned with satellites that are out-of-control. EVA provides one means to approach and stabilize such satellites. A stabilization kit has been concepted consisting of a line casting gun and reel with provision for setting reel drag. The line casting gun operates on a gas cartridge or spring mechanism and is used to fire a weighted snare line across the path of the satellite which is snared by the satellite as it tumbles or spins.

Casting the line and ensnaring the satellite is shown in the accompanying illustration (a).

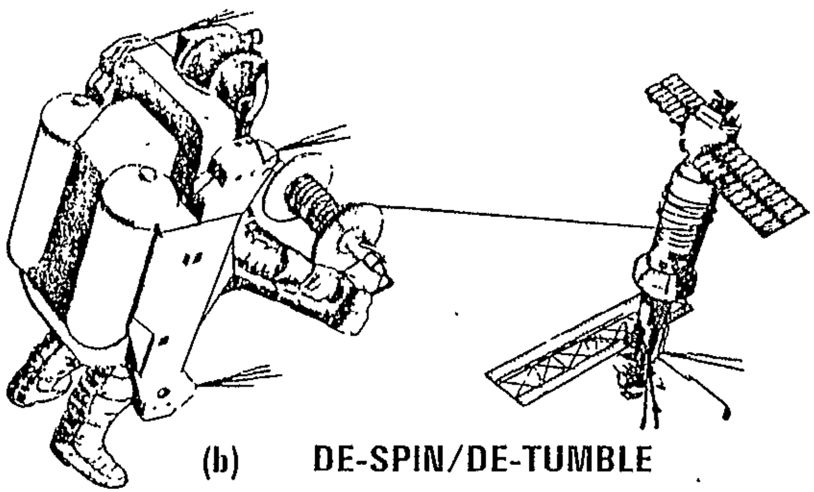
Once the satellite has been ensnared, the EVA crewman pays out line, which wraps around the spinning or tumbling satellite. Setting the MMU in automatic station-keeping mode, the crewmember then sets reel drag, thus removing kinetic energy from the satellite, as shown in accompanying illustration (b). Periodically the crewmember removes reel-drag and moves to a new position to compensate for any alteration of satellite dynamics. The EMU computer could be used to process a Range-Rate-Spin signal from a laser detector to generate control signals for the MMU to correct for altered dynamics between the crewmember and satellite. When the satellite's spin/tumble kinetic energy has been reduced to a safe level, the EVA astronaut can safely approach the satellite.

The EVA astronaut uses MMU thrusters in a station-keeping mode to provide fine satellite stabilization as illustrated in accompanying illustration (c).

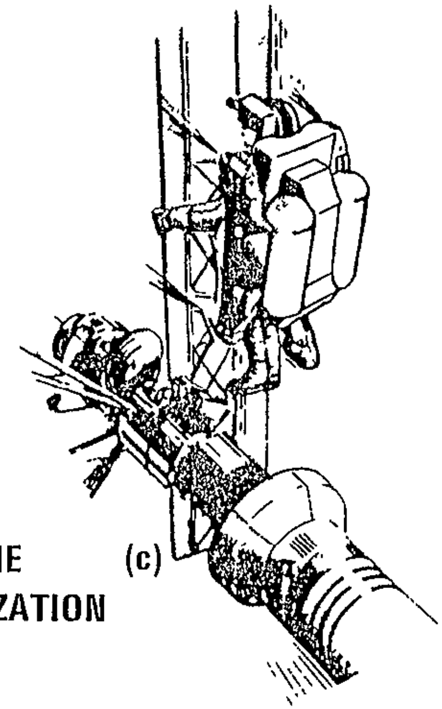
SATELLITE STABILIZATION



(a) LINE CAST



(b) DE-SPIN/DE-TUMBLE



FINE STABILIZATION (c)

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 deactivating subsystems. These activities will require EVA because satellites are not expected to be self-folding or self-safing.

Contingency preberthing activities deal with damaged or stuck appendages which may have to be cut off using EVA, or performing safing activities such as antenna removal, electrical deactivation, pressurant release or mechanical baffling of thrusters. These safetying activities are depicted in the accompanying illustration (a).

In addition, EVA may be required to defuel satellites, attach an FSS adapter if one does not exist on the satellite, and trim away debris from the satellite.

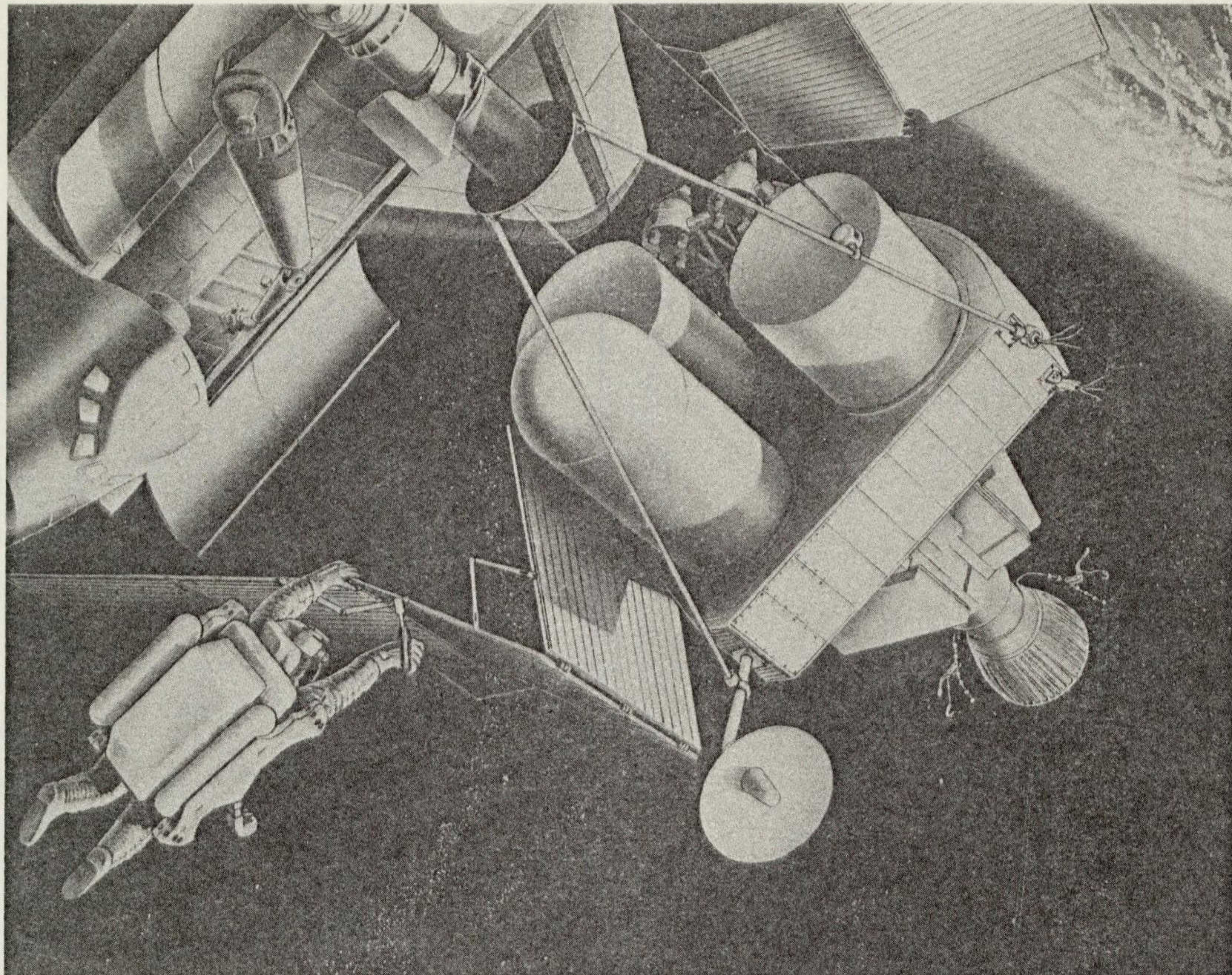
Safetying activity may be required to make a satellite safe before it can be berthed to the Shuttle or have maintenance performed remotely by the EVA crewmen. A safetying kit has been concepted for safetying satellite subsystems and triming away damaged or unfolding appendages prior to berthing. The kit consists of antenna/appendage cutters, sharp edge padding, sensor protection, and hardware and tools for depressurizing pressure vessels and thruster baffling.

Berthing Assist - Two EVA crewmen are in the accompanying illustration (a) assisting with RMS berthing. One crewman is shown removing the thruster pack from the satellite, which has been retrieved from a remote orbit. The thruster pack will be stowed in the Orbiter payload bay and readied for reuse. Releasing the thruster pack from the satellite exposes the graphing pin on the tripod bracket attached to the satellite. The second crewman is shown assisting the RMS to snare the satellite via the graphing pin.

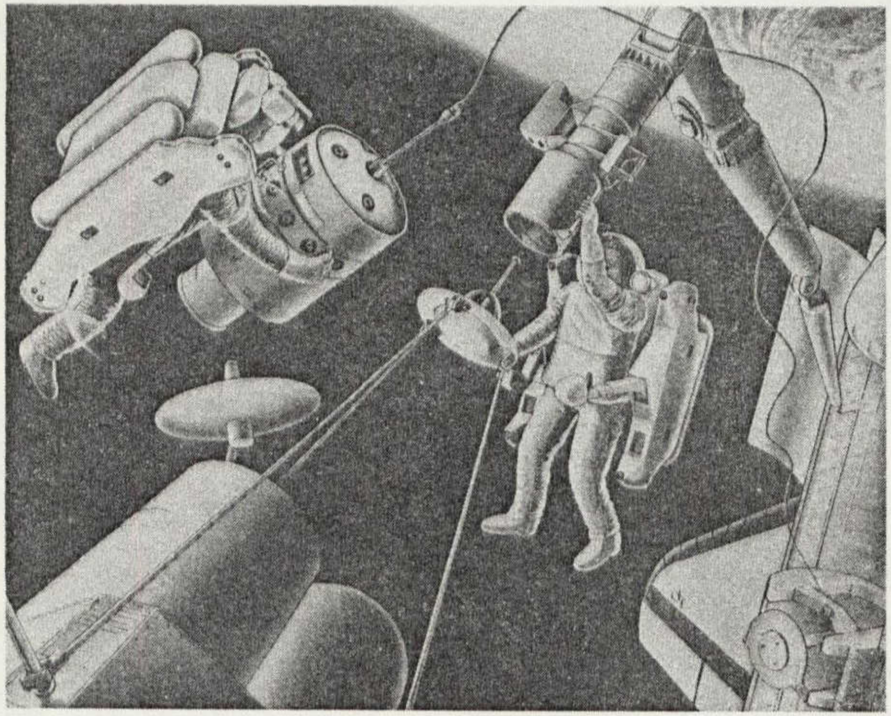
Illustration (b) shows EVA assisting in berthing a satellite to the Flight Support System (FSS) mounted in the payload bay.

Debris Management - Debris management in 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 to return to Earth.

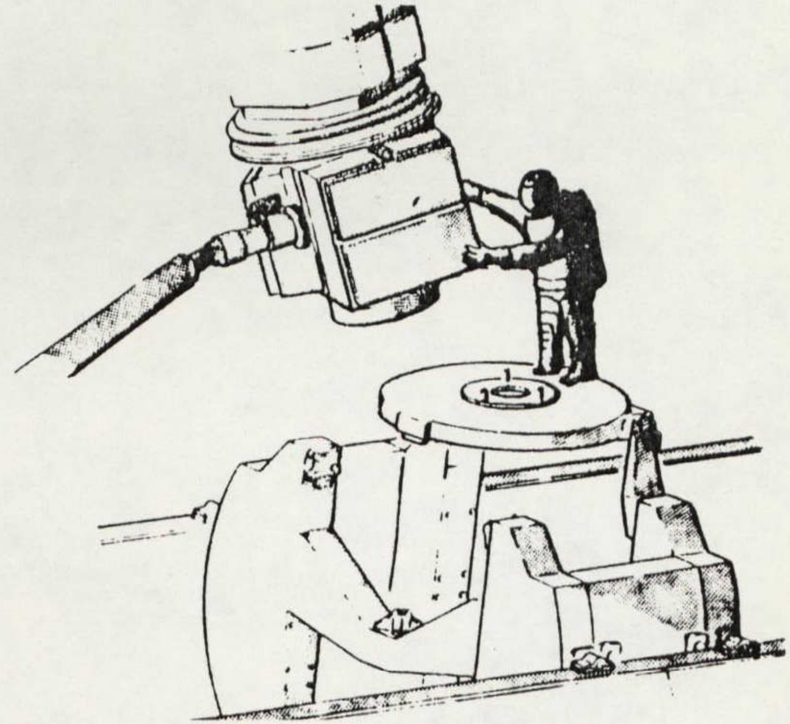
SATELLITE SAFETYING



SATELLITE BERTHING ASSIST



(a) THRUSTER REMOVAL



(b) FSS BERTHING ASSIST

RETRIEVAL EQUIPMENT (Continued)

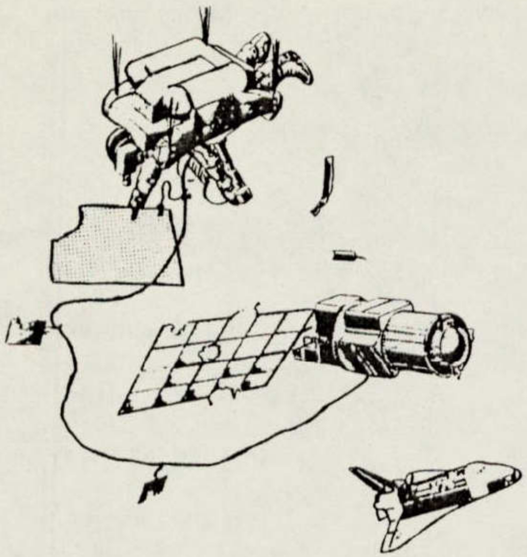
Debris is collected and transported to the Orbiter using the debris management kit, which consists of a collecting basket for storing small debris for transport back to the Orbiter, and a reel-line for tethering larger debris.

Use of the kit is illustrated in the accompanying pictures in illustration (a). The reel line is attached to the satellite. Large debris is tethered to the line using alligator clamps on velcro straps.

Illustration (b) shows the collection basket being used to stow smalldebris. The bristle top permits adding debris to the collection basket, but prevents debris from escaping inadvertently. The back of the basket is padded to prevent sharp debris from damaging the legs of the EMU.

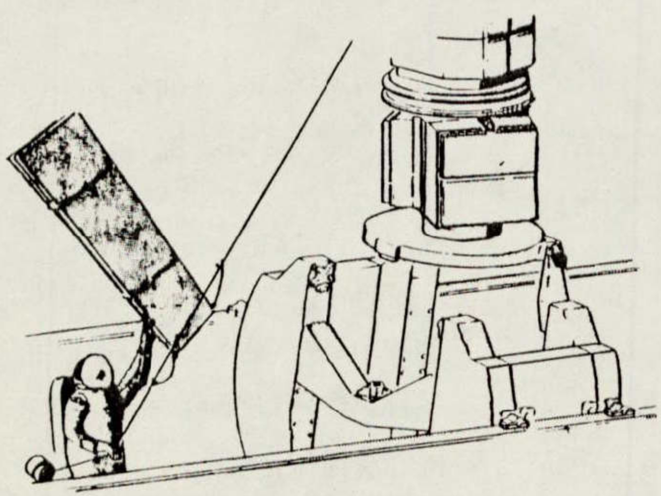
Illustration (c) shows large debris being moved down the reel line to the payload bay. The debris will be stowed in the payload bay for return to Earth.

DEBRIS MANAGEMENT



LARGE DEBRIS MANAGEMENT
(a)

SMALL DEBRIS MANAGEMENT
(BRISTLE BASKET)
(b)



DEBRIS & COMPONENT STOWAGE
(c)

SATELLITE SERVICE EQUIPMENT

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

Service Task Description	Potential Service Equipment Required
Electronic Systems Checkout	Diagnostic computer, EMU computer, dummy sensors, & loads
Transport of supplies and tools to remote work site	MMU Remote service kit work site
Fluid Service	Refuel/defuel facility
Heavy-duty hand tool work	Hand power tool and drill, impact and torque socket wrench, and screwdriver, saw, grind and shear accessories
Payload handling, payload bay and vicinity	RMS, FSS
Crewman transport to remote work site	MMU
Leak detection	IR detector, gas bag cuff, mass spectrometer
Item inspection	Optical magnifying device
Optical alignment	Portable laser
Measure electrical quantities	Multimeter, Oscilloscope
Other Hand tool operations	Fuse bond/weld/rivet tool, tools to measure/set mechanical clearances, harness repair kit, pliers, vice grips, mirror, knife, marker pen, hammer, rubber mallet, strap, camera, debris stowage bag, welding or fuse-bonding, EVA adhesive tape, hydraulic jack, prybar, cable cutter, wire stripper, sheet metal bending and forming tool, lens cleaner, tubing repair kit
Diagnostics, Visual Inspection	MMU, TV monitor

SATELLITE SERVICE EQUIPMENT (Continued)

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 preselected 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.

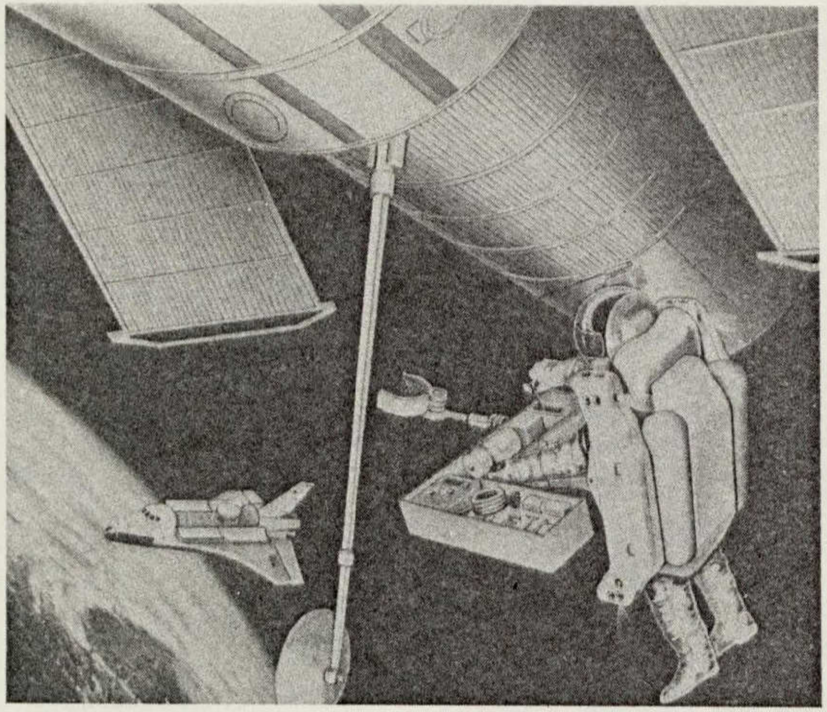
More Distant Inspection - In the accompanying illustration (a) an EVA crewman has left the Shuttle to inspect operational status of a satellite orbiting at a distance from Shuttle. The TV monitor provides information input to IV crewman for decisions such as to retrieve or abandon the satellite, and to service it remotely or at the Orbiter. Remote inspection 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.

More Distant Diagnosis - An EVA crewman is shown in the illustration (b) at a satellite service site remote from Shuttle, performing satellite diagnosis. The diagnosis/checkout computer kit, which has been carried out in the mobile service kit shown docked to the satellite, has been plugged into the satellite. The TV monitor is used to relay diagnostic information visually to an IV crewman. This step may be required before a decision is made to retrieve satellite for service at the Shuttle. Pre-prepared subsystem diagnostic software could be supplied by the subsystem manufacture in the form of modules to be plugged into the diagnosis/checkout computer.

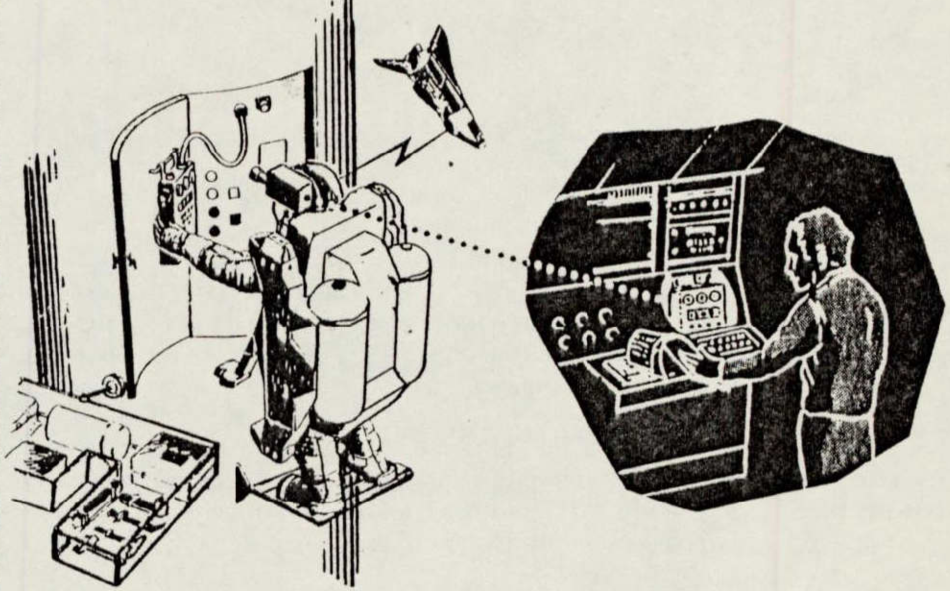
More Distant Service - More distant service consists of simple, routine tasks, such as experiement retrieval and film pack replacement. These tasks can be performed by EVA on a satellite that is performing normally.

A pallet, shown in illustration (b), can be attached to the EMU mini-work station to transport materials and supplies to remote service areas. Also tools and the diagnosis/checkout computer kit may be carried in the remote service kit as required. The kit contains portable workstand restraints and work aids to secure the crewman to the remote satellite service work site.

MORE DISTANT SATELLITE SERVICE



REMOTE INSPECTION
(a)



REMOTE DIAGNOSTICS
(b)

SATELLITE SERVICE EQUIPMENT (Continued)

Service at Shuttle - The view in accompanying illustration (a) shows an EVA crewman in the payload bay on a RMS work platform about to receive a replacement solar panel module for subsequent installation. The two reel tram line is being used to transport the module from the storage area.

In illustration (b) a crewman is shown performing contingency service on the RMS end effector. Repair of the Shuttle vehicle represents another potential orbital contingency service task. Payload bay service includes all service operations that might be performed on satellite systems orbiting remotely as well as more extensive system checkout, instrument change out, or replacement of modular elements such as solar arrays, antennas or propulsion packages.

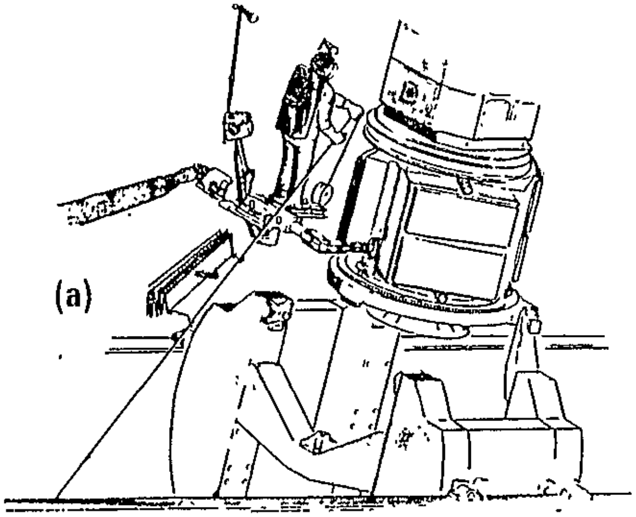
In illustration (c) the crewman on the right is shown performing final service checkout of satellite systems by way of the diagnostic/echeckout computer kit. The lower crewman is monitoring the satellite fueling/ pressurizing operation at a fluid service module located beneath the FSS platorm

The fluid service module provides electrical power to satellites for system checkout and includes satellite propellant defueling, refueling, and pressurizing capability. The FSS system consists of a tilting platform on which a satellite is mounted for payload bay stowage, assembly, deployment, and service. The platform bolts into the Shuttle bay, without scar, and includes spin-up capability and spring mechanism for use in satellite deployment.

An EVA astronaut is shown in illustration (d) performing refuel-only satellite service on a satellite spacecraft docked to the Shuttle RMS arm. Service performed with the satellite contained on the RMS generally would include straight forward tasks of instrument service and refueling.

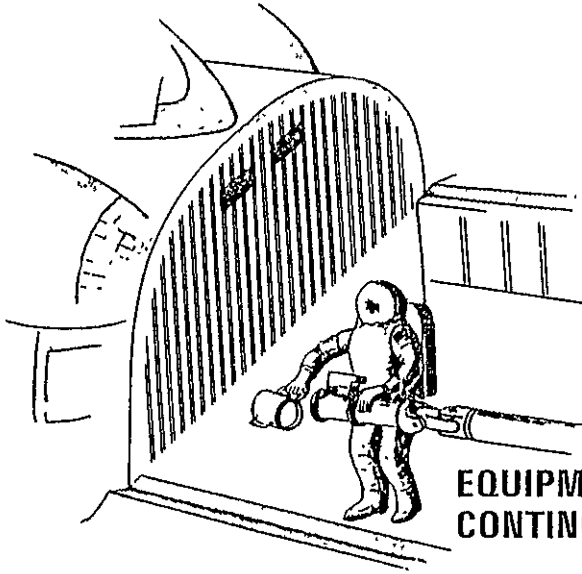
SATELLITE SERVICE AT SHUTTLE

(a)



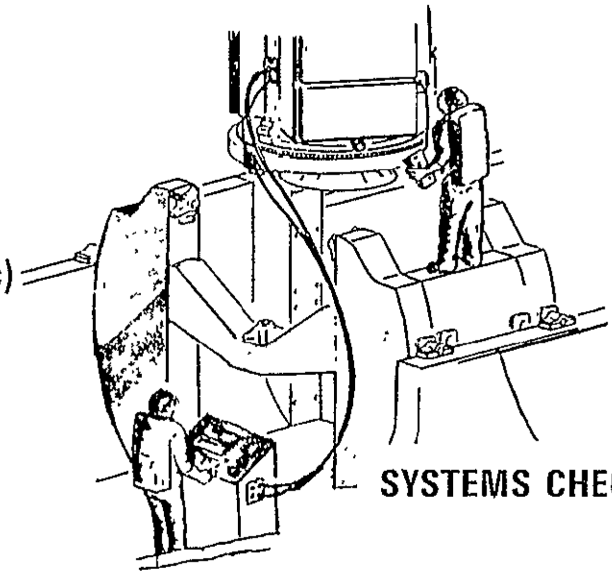
COMPONENT REPLACEMENT

(b)



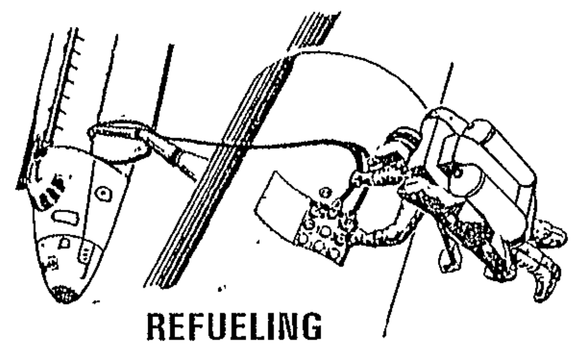
EQUIPMENT DAMAGE-
CONTINGENCY

(c)



SYSTEMS CHECKOUT

(d)



REFUELING

EVA SUPPORT EQUIPMENT

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	Shoulder lights on backpack, spotlight
IV/EV communication	TV monitor, EMU EVCS
Payload bay thermal protection	Extra suit insulation
Higher work mobility	Low force shoulders, wrists, elbows
Greater tactility	High tactility glove
Greater work mobility	Wrist display DCM
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, increased ΔV

EVA SUPPORT EQUIPMENT (Continued)

Requirement	Approach
Work System	
Transport supplies and parts in payload area	Tram line
Transport tools	Tool caddy
Astronaut restraint	Tether, movable foot restraints, workstands
Work bench mount	Mini-work station
Hardware restraint	Tether, velcro, clips, cart, tram line
Crewman transport	MMU, RMS, worklines
EMU Decontamination	Decontamination unit
Equipment transport	Portable service tray

SATELLITE SERVICE WORK AIDS

Tool Caddy - Two tool caddy concepts are presented as shown in the accompanying illustration (a) 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.

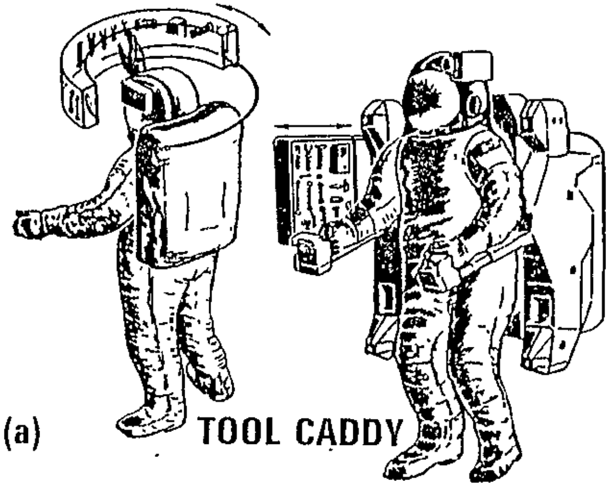
More Distant Equipment Transport - A service kit has been concepted as shown in the accompanying illustration (b) for transporting equipment and other service materials to a more distant work site. The container tray attaches to the waist mini-work-station and is propelled together with the crewman by the MMU propulsion unit.

Crewman Restraint - The concept proposed is an adjustable rigid restraint mechanism that is part of the crewman mini-work-station which is already under development. The adjustable restraint mechanism then attachs to fixed satellite restraint points, is adjusted and clamped in place to provide rigid crewman restraint during EVA work activities.

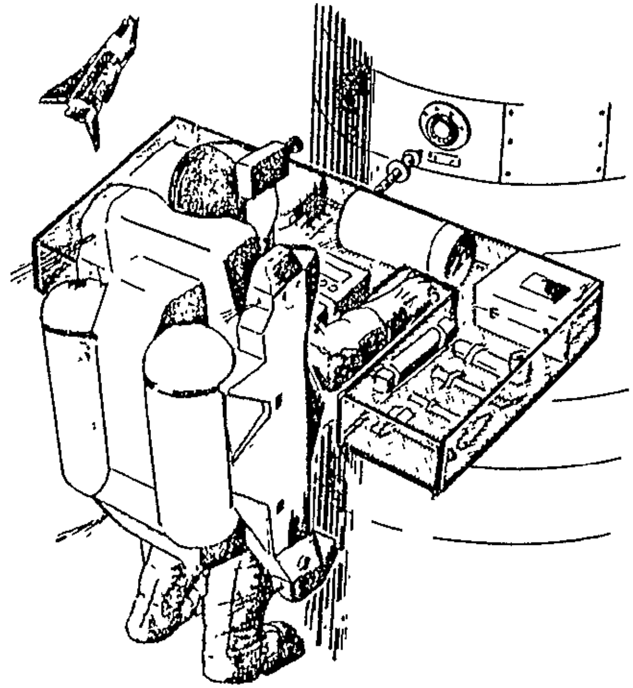
Restraint Attachment Points on Satellite - The concept proposed involves hot-melt adhesive-bonded adapters that can be bonded to work site surfaces and subsequently removed without scar. A bonding tool has been concepted for attaching such adapters at work sites where fixed adapters have not been provided.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

Decontamination Unit - The concept presented in the accompanying illustraction (c) is an Air-Lock Gas Management Unit that heats inlet air entering unit from the airlock, removes toxic contaminants by way of a catalytic bed and discharges filtered air through an adjustable nozzle back to the airlock. The nozzle discharge can be directed by the crewman. An inlet sensor senses when safe limits on trace contaminants have been reached. EMU equipment contamination, such as hydrazine, can thereby be purged from airLock atmosphere prior to crewman entering Shuttle cabin environment.

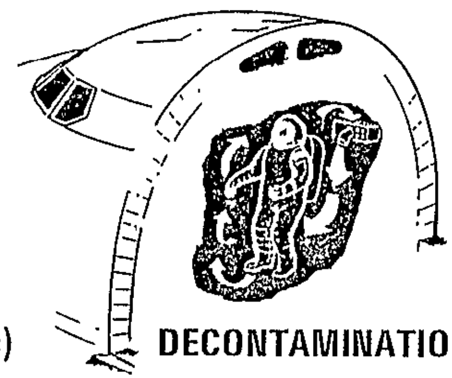
SATELLITE SERVICE WORK AIDS



(a) TOOL CADDY



(b) MORE DISTANT SERVICE



(c) DECONTAMINATION

SATELLITE SERVICE EMU

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-refringent 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.

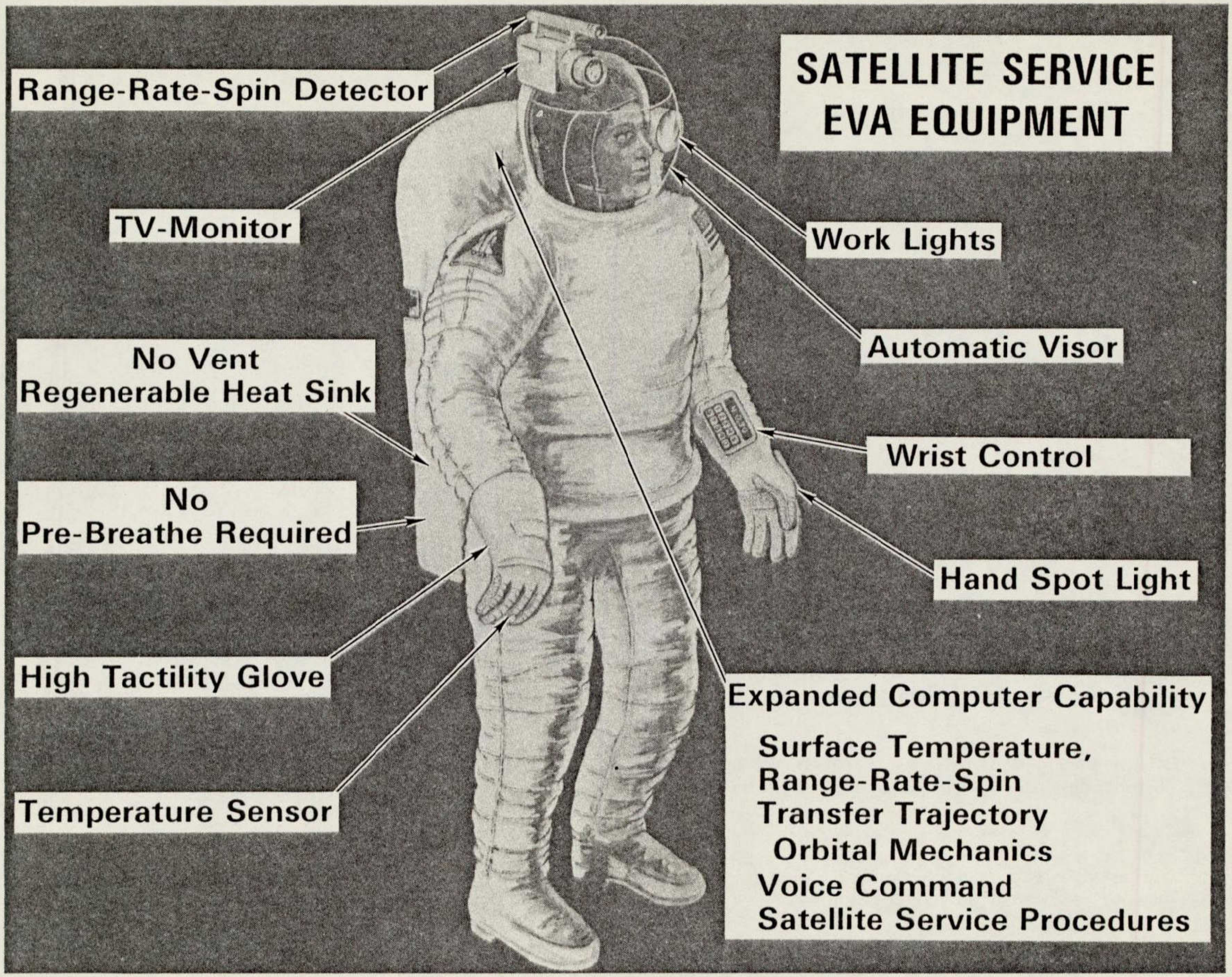
- No-Prebreathe Requirement - EMU suit requiring would reduce consumption of O_2 expendables and simplify EVA preparation. Several approaches hold promise, including increased suit pressure, reduced Shuttle cabin pressure, and preprogrammed suit depressurization to 4 psia during EVA.

- 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.

- TV Monitor - A portable TV monitor to provide a real-time visual data link to IV crew supporting the EVA tank.

- 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.


SATELLITE SERVICE
EVA EQUIPMENT
Range-Rate-Spin Detector
TV-Monitor
Work Lights
Automatic Visor
No Vent
Regenerable Heat Sink
Wrist Control
No
Pre-Breathe Required
Hand Spot Light
High Tactility Glove
Expanded Computer Capability
Surface Temperature,
Range-Rate-Spin
Transfer Trajectory
Orbital Mechanics
Voice Command
Satellite Service Procedures
Temperature Sensor

SATELLITE SERVICE EMU (Continued)

- Differential Orbital Mechanics - The Range/Rate/Spin signals would be processed by the EMU computer to determine relative changes in velocity and range between the EVA crewmember and satellite. Subsequent MMU control signals would be generated to correct for differential orbital mechanics during satellite stabilization.

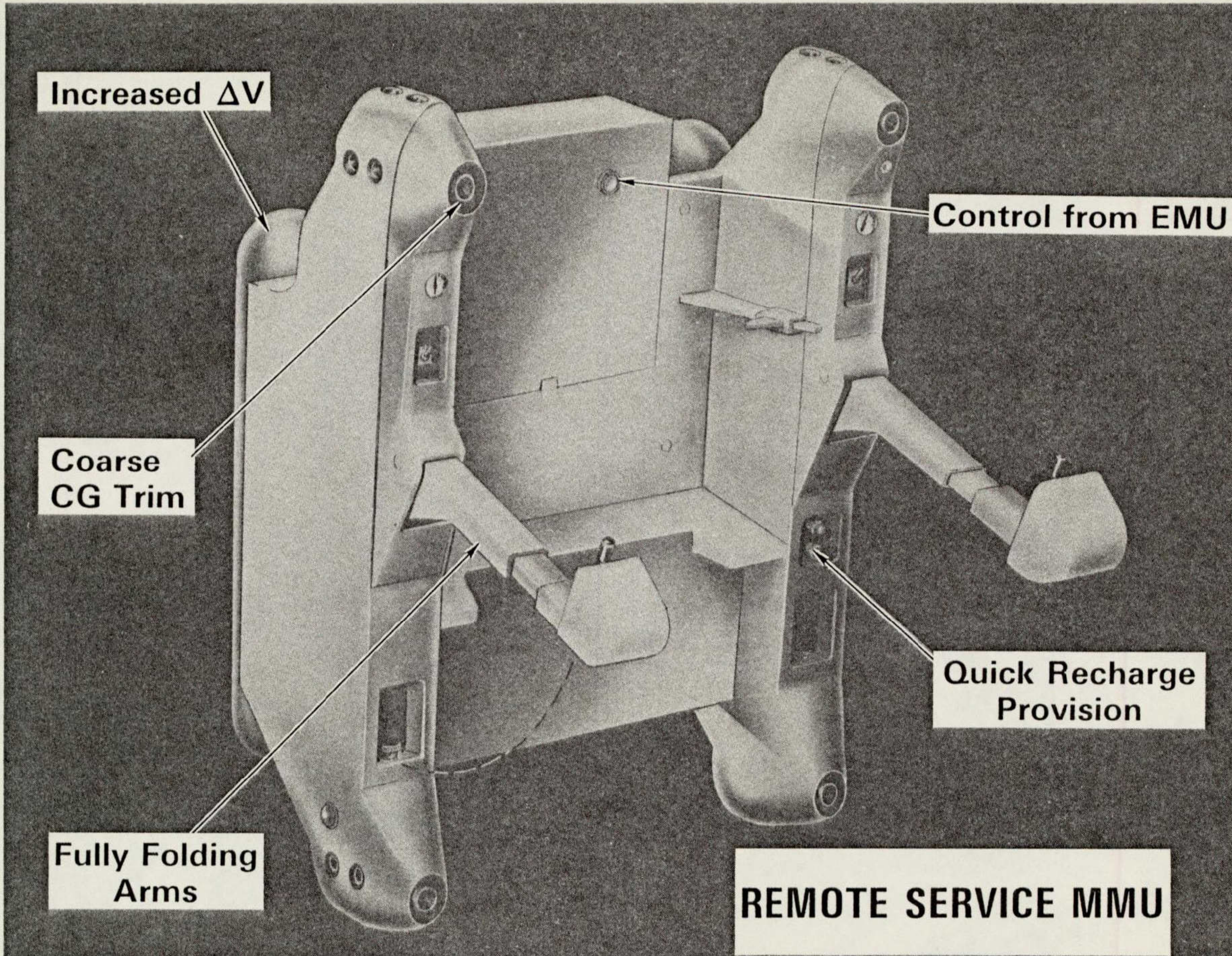
- Temperature Sensor - An IR sensor control be located on the glove to provide an analog temperature signal for microprocessor processing and display. This capability would make surface temperature known before the crewmember touches it.

- 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.

REMOTE SERVICE MMU

The following features are proposed to be added to the basic MMU propulsion unit to support more distant satellite service capability. These features are indicated in the accompanying illustration.

- Higher Δ V to permit removal of more unwanted dynamic energy from satellites during stabilization activities.
- Control provision from the EMU computer in response to differential orbital mechanics or voice command signals.
- Fully retractable control arms to permit closer approach to the service work site.
- 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/Payload System.


Increased ΔV
Control from EMU
Coarse CG Trim
Quick Recharge Provision
Fully Folding Arms
REMOTE SERVICE MMU

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 3, Satellite Service

Introduction

Satellite Characteristics

Service Task Requirements

Service Equipment Concepts

Service Capability Packages

Appendices

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SATELLITE SERVICE CAPABILITY PACKAGES

Preceding sections discussed satellite servicing tasks in orbit and identified techniques and equipment concepts for performing them. Developing orbital satellite service capability is expected to proceed from more simple tasks towards more complex tasks, using the experience and confidence gained at each step to perform more ambitious successive steps. Therefore, it is of interest to future program planning to define and arrange the satellite service tasks, techniques and equipment concepts into incremental steps leading to increased service capability.

The approach taken considers both increasing task complexity and greater distance from the Orbiter at which the task is performed. Successive steps represent service capability packages, consisting of equipment and techniques required to perform service tasks of increasing complexity, first within the payload bay or on the RMS, then near by the Orbiter, and finally at more distance from the Orbiter.

The capability package progression is shown in the accompanying chart. Detailed task capability and required equipment are linked for each service capability package in Appendix 3 of this volume. Rationale for the capability packages is as follows:

- Seven increments will develop EVA capability from present baseline to operations up to 10 km distant.

- Increment sequence is consistent with STS capability evolution.

- Increments track increasing satellite population and serviceability.

- Increments group interrelated changes together to simplify program management. There is only one integration task per package.

- Increments reflect technology development lead times.

- Increments develop EVA capability first in the vicinity of the Orbiter. This allows accumulation of experience and confidence before commuting to more distant EVA.

SATELLITE SERVICE CAPABILITY PACKAGES

Pkg	Increasing Service Capability	Capability Package Required: Payload Bay & RMS Envelope	Capability Package Required: Within 100m	Capability Package Required: Within 10 km
7.	More Distant EVA Capability – EVA Stabilization & Retrieval – Free Flying Debris Collection			Pkg 6+ Stabilization Kit Retrieval Kit Debris Kit Use of Enhanced Computer Capability
6.	Near-in EVA Capability – Snaring Assistance – Remote Diagnostics & Service		Pkg 5+ Satellite Service MMU TV Monitor Remote Service Kit Manipulator Module Rigid Leg Enclosure	
5.	Improved EMU Capability – Reduced Consummables Use – Support High EVA Levels Increased Satellite Service Capability	Pkg 4+ Long Life SSA & Incremental Hazards Protection Regenerable CO_2 Removal Non-Venting Heat Sink 8-Hr EVA Capability Enhanced Computer Capability Repackaged LSS		
4.	• Mature Service Capability – Fluid System & Minor Electrical Repairs – Electrical/Electronic Diagnosis & Checkout	Pkg 3+ Subsystems Diagnostics & Checkout Kit Leak Detection Kit Fluid System Refill Kit Fluid Isolation Kit		
3.	• Structural Repair – Material Cutting & Bonding – Rapid Fastener Handling	Pkg 2+ Hand-Held Power Tool Fuse-Bond Tool		
2.	• Routine Servicing – Subsystem Safetying & Debris Stowage – Lens/Sensor Cleaning & Refueling – Two-Handed Work Capability – Eliminate Prebreathe	Pkg 1+ Service Materials, Supplies, & Repair Parts Hand Tools, Tool Caddy & Tram Line Baffles, Shields & Adapters Work Platform & Adhesive Bond Gun Wide Angle Helmet & Rugged Gloves Decontamination Facility Refuel Facility		
1.	Baseline Capability – Normal & Contingency Deployment & Berthing – Inspection of Orbiter & Payloads – Module Replacement – Tile Repair, P/L Door Closure, Rescue	Shuttle EMU MMU RMS Select Hand Tools		

Work Distance from Orbiter

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 3, Satellite Service

- Introduction
- Satellite Characteristics
- Service Task Requirements
- Service Equipment Concepts
- Service Capability Packages
- **Appendices**

HAMILTON STANDARD
Division of UNITED TECHNOLOGIES

APPENDICES

The following appendices contain detailed considerations that are summarized in preceding sections of this volume.

Appendix	Contents
1	Proposed Delivery of LEO Spacecraft (1979-1989) Projected Cargo Manifest for the First 35 Space Shuttle Flights
2	Satellite Subsystem Service Tasks
3	Satellite Service Capability Packages

APPENDIX 1

- Proposed Delivery of LEO Spacecraft (1979-1989) (4)
- Projected Cargo Manifest for the First 35 Space Shuttle Flights

	Mission Name	Sponsor	Launch Schedule											Payload(b) Total	Spacecraft Parameters		S/C Configuration	Delivery Orbit		Launch Site
			79	80	81	82	83	84	85	86	87	88	89		Mass Lb	Length Dia. Ft.		Apogee Perigee N.Mi.	Incl. deg	
1.	Extreme UV Explorer	NASA-OSS				1								1	680	2.95/ 15.0	FF	300/ 300	28.5	ETR
2.	High Energy Explorer	NASA-OSS					1		1		1		1	4	5000	15.0/ 15 0	FF	250/ 250	28.5	ETR
3.	Low Energy Explorer	NASA-OSS									1		1	2	2200	5.9/ 4.6	FF	300/ 300	44.9	ETR
4.	Cosmic Background Explorer (COBE)	NASA/OSS						1				1		2	1800	0.5/ 14.4	FF	490/ 490	99	WTR
5.	IR Astronomy Explorer	NASA-OSS										1		1	2000	8.2/ 4.9	FF	410/ 430	98-99	WTR
6.	Electrodynamic Explorer A	NASA-OSS								1				1	1500	5.9/ 4.6	FF	270/ 110	90	WTR
7.	Gravity Probe B (Relativity)	NASA-OSS									1			1	2000	11.8/ 7.2	FF	280/ 280	90	WTR
8.	Solar Maximum	NASA-OSS	1			R		1		R	1	R	1	4	4500	13.1/ 7.2	MMS	250/ 250	28.5	ETR
9.	Upper Atmosphere Research Sat (UARS)	NASA-OSS					1		1V		VV		V	2	5300	16.4/ 13.1	MMS	300/ 300	56/70	ETR
10.	Gamma Ray Observatory (GRO)	NASA-OSS					1		R	1	V	V	R	2	22000	23.9/ 14.1	FF	216/ 216	28.5	ETR
11.	1.2M X-Ray Observatory	NASA-OSS							1		R1	V	V	2	22000	40.7/ 14.1	FF	270/ 270	28.5	ETR
12.	Space Telescope	NASA-OSS						1		R	1		V	2	21000	42.3/ 15.0	FF	270/ 270	28.5	ETR
13.	UV Photometric/Polarimetric Explorer (UPPE)							1						1	2464	8/7	FF	216/ 216	28.5	
14.	Large Area Modular Array of Reflectors (LAMAR)										1			1	11440	16/15	FF	216/ 216	28.5	
15.	X-Ray Observatory (XRO)												1	1	7810	16/15	FF	216/ 216	28.5	
16.	Cosmic Ray Observatory (CRO)									1		R	1	2	39600	33/15	FF	216/ 216	56	
17.	UV Optical Interferometer (UVOI)												1	1	7040	36/15	FF	300/ 300	28.5	
18.	Electrodynamic Explorer	NASA-OSS								1				1	1650	5.9/ 4.5	FF	20,000/ 160	90	WTR
	TOTALS (PAYLOADS)(b)		1			1	3	4	3	4	7	2	6	31						

(a) Sun-synchronous orbit.
(b) Retrievals (Ra) and visits (Va) not included.

	Mission Name	Sponsor	Launch Schedule											(c) Payload Total	Spacecraft Parameters		S/C Configuration	Delivery Orbit		Launch Site
			79	80	81	82	83	84	85	86	87	88	89		Mass Lb	Length Dia. Ft.		Apogee Perigee N.Mi.	Incl. deg	
19.	Earth Radiation Budget Sats (ERBSS)	NASA-OSTA				1								1	1000	14.1/ 6.9	FF	380/ 380	56	ETR
20.	LANDSAT D	NASA-OSTA			△1		R1		R		1			3	3750	14.1/ 7.2	MMS	380/ 380	98.2	WTR
21.	Stereosat						1							1	3750	14.1/ 7.2	FF	180/ 380	98.2	WTR
22.	MAGSAT	NASA-OSTA						1						1	660	3.0/ 3.0	FF	186/ 186	99	WTR
23.	NOS						1	1			R1			3	5900	20/7	FF	400/ 400	87	WTR
24.	TIROS O	NASA-OSTA							1					1	2400/ 3500	23/ 11.8	FF or MMS	450 or 920[b]	99 or 103	MED/ APP/FF
25.	Environmental Monitor Sat (LOW)	NASA-OSTA							1	1				2	3500/ 4400	17.0/ 7.5	MMS	320/ 320	56	MMS
26.	Earth Survey	NASA-OSTA									1		1	2	1700	9.8/ 4.92	FF	490/ 490	100	WTR
27.	Global Resources Mon Info System	NASA-OSTA							1					1	3500/ 4400	20.0/ 13.1	MMS	380/ 380	98.2	WTR
28.	GRAVSAT	NASA-OSTA						1				1		2	4409	7.2/ 13.1	MMS	160/ 160	90	WTR
29.	COASTSAT							1						1	5900	20/7	FF	400/ 400	87	WTR
	TOTAL				1	1	3	4	3	1	3	1	1	18						
	NASA-OAST																			
30.	Space Technology Research Satellite	NASA-OAST									1		R1	2	10.000	11.8/ 7.9	FF	230/ 230	28.5	ETR
	TOTAL										1		R1	2						
	NASA SUMMARY																			
	OSS Total		1			1	3	4	3	4	7	2	6	31						
	OA Total				1	1	3	4	3	1	3	1	1	18						
	OAST Total										1		1	2						
	NASA TOTAL				1	2	6	8	6	5	11	3	8	51						

(a) Includes PM-1 propulsion module to be used for on-orbit attitude control and stationkeeping only.
(b) Circular orbit
(c) Retrievals not included.

	Mission Name	Sponsor	Launch Schedule											Payload Total	Spacecraft Parameters		S/C Configuration	Delivery Orbit		Launch Site
			79	80	81	82	83	84	85	86	87	88	89		Mass Lb	Length Dia. Ft.		Apogee Perigee N.Mi.	Incl. deg	
31.	System 85	NOAA/U.S. Govt.								1	1	1	1	4	2500	22.9/ 11.8	FF or MMS	450 or 920[d]	or 103[a]	WTR
32.	Govt. Earth Resources – A (low)	U.S. Govt.							1		R	1		2	3750[b]	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
33.	Govt Earth Resources – B (low)	U.S. Govt.								1		R	1	2	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
34.	Govt Earth Resources – C	U.S. Govt.									1		R	1	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
35.	INRESAT A	International								1		R		1	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
36.	INRESAT B	International										1		1	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
37.	INRESAT C	International											1	1	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
38.	Private Earth Resources – A (low)	Commercial								1		R		1	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
39.	Private Earth Resources – B (low)	Commercial										1		1	3750	14.1/ 7.21	MMS	380/ 380	97–98[a]	WTR
	TOTAL								1	4	2	4	3	14						

(a) Sun-synchronous orbit
(b) Includes MMS PM-1
(c) Retrievals not included.

	Mission Name	Sponsor	Launch Schedule											Payload(b) Total	Spacecraft Parameters		S/C Config-uration	Delivery Orbit		Launch Site
			79	80	81	82	83	84	85	86	87	88	89		Mass Lb	Length Dia. Ft.		Apogee Perigee N.Mi.	Incl. deg	
	Foreign																			
40.	Polaire	Canada					1					1		2	2000		FF	450/ 450	90	WTR
41.	European Scientific	Europe									1		1	2	880	4.9/ 3.9	FF	300/ 300	28.5	ETR
42.	All Weather Canadian Wave Environmental	Canada									1			1	5900	20/7	FF	400/ 400	87	WTR
43.	Earth Resources Foreign (low)	Foreign									1		1	2	2300	26.9/ 4.9	FF	490/ 490	99	WTR
44.	UKMD								1		V			1	5900	16/8	MMS	400/ 400	56	ETR
	TOTAL						1		1		3	1	2	8						
	DoD(a)																			
45.	USAF Space Test Program	DoD		1	1	1	1	1	1	1	1	1	1	10	2000	3.3/ 13.1	FF	400/400 Circ.	28.5- 100	ETR- WTR(d)
46.	USAF Meteorological Satellite	DoD							1	1	1	1	1	5	2500	19.9/ 9.8	FF	400/ 400	98.4	WTR
	TOTAL			1	1	1	1	1	2	2	2	2	2	15						

(a) Battelle 3/78 best estimate of unclassified low energy DoD missions.
(c) Retrievals and visits not included.
(d) Launches in 1980-1982, 1984, 1986, 1988, 1990 were assumed to be from ETR.
The remainder were assumed to be from WTR.

PROJECTED CARGO MANIFEST FOR THE FIRST 35 SPACE SHUTTLE FLIGHTS

Flight No.	Approx. Date	Payload	Description
1	Early 1980	§ Deployed Flight Instrumentation	An instrument package deployed in orbit by Shuttle's manipulator arm to help test and monitor the Shuttle's flight.
2	3/6/80	§ Deployed Flight Instrumentation	Same as Flight 1.
		Office of Science and Terrestrial Applications pallet	A pallet bearing instruments for earth viewing.
3	6/5/80	§ Deployed Flight Instrumentation	Same as Flight 1.
		Payload Deployment/Retrieval System test article	Simply a test mass that the remote manipulator arm can grasp and maneuver.
4	8/26/80	§ Deployed Flight Instrumentation	Same as Flight 1.
		Geosynchronous Operational Environmental Satellite-D	The fourth in a series of satellites managed by the National Oceanic and Atmospheric Administration to monitor the environment.
5	10/28/80	§ Deployed Flight Instrumentation	Same as Flight 1.
		Office of Space Sciences pallet	Instrumentation pallet for physical and astronomical experiments for outer space.
6	12/10/80	§ Deployed Flight Instrumentation	Same as Flight 1.
		Contingency space	To be used for any additional testing that could prove necessary after the first five test flights.
7	2/27/80	‡ Tracking and Data Relay Satellite-A	The first in a series of satellites to relay communications and data to either the Shuttle orbiter or to earth. Boosted to geosynchronous orbit by an upper stage.
8	3/26/80	● Geosynchronous Operational Environmental Satellite-E	The fifth in a series of National Oceanic and Atmospheric Administration satellites for environmental monitoring (see Flight 4).
		‡ Satellite Business Systems-A	The first in a series of commercial spacecraft placed in geosynchronous orbit by an upper stage for data relay.
		■ Anik-C/1	The first in a series of Canadian communications satellites placed in geosynchronous orbit by an upper stage.
		■ Spas-01	A special West German pallet for free-flying experiments and payloads.

Symbol Code

- * NASA missions
- ■ Foreign governments and commercial
- □ U.S. Department of Defense
- ● Civilian U.S. Government agencies other than NASA
- ‡ U.S. commercial payloads
- † Cooperative NASA/European Space Agency Missions
- § Orbital test flights
- @ Unscheduled space

PROJECTED CARGO MANIFEST FOR THE FIRST 35 SPACE SHUTTLE FLIGHTS (Continued)

Flight No.	Approx. Date		Payload	Description
9	4/23/81	‡	Intelsat F5	An international communications satellite to be placed in geosynchronous orbit by an upper stage.
		■	Insat-1/A	First in a series of communications satellites (for broadcasting) by India.
		*	Office of Science and Terrestrial Applications pallet	Same as Flight 2.
10	5/29/81	‡	Tracking and Data Relay Satellite-B	The second in a series (see Flight 7).
11	7/1/81	‡	Intelsat F6	Another Intelsat (see Flight 9).
		‡	Satellite Business Systems-B	The second in a series (see Flight 8).
		■	Anik-C/2	The second in the Canadian Series (see Flight 8).
12	8/12/81	†	Spacelab 1	The first Spacelab flight. A joint NASA/European Space Agency flight to verify the system and perform some experiments. Four scientists – two from the U.S. and two from European nations – will work inside the Spacelab while it rests in the Shuttle's cargo bay during flight.
13	9/17/81	‡	Tracking and Data Relay Satellite-C	The third in a series (see Flights 7 and 10).
		@	Upper stage opportunity	An unassigned spot, with space for a satellite using an upper stage to boost it to geosynchronous orbit.
14	10/16/81	*	Long Duration Exposure Facility deployment	A passive 15 x 30-ft craft to be exposed to the space environment for six to nine months. Its surface has mounts for materials and experiments.
		*	Solar Maximum Mission retrieval	Retrieval of the Solar Maximum Mission launched late in 1979 by a Delta booster. This flight will mark the first retrieval of a satellite from space to be refurbished on earth and reused.
15	11/17/81	□	Department of Defense 82-0	A Department of Defense mission with an unannounced payload.
16	1/6/82	*	Galileo Explorer	Satellite launched to Jupiter from the Shuttle by an upper stage. The Galileo Explorer will orbit and examine that planet and its moons.

Symbol Code

- * NASA missions
- ■ Foreign governments and commercial
- □ U.S. Department of Defense
- ● Civilian U.S. Government agencies other than NASA
- ‡ U.S. commercial payloads
- † Cooperative NASA/European Space Agency Missions
- § Orbital test flights
- @ Unscheduled space

PROJECTED CARGO MANIFEST FOR THE FIRST 35 SPACE SHUTTLE FLIGHTS (Continued)

Flight No.	Approx. Date	Payload	Description
17	1/22/82	* Spacelab 2	Testing of a different hardware configuration than that used in the first Spacelab flight. Experiments to study cosmic rays will be conducted in the open payload bay of the Shuttle, while the scientists monitor the tests from the aft portion of the Shuttle cabin.
18	2/24/82	‡ RCA-D	An RCA commercial communications satellite boosted to geosynchronous orbit by an upper stage.
		● Geosynchronous Operational Environmental Satellite-F	The sixth in a series by the National Oceanic and Atmospheric Administration (see Flights 4 and 8).
		‡ Syncom IV-1	Communications satellite designed by Hughes Aerospace Corp. This is the first design using the entire 15-ft diameter of the Shuttle payload pay
19	3/10/82	‡ Tracking and Data Relay Satellite-D	The fourth in the series (see Flights 7, 10, and 13).
		■ Anik-D/1	The third in the Canadian Anik series (see Flight 8 and 10).
20	4/7/82	□ Department of Defense 82-1	A mission with unannounced payload.
21	4/23/82	* Spacelab 3	The first fully operational Spacelab flight. Scientists will work inside Spacelab's pressure module for earth-viewing experiments.
22	5/13/82	@ Reflight opportunity	Flight with unassigned payloads. Can be used for retrieval or to reschedule any early missions, if needed.
23	6/2/82	■ Arabsat-A	A communications satellite developed for use by a consortium of Arab countries. It will be boosted to geosynchronous orbit by an upper stage.
		‡ Syncom IV-2	The second in the Hughes Aerospace series (see Flight 18).
		* Materials Science Spacelab	Flight with a single pallet, mounted with materials and the metallurgical experiments in the open cargo bay. Scientists will work inside the Shuttle.
24	6/22/82	■ PRC Comsat	A slot for a communications satellite reserved for the People's Republic of China.
		■ Palapa-B/1	The first in a series of communications satellites developed by Indonesia for radio and video broadcasts.
		■ Insat-1/B	The second in India's series (see Flight 9).

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- † Cooperative NASA/European Space Agency Missions
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PROJECTED CARGO MANIFEST FOR THE FIRST 35 SPACE SHUTTLE FLIGHTS (Continued)

Flight No.	Approx. Date	Payload	Description
25	7/9/82	‡ Satellite Business Systems-C	The third in the series (see Flights 8 and 11).
		■ Anik-C/3	The fourth in the Canadian series (see Flights 8, 11 and 19).
		@ Pallet opportunities	Space for two instrument pallets – thus far unassigned.
26	7/28/82	* Long Duration Exposure Facility Retrieval	Retrieval of craft placed in orbit by the Shuttle on Flight 14. It will be refurbished and reused.
		† Active Magnetospheric Particle Tracer Explorer	A U.S./West German satellite to study and measure chemical releases in the magnetosphere.
27	8/17/82	* Life Sciences Spacelab	A NASA mission for life-sciences experiments (biology, hematology, etc.)
28	9/2/82	□ Department of Defense 82-2	A mission with unannounced payload.
29	9/30/82	* Physics and Astronomy Spacelab	A mission for physical and astronomical observations of outer space.
30	10/20/82	■ Palapa-B/2	The second in the Indonesian series (see Flight 24).
		‡ RCA-E	Another RCA communications satellite (see Flight 18).
		‡ Syncom IV-3	The third in the Hughes series (see Flights 18 and 23).
31	11/10/82	@ Spacelab opportunity	A flight with a thus far unassigned mission. Could refly earlier experiments that failed or could be a completely new mission.
32	12/2/82	■ Arabsat-B	The second in the Arabian series (see Flight 23).
		■ PRC Comsat	A slot for a communications satellite reserved for the People's Republic of China.
		■ West Germany TV	A TV satellite for television relays.
33	1/5/83	■ BMFT-1 Spacelab	A mission completely sponsored by West Germany. The experiments are thus far unscheduled.
34	1/26/83	□ Department of Defense 83-1	A mission with unannounced payload.
35	2/3/83	† International Solar Polar Mission	A cooperative NASA/European Space Agency mission in which two spacecraft will be launched from the Shuttle to view the polar regions of the sun. Both spacecraft will fly to Jupiter first and use that planet's gravitational field to modify their trajectories for flight back over the sun's polar regions.

Symbol Code

- * NASA missions
- ■ Foreign governments and commercial
- □ U.S. Department of Defense
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- ‡ U.S. commercial payloads
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- § Orbital test flights
- @ Unscheduled space

APPENDIX 2

SATELLITE SUBSYSTEM SERVICE TASKS

ATTITUDE CONTROL SUBSYSTEM

Service Operations	Service Tasks
Subsystem safetying	Install/remove thruster baffles Mate/demate electrical connectors
Subsystem checkout	Fuel/oxidizer/pressurant leakage Electrical continuity Valve operations and engine operation Visual inspection
Replace modular elements	Install/remove mechanical fasteners Mate/demate fluid connectors Mate/demate electrical connectors Install/remove ACS module Decontaminate removed module
Hardware repair	Straighten interface metal Repair fluid leakage at interface fittings Repair interface electrical connectors Replace mechanical fasteners

PROPULSION SUBSYSTEM

Service Operations	Service Tasks
Subsystem safetying	Shield pressure vessels Vent pressure vessels Isolate fluids
Subsystem checkout	Fluid leakage Electrical continuity Gage fluid quantities Visual inspection
Replace modular elements	Mate/demate fluid connections Mate/demate electrical connectors Install/remove mechanical fasteners Install/remove propulsion module Decontaminate removed module
Refuel/repressurize	Mate/demate fluid connections. Gage fluid quantities Distribute fluid quantities Vent pressure vessels
Hardware repair	Straighten interface metal Repair fluid leakage at interface fitting Repair interface electrical connectors Isolate and repair leaking/damaged tubing Replace mechanical fasteners

POWER SOURCE SUBSYSTEM

Service Operations	Service Tasks	Solar Cells	Source Type Batteries	Fuel Cells	Nuclear Gen
Subsystem safetying	Electrical deactivation	X	X	X	X
	Power source deactivation	-	-	X	X
	Shielding (pressure, radiation)	-	-	X	X
Subsystem checkout	Performance checkout/ diagnostics	X	X	X	X
	Electrical continuity	X	X	X	X
	Visual inspection	X	X	X	X
Replace modular elements	Install/remove mechanical fasteners	X	X	X	X
	Mate/demate electrical connectors	X	X	X	X
	Mate/demate fluid connections	-	-	X	X
	Install/remove source	X	X	X	X
Refuel source		-	-	(1)	
Hardware repair	Straighten interface metal	X	X	X	X
	Trim away damaged panel	X	-	-	
	Repair electrical interface connectors	X	X	X	X
	Isolate and repair damaged/ leaking tubing	-	-	X	X
	Replace mechanical fasteners	X	X	X	X

Note: (1) Same as for Propulsion subsystem

POWER CONDITIONING SUBSYSTEM

Service Operations	Service Tasks
Subsystem safetying	Electrical deactivation
Module checkout	Performance checkout/diagnostics Electrical continuity Visual inspection
Replace modular elements	Install/remove mechanical fasteners Mate/remate electrical connectors Install/remove power module
Hardware repair	Straighten interface metal Repair electrical interface connectors Repair electrical harness damage Replace electrical harness sections Replace mechanical fasteners

COMMAND SUBSYSTEM

Service Operations	Service Tasks
Subsystem safetying	Mate/demate electrical connectors Remove antenna
Subsystem checkoug	Performance checkout/diagnostics Electrical continuity Visual inspection
Replace module elements	Install/remove mechanical fasteners Mate/demate electrical connectors Install/remove module/submodule
Hardware repair	Straighten interface metal Repair interface electrical connectors Repair electrical harness damage Replace electrical harness sections Replace mechancial fasteners

HEAT REJECTION SUBSYSTEM

Service Operations	Service Tasks	Module Type Active	Module Type Passive
Subsystem safetying	Electrical deactivation	X	
	Vent pressure vessels	X	
	Isolate fluids	X	
Subsystem checkout	Performance checkout/diagnosis	X	
	Electrical continuity	X	
	Fluid leakage	X	
	Gage fluid quantities	X	
	Visual inspection	X	X
Replace modular elements	Mate/demate fluid connections	X	
	Mate/demate electrical connectors	X	
	Remove/install mechanical fasteners	X	
	Remove/install module/component	X	
Hardware repair	Straighten interface metal	X	X
	Repair leakage at interface fitting	X	
	Isolate and replace damaged/leaking tubing	X	
	Replenish fluid	(2)	
	Repair electrical harness damage	X	
	Replace/refurbish passive surfaces	(3)	X
	Replace mechanical fasteners	X	

Note: (2) Same as for propulsion module (refuel/repressurize)
(3) Replace is same as component replacement above.

PAYLOADS

Service Operations	Service Tasks	LDEF	Payload Type Passive-Earth Passive-Solar, Stellar	Active-Earth	Biomedical
Payload safetying	Electrical deactivation	-	X	X	X
Sample/film/Experiment/item replacement	Install/remove/actuate mechanical fasteners	X	X	X	X
	Mate/demate electrical connectors	-	X	X	X
	Remove/install item/experiment	X	X	X	X
Payload checkout	Performance checkout/diagnostics	-	X	X	X
	Electrical continuity	-	X	X	X
	Visual inspection	X	X	X	X
Payload repair	Sensor/lens cleaning		X	X	
	Straighten interface metal	X	X	X	X
	Repair interface electrical connectors	-	X	X	X
	Repair/replace damaged electrical harnesses	-	X	X	X
	Replace mechanical fasteners	X	X	X	X
	Calibrate sensor	-	X	X	X

BASIC STRUCTURE

Service Operations	Service Tasks
Structure safetying	Smooth rough edges Shield/guard jagged edges
Structure checkout	Visual inspection Length/straightness measurement
Replace structure	Remove/install mechanical fasteners Remove/install structure element Secure/release supported equipment Remove/replace thermal blanket
Repair structure	Cut away damaged material Straighten bent/deformed material Drill/punch fastener holes Fabricate repair section Install repair section - Mechanical fasteners - Weld - Bond Smooth rough edges Shield/guard jagged edges

APPENDIX 3

SATELLITE SERVICE CAPABILITY PACKAGES

CAPABILITY PACKAGE NO. 1

1. Capability

   Baseline capability using existing Shuttle EVA equipment.

2. Equipment

   EMU, MMU, RMS, Select Hand Tools & Supplies MWS

3. Satellite Operation

   Deployment, berthing, inspection

4. Satellite Subsystems

   Entire satellite

5. Service Operation Location

   Payload bay & within RMS reach envelope

6. Specific Service Tasks

   - Normal deployment (IV)
   - Normal snaring & berthing (IV)
   - Contingency deployment (EVA release of stuck appendages)
   - Inspection of Orbiter and payload. Interior access may be limited by lack of hand-holds and panels.
   - Module replacement, mate/demate electrical connectors, actuate switches & breakers.
   - Service experiments, deploy booms, retrieve film.
   - Contingency EVA - repair of tiles, payload bay door closure and rescue.

CAPABILITY PACKAGE NO. 2

1. Capability

   Routine payload servicing
   2-handed EVA work capability

2. Experiment

   Package No. 1 plus, hand tools, tool caddy, tram line, refuel facility, baffles, shields & adapters, decontamination facility, work platform and adhesive bond gun, wide angle helmet & rugged gloves.

3. Satellite Operation

   Clean lenses & sensors, disarm subsystems, refuel

4. Satellite Subsystems

   ACS, payload

5. Service Operation Location

   Payload bay & attached to RMS.

6. Specific Service Tasks - Tasks of Pkg. 1 plus:

   - Refuel, connect/disconnect fluid lines, gage & distribute fluuantities, actuate valves, vent pressure vessels.
   - Shield pressure vessels & radiation sources.
   - Clean lenses & sensors, refurbish surfaces.
   - Trim away damaged or unwanted appendages, stow debris in payload bay.
   - Decontaminate removed hardware.
   - Install FSS adapter
   - Fold appendages.
   - Tether & release unsupported items.

CAPABILITY PACKAGE NO. 3

1. Capability

Perform structural repair

2. Equipment - Pkg. No. 2 plus:

Hand-held power tool
Fuse-bond hand tool

3. Satellite Operation

Trim away damaged structure & appendages.
Fabricate and install repair structure.

4. Satellite Subsystems

Structure and external elements.

5. Service Operation Location

Payload bay & attached to RMS

6. Specific Service Tasks - Tasks of Pkg 2 plus:

- Shield jagged edges.
- Smooth rough edges.
- Trim away damaged material
- Make fastener holes.
- Tighten & loosen fasteners rapidly.
- Bond/weld new structure into place.
- Measure length, gage straightness.
- Straighten deformed metal.

CAPABILITY PACKAGE NO. 4

1. Capability

   Achieve mature satellite service capability

2. Equipment - Pkg. No. 3 plus:

   Subsystems diagnostics and checkout kit
   Leak detection kit
   Fluid isolation kit
   Fluid system refill kit

3. Satellite Operation

   Fluid system repairs
   Electronic system diagnosis and checkout, minor electrical repairs

4. Satellite Subsystems

   Radiator subsystem
   All electronic/electric subsystems

5. Service Operation Location

   In payload bay or on RMS.

6. Specific Service Tasks - Tasks of Pkg. 3 plus:

   - Repair of leaking fittings
   - Replacement of damaged tubing
   - Straighten bend electrical connector pins
   - Repair damaged electrical harnesses
   - Detect fluid leakage
   - Check subsystem performance
   - Calibrate sensors
   - Refill fluid subsystem

CAPABILITY PACKAGE NO. 5

1. Capability

Improve EMU capability

- Reduce dependence on vehicle-supplied consummables
- Improve life of EVA soft goods
- Increase EVA duration

2. Equipment - Pkg. No. 4 plus:

- Long life, modular SSA soft goods •
- Incremental hazards protection
- Enhanced computer capability, including wrist display/control, automatic temperature control, plug-in diagnostic & service routines.
- 8 hour EVA capability
- Regenerable CO_2 removal
- Non-venting heat sink

3. Satellite Subsystems

Same as for Pkg's 2,3 & 4.

4. Satellite Subsystems

Same as for Pkg's 2, 3 & 4.

5. Service Operation Location

Payload bay or within RMS reach ènvelope

6. Specific Service Tasks - Tasks of Pkg's 2, 3 & 4 plus:

- Longer EVA capability
- Reduced IV service time
- Automatic stepping of service procedures

CAPABILITY PACKAGE NO. 6

1. Capability

   Develop near-in EVA capability

2. Equipment - Pkg. No. 5 plus:

   - Satellite services MMU
   - Rigid LCG environment with radiator
   - Remote TV monitor
   - Remote service kit
   - Manipulator module

3. Satellite Operation

   Near-in inspection, safetying & service

4. Satellite Subsystems

   Same as for Pkg's 2, 3 & 4.

5. Service Operation Location

   Within 100 m of Orbiter

6. Specific Service Tasks - Tasks of Pkg's 2, 3 & 4 plus:

   - Free flying assistance with docking, berthing & snaring
   - Remote inspection, safetying, diagnostics and service

CAPABILITY PACKAGE NO. 7

1. Capability

Service up to 10 km from Orbiter

2. Experiment

Pkg. No. 6 plus:
- Rate-Range-Spin detector
- Voice control of maneuvering unit
- Transfer trajectory orbital mechanics
- Heads-up data display

3. Satellite Operation

Stabilize & retrieve out-of-control satellites
Free flying collection of debris

4. Satellite Subsystems

All subsystems

5. Service Operation Location

Up to 10 km from Orbiter

6. Specific Service Tasks - Tasks of Pkg 6 plus:

- Stabilize tumbling, out-of-control satellite
- Retrieve unpowered satellite
- Retrieve free-flying debris

SECTION 7.0
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