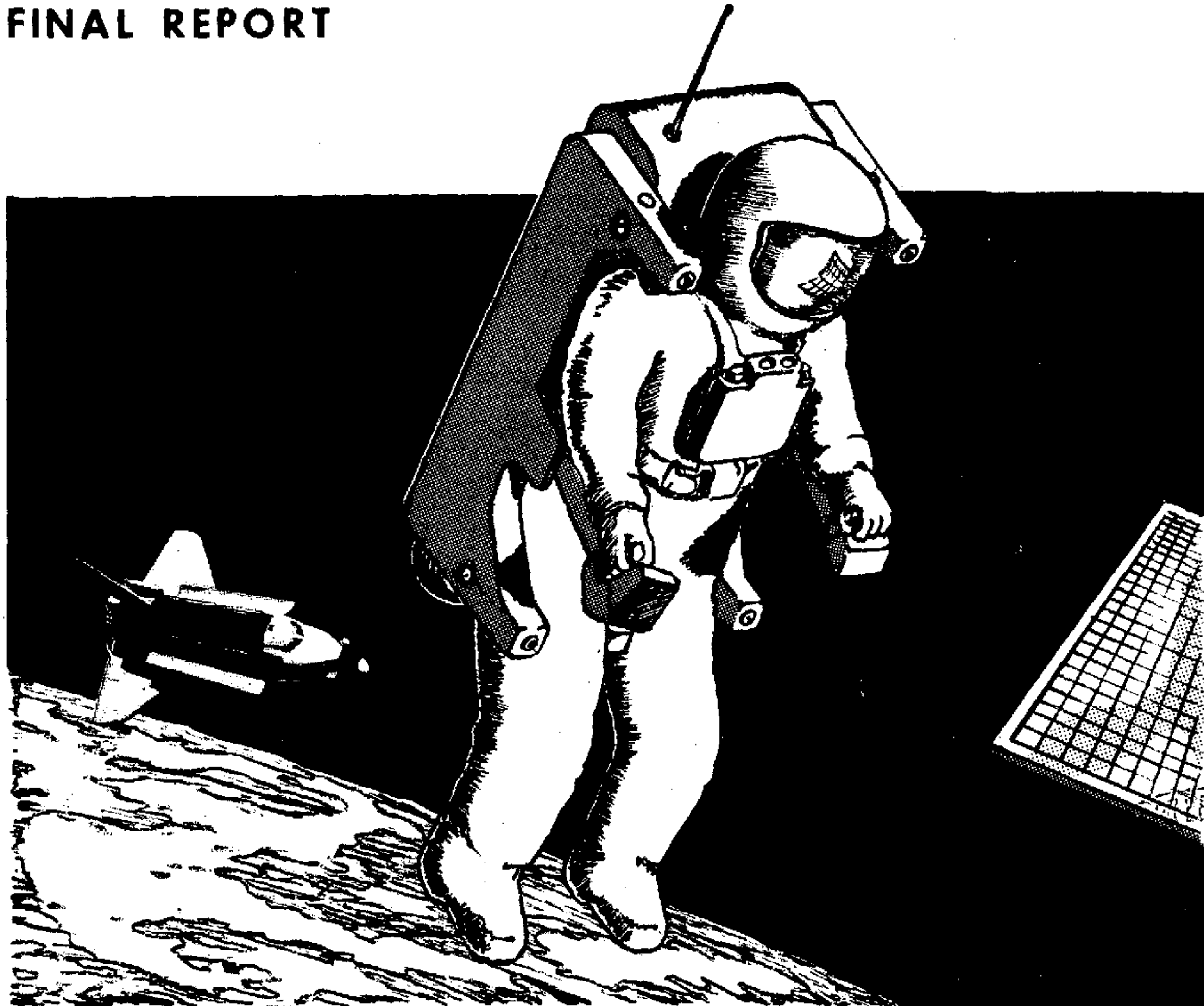
MANNED MANEUVERING UNIT MISSION DEFINITION STUDY

NASA CR-
141632

FINAL REPORT



VOLUME II

APPENDICES TO THE MMU APPLICATIONS ANALYSIS

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URS MATRIX LIFE and ENVIRONMENTAL SCIENCES DIVISION
SUITE 103, 1275 SPACE PARK DRIVE, HOUSTON, TEXAS 77058 (713) 333-3242

JANUARY 1975

MANNED MANEUVERING UNIT MISSION DEFINITION STUDY

FINAL REPORT
CONTRACT NAS 9-13790
MODIFICATION NO. 1S

VOLUME II:

APPENDICES TO THE MMU APPLICATIONS ANALYSIS

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

URS CORPORATION
URS/MATRIX COMPANY
LIFE AND ENVIRONMENTAL SCIENCES DIVISION
1275 SPACE PARK DRIVE
HOUSTON, TEXAS 77058

URS MATRIX

JANUARY 1975

FOREWORD

The Manned Maneuvering Unit (MMU) Mission Definition Study was conducted as the result of an Engineering Change Request to Contract NAS 9-13790 entitled, "Development of an EVA Systems Cost Model." The study was sponsored by the Bio-Engineering Division, Life Sciences Office of NASA Headquarters under the responsibility of Dr. Stanley Deutsch, Director. The work was managed under the technical direction of Mr. David C. Schultz, Chief of the Procedures Branch, Crew Training and Procedures Division, Flight Operations Directorate at the Lyndon B. Johnson Space Center, Houston, Texas. The Contracting Officer was Mr. James W. Wilson/BC76, Program Procurement Division.

The major objectives of the study were the following: (1) identify MMU applications which would supplement Space Shuttle safety and effectiveness; (2) define general MMU performance and control requirements to satisfy candidate Shuttle applications; (3) develop concepts for attaching MMUs to various worksites and equipment; and (4) identify requirements and develop concepts for MMU ancillary equipment. The study was performed over a seven-month period beginning June 1974.

The final report for the contract is presented in the following three volumes:

Volume I: MMU Applications Analyses and Performance Requirements

Volume II: Appendices to the MMU Applications Analyses

Volume III: MMU Ancillary Support Equipment and Attachment Concepts

This report (Volume II) presents supporting data for the material contained in Volume I of the Manned Maneuvering Unit Mission Definition Study.

ACKNOWLEDGMENTS

The NASA Technical Monitor for this study was Mr. David C. Schultz, Chief, Procedures Branch/CG2, Crew Training and Procedures Division, Flight Operations Directorate, Johnson Space Center, Houston, Texas. Contract monitoring assistance was provided by Mr. Louis V. Ramon in the Experiments Procedures Section of the Crew Training and Procedures Division. Appreciation is expressed to Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, for his efforts in arranging for the conduct of the study.

Valuable assistance in obtaining quantitative data and technical information was supplied by personnel within the NASA Johnson Space Center. Special appreciation is due Comdr. Bruce McCandless, II/CB, Maj. Charles E. Whitsett/ZR1, Mr. William L. Burton, Jr./EC6, and Mr. Louis V. Ramon/CG2.

The contractor Principal Investigator for the study was Mr. Nelson E. Brown, Division Director, Life and Environmental Sciences Division, URS/Matrix Company, URS Corporation. Principal contributors within the URS/Matrix Company were Mr. Billy K. Richard, Mr. Bobby J. Thompson, Mr. G. Lloyd Philpot, and Mrs. Betty K. Bielat.

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ACRONYMS AND ABBREVIATIONS

AMPS	ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE
AMU	ASTRONAUT MANEUVERING UNIT
ASMU	AUTOMATICALLY STABILIZED MANEUVERING UNIT
ATL	ADVANCED TECHNOLOGY LABORATORY
CMG	CONTROL MOMENT GYRO
DoD	DEPARTMENT OF DEFENSE
EVA	EXTRAVEHICULAR ACTIVITY
FFTO	FREE FLYING TELEOPERATOR
FFTS	FREE FLYING TELEOPERATOR SPACECRAFT
FT	FOOT
HHMU	HAND-HELD MANEUVERING UNIT
JSC	JOHNSON SPACE CENTER
KG	KILOGRAM
LB	POUND
LDEF	LONG DURATION EXPOSURE FACILITY
LEO	LOW EARTH ORBIT
LIDAR	LASER RADAR
LST	LARGE SPACE TELESCOPE
M	METER
MMU	MANNED MANEUVERING UNIT
MSFC	MARSHALL SPACE FLIGHT CENTER

NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
PR	PERSONNEL RESCUE
RCC	REINFORCED CARBON-CARBON
RCS	REACTION CONTROL SYSTEM
RMS	REMOTE MANIPULATOR SYSTEM
RSI	REUSABLE SURFACE INSULATION
SIMS	SHUTTLE IMAGING MICROWAVE SYSTEM
SSPD	SPACE SHUTTLE PAYLOADS DESCRIPTIONS
SSM	SUPPORT SYSTEMS MODULE
TPS	THERMAL PROTECTION SYSTEM
WBS	WORK BREAKDOWN STRUCTURE

INTRODUCTION

A major objective of the study was to identify and describe candidate applications of Manned Maneuvering Units (MMUs) to the Space Shuttle Program. The applications analyses included studies of the Shuttle Orbiter, Orbiter subsystems, and both Sortie and Automated Payloads proposed in mid-1974 for subsequent flights. Based on the stronger practicable MMU applications, general performance and control requirements for Shuttle supporting maneuvering units were defined and compared to units evaluated on Skylab. The results of the MMU applications analyses and the general MMU performance and control requirements identified are presented in Volume I of the MMU report with supporting material contained in this volume, "Appendices to the MMU Applications Analyses."

This volume contains informal information used in identifying representative MMU missions from the many Automated and Sortie Payloads and the Orbiter subsystems. Eleven representative missions (Table 1) were selected to represent typical MMU applications across all payloads and Orbiter subsystems. Data analysis sheets are provided along with other applicable information. Calculations used in defining MMU general performance and control requirements to satisfy the eleven missions are also included.

General information considered valuable in assisting the reader in comprehending the MMU applications analyses criteria and results are included. It should be noted that excerpts from other NASA and contractor documents are included for reader convenience in lieu of only references to such documents.

This appendices report is not intended to be sufficiently inclusive to be used alone and must be employed in conjunction with Volume I, "MMU Applications Analyses and Performance Requirements."

TABLE 1

PAYLOADS AND ORBITER SUBSYSTEMS SELECTED

FOR DETAILED MMU APPLICATIONS ANALYSIS

SHUTTLE ORBITER SUBSYSTEMS
• Orbiter Thermal Protection System (TPS) including Orbiter exterior inspection • Orbiter External Doors • Remote Manipulator System (RMS) • Rescue
AUTOMATED PAYLOADS
• Large Space Telescope (AS-01-A) • Long Duration Exposure Facility (ST-01-A) • High Energy Observatory A (HE-11-A)
SPACELABS--SORTIE PAYLOADS
• Atmospheric, Magnetospheric and Plasmas in Space (AMPS) (AP-06-S) • Shuttle Imaging Microwave System (SIMS) (EO-05-S) • Advanced Technology Laboratory (ATL) (ST-21-S, ST-22-S, ST-23-S)

APPENDIX A

CRITICALITY CATEGORIES - GLOSSARY OF TERMS

APPENDIX A INTRODUCTION

The information in Appendix A is provided as a convenience to the reader to aid in understanding those terms defined by NASA which are pertinent to this document. Several important terms relative to Appendix A include criticality categories, fail-safe, loss of personnel capability, loss of systems, etc. Instead of listing only those terms directly applicable to the MMU applications analysis, all terms contained in the NASA Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program, NHB 5300.4 (1D-1), August 1974 document were included. Appendix A is an exact excerpt from the above document.

APPENDIX A

CRITICALITY CATEGORIES - GLOSSARY OF TERMS

ACCEPTANCE - The act of an authorized agent of the procuring organization by which the procuring organization assents to ownership of existing and identified contract items, or approves specific services rendered as partial or complete performance of a contract.

ACCEPTANCE TESTING - Tests to determine that a part, component, subsystem, or system is capable of meeting performance requirements prescribed in the purchase specification or other documents specifying what constitutes adequate performance capability for the item in question.

ACCIDENT - An unplanned event which results in an unsafe situation or operational mode.

ACCIDENT PREVENTION - Methods and procedures used to eliminate the causes which lead, or could lead, to an accident.

CERTIFICATION TESTING - Certification tests consist of the subsystem qualification tests and the subsystem higher-level-of-assembly tests plus vehicle level tests. Certification testing does not include exploratory, design verification, development, prequalification, piece-part qualification, acceptance or checkout tests, except where such tests are required for certification.

COMPONENT - A combination of parts, devices, and structures, usually self-contained, which performs a distinctive function in the operation of the overall equipment. A "black box" (e.g., transmitter, encoder, cryogenic pump, star tracker.)

CORRECTIVE ACTION - Action taken to preclude occurrence of an identified hazard or to prevent recurrence of a problem.

CREDIBLE ACCIDENT - An accident, the scope and magnitude of which have been defined to allow the design to provide for contingency survival and/or continued operation.

CRITICAL PROCESS - A process which could have adverse effect on hardware performance as determined through a failure mode and effect analysis, on hardware designated for fracture control, or on ordnance hardware.

CRITICAL INSPECTION AND TEST METHOD - An inspection or test method which is used to verify a critical process.

CRITICALITY CATEGORIES

CATEGORY	DEFINITION
1	Loss of life or vehicle
2	Loss of mission
3	All others

Notes:

Category 1 includes loss or injury to the public.

Category 2 includes both post-launch abort and launch delay sufficient to cause mission scrub.

DEFECT - A condition of any hardware in which one or more characteristics do not conform to the specified requirements.

DESIGN SPECIFICATION - Generic designation for a specification which describes functional and physical requirements for an article, usually at the component level or higher levels of assembly. In its initial form, the design specification is a statement of functional requirements with only general coverage of physical and test requirements. The design specification evolves through the project life cycle to reflect progressive refinements in performance, design, configuration, and test requirements.

DESIGNEE - Certain trained and qualified manufacturing and test personnel who represent the contractor quality assurance activity in the performance of selected quality assurance functions.

DEVIATION - A deviation is a specific authorization, granted before the fact to depart from a particular requirement of specifications or related documents.

ESCAPE - The utilization of equipment or subsystems without outside assistance to effect egress from the immediate proximity of danger.

FAIL-OPERATIONAL - The ability to sustain a failure and retain full operational capability for safe mission continuation.

FAIL-SAFE - The ability to sustain a failure and retain the capability to successfully terminate the mission.

FAILURE - The inability of a system, subsystem, component, or part to perform its required function within specified limits, under specified conditions for a specified duration.

HAZARD - The presence of a potential risk situation caused by an unsafe act or condition.

HAZARD ANALYSIS - The determination of potential sources of danger and recommended resolutions in a timely manner for those conditions found in either the hardware/software systems, the man-machine relationship, or both, which could cause loss of personal capability, loss of system, or loss of life or injury to the public.

HAZARD LEVELS - A hazard whereby environment, personnel error, design characteristics, procedural deficiencies, or subsystem malfunction may result in loss of personnel capability or loss of system shall be categorized as follows:

a. Catastrophic - No time or means are available for corrective action.

b. Critical - May be counteracted by emergency action performed in a timely manner.

c. Controlled - Has been counteracted by appropriate design, safety devices, alarm/caution and warning devices, or special automatic/manual procedures.

INTEGRITY CONTROL-A formalized system established to ensure that only authorized changes, modifications and entries are made to hardware.

LAUNCH ESSENTIAL GSE - Those items of ground support equipment whose functions are necessary to support the countdown phase and those items of ground support equipment used in pre-countdown phases whose problems can create a safety hazard, cause vehicle damage or inability to detect a vehicle problem.

LIMITED LIFE ITEM - Any item designated as having a limited useful life regardless of whether it is a limited operating life, limited shelf life, operating life sensitive, or combinations of these. This includes, where appropriate, fluids, elastomers, and polymers.

LIMITED OPERATING LIFE ITEM - Any item which deteriorates with increased accumulation of operating time/cycles and thus requires periodic replacement or refurbishment to assure that its operating characteristics have not degraded beyond acceptable limits including consideration for total mission time/cycles and safety factor margins.

LIMITED SHELF LIFE ITEM - Any item which deteriorates with the passage of time and thus requires periodic replacement, refurnishment, retesting, or operation to assure that its operating characteristics have not degraded beyond acceptable limits. This includes installed as well as stored components.

LOSS OF PERSONNEL CAPABILITY - Loss of personnel function resulting in inability to perform normal and/or emergency operations. Also includes loss or injury to the public.

LOSS OF SYSTEM - Loss of the capability to provide the level of system performance required for normal and/or emergency operations.

LOT - Articles produced in a given time sequence with no changes in materials, tooling, processes, personnel, techniques or configuration.

NONCONFORMANCE - A condition of any article or material or service in which one or more characteristics do not conform to requirements. Includes failures, discrepancies, defects, and malfunctions.

OFF-THE-SHELF HARDWARE - Production or existing design hardware (black box, component) used in or for NASA, military, and/or commercial programs.

OPERATING CYCLES - The cumulative number of times an item completes a sequence of activation and return to its initial state; e.g., a switched-on/switched-off sequence, a valve-opened/valve-closed sequence, tank pressurized/depressurized, or dewar cryogenic exposure/drain.

OPERATING LIFE - The maximum operating time/cycles which an item can accrue before replacement or refurbishment without risk of degradation of performance beyond acceptable limits.

OPERATING PARAMETER SENSITIVE ITEM - Any item which has a limited life due to variances in its operating parameters (i.e., drift rate in gyro mechanisms) which may not be directly related to operating or calendar time.

ORDNANCE DEVICE FLIGHT CERTIFICATION - An assessment of each device (by lot) which includes satisfactory premanufacture facility reviews, quality data, and destructive and nondestructive test results.

ORDNANCE LOT (ASSEMBLY) - Those assemblies produced in a given time sequence from a single hardware lot and a single explosive lot with no changes in materials, tooling, processes, personnel, techniques, or configuration.

OVERSTRESS - A value of any stress parameter in excess of the upper limit of the normal working range or in excess of rated value.

PART - One or more pieces joined together which are not normally subject to disassembly without destruction.

Deviated Parts - Parts deviating to some degree from their controlling specification(s).

EEE Parts - EEE (electrical, electronic, and electromechanical) parts such as transistors, diodes, microcircuits, resistors, capacitors, relays, connectors, switches, transformers, and inductors.

Substitute Parts - Parts differing from those specified in the approved equipment design.

PROBLEM - Any nonconformance which fits or which is suspected of fitting one of the following categories:

- Failure or unsatisfactory condition occurring during or subsequent to production acceptance testing.

- Failure or unsatisfactory condition which occurs prior to acceptance testing that will or has the potential to adversely affect safety, contribute to schedule impact or launch delay, or result in design change.

- Problem Analysis. Documented results of the investigation performed to determine the cause of the problem.

- Cause (Problem Cause). The event or series of events directly responsible for the problem.

- Closed Problem. A problem is closed when the hardware supplier is formally notified of NASA concurrence with the problem analysis (including determination of the cause) and has implemented corrective action to preclude recurrence of the problem after acceptance tests. A lack of corrective action may be acceptable to NASA if analytical/test evidence from the hardware supplier shows that the problem is always detectable during the performance of an established test prior to use and that the problem would not occur subsequent to this test.

- Explained Problem. A problem is explained when the supplier is formally notified of NASA's concurrence with the problem analysis and rationale for not establishing corrective action. The rationale must establish that a planned mission may proceed with no detrimental effects should the problem recur and that a responsible NASA authority has decided that no corrective action need be established as defined for a closed problem.

- Open Problem. A problem for which responsible NASA management personnel have not approved the problem resolution submitted by the supplier. The problem is deemed to be open until the supplier is formally notified by NASA that resolutions are acceptable for all deliverable end items for which the problem is applicable.

- Resolved Problem. A problem that has been closed or explained.

PROBLEM REPORTING AND CORRECTIVE ACTION - A controlled technique for identification, reporting, analysis, remedy, and prevention of recurrence of problems which occur throughout specified portions of the contract effort.

RELIABILITY NUMERICAL ESTIMATE - A characteristic of a system or any element thereof expressed as a probability that it will perform its required functions under defined conditions at designated times for specified operating periods.

REMEDIAL ACTION - Action to correct a nonconforming article or material.

RESCUE - The utilization of outside assistance by means of personnel, equipment, or separately based vehicles to effect a return to a reasonably permanent safe haven.

RESIDUAL HAZARD - Hazard for which safety or warning devices and/or special procedures have not been developed or provided for counteracting the hazard.

RISK - The chance (qualitative) of loss of personnel capability, loss of system, or damage to or loss of equipment or property.

SAFETY - Freedom from chance of injury or loss of personnel, equipment or property.

SFP (SINGLE FAILURE POINT) - A single element of hardware, the failure of which would lead directly to loss of life, vehicle or mission. Where safety considerations dictate that abort be initiated when a redundant element fails, that element is also considered a single failure point.

SFPS (SINGLE FAILURE POINT SUMMARY) - Summary listing of those single failure points identified in the FMEA. The SFPS amplifies the recommended corrective action for elimination or minimization of the effect associated with each failure mode or the justification for retaining the failure mode.

SURVIVAL - The utilization of equipment to provide a temporary safe haven to which personnel/crew may escape, and from which rescue may be accomplished.

SYSTEM SAFETY - The optimum degree of risk management within the constraints of operational effectiveness, time and cost attained through the application of management and engineering principles throughout all phases of a program.

UNSATISFACTORY CONDITION - Any defect for which engineering resolution is required and which requires recurrence control beyond the specific article under consideration. Included in this definition are conditions which cannot be corrected to the specified configuration using the standard planned operations or an event which could lead to a failed condition but does not affect the function of the article such as contamination, corrosion, workmanship requiring engineering disposition, etc.

WAIVER - Granted use or acceptance of an article which does not meet specified requirements; a waiver is given or authorized after the fact.

APPENDIX B

MMU APPLICATIONS

FOR

SHUTTLE ORBITER SUBSYSTEMS

APPENDIX B

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APPENDIX B INTRODUCTION

Appendix B contains informal data used in identifying and supporting the potential MMU missions selected by the contractor as representative Shuttle Orbiter applications. Initially, a review of 8 Orbiter subsystems was conducted including crewman rescue from a disabled Orbiter (see Table B2-1). Five Orbiter subsystems and the crewman rescue mission were selected for detailed applications analysis. Supporting data are provided for these 6 representative MMU missions and include:

- Orbiter subsystems analysis sheets
- Preliminary mission description and timelines
- MMU mission scenario including delta velocity requirements
- Performance and control requirements charts
- Calculations for supporting MMU performance and control requirements
- Other pertinent data to qualify unique applications

In developing the typical MMU scenarios each mission was based on two crewmen for conducting EVAs on the operational Shuttle missions. However, one-man MMU-EVA operations can satisfy each representative MMU Orbiter subsystem application. All MMU systems and supporting hardware will be designed for one-man spacesuited operation. One-man EVAs are permissible on the Space Shuttle missions in contingency situations.

APPENDIX B1

ORBITER SUBSYSTEMS REVIEWED

TABLE B2-1: Orbiter Subsystems Reviewed

For

MMU Shuttle Applications

ORBITER SUBSYSTEM	INITIAL REVIEW CONDUCTED	MMU APPLICATION	PRELIMINARY ANALYSIS CONDUCTED	MMU CANDIDATE TASKS/OPERATIONS	DETAILED ANALYSIS CONDUCTED
Orbiter Inspection	X	yes	yes	Inspect complete vehicle exterior	yes
Thermal Protection System (TPS)	X	yes	yes	Repair TPS for reentry on 95% of Shuttle exterior surface	yes
Orbiter External Doors	X	yes	yes	Close and secure doors for reentry.	yes
Personnel Rescue	X	yes	yes	Rescue crewmen from unstable Orbiter	yes
Shuttle Orbiter Main Engines	X	--	no	No specific on-orbit servicing identified to date	no
Remote Manipulator Systems (RMS)	X	yes	yes	Retract/jettison unit; backup to RMS normal functions	yes
Orbiter Control Surfaces	X	no	no	Repair operations if components accessible	no
Orbiter Windows	X	yes	no	Clean windows	no

APPENDIX B2

THERMAL PROTECTION SYSTEM (TPS)

SHUTTLE ORBITER SYSTEM GENERAL INFORMATION

SHUTTLE SYSTEM: TPS

SHUTTLE ORBITER SYSTEM			
Orbiter Thermal Protection System (TPS)			
SUBSYSTEM OR COMPONENT			
LRSI tiles (Low Temperature Reusable Surface Insulation) HRSI tiles (High Temperature Reusable Surface Insulation) RCC (Reinforced Carbon Carbon)			
LOCATION ON ORBITER			
95% of Orbiter exterior			
SUBSYSTEM--WBS MANAGER/LOCATION			
G. Strouhal, JSC/ES3, (713) 483-3637			
MMU/EVA REQUIREMENTS	PLANNED EVAs	TASK	In study phase
		NO./MISSION	
		DURATION (hrs.)	
	CONTINGENCY EVAs	PROBABLE TASK	Inspect, remove panels, connect/disconnect, repair, spray special coating
		DURATION (hrs.)	3+ (task dependent)

SHEET No. 1 of 4

EVA TASK DESCRIPTION

SHUTTLE SYSTEM: TPS

TASK OBJECTIVE

Inspect and repair damaged TPS tiles or apply ablative cover

EVA/MMU TASK DESCRIPTION

- Prepare for EVA, egress airlock, don MMU and attach TPS repair kit
- Fly inspection pattern (TBD) if damage location unknown
- Assess total damage
- Initiate repairs from free-flying MMU, if feasible

OR

Retrieve stabilization/restraint device, attach to worksite and initiate repair

- Return to payload bay
- Stow TPS repair kit
- Doff MMU and ingress airlock

UNIQUE TASKS OR HAZARDOUS CONDITIONS TO EVA CREW

None identified to date

SHEET NO. 2 of 4

ORBITER REQUIREMENTS AND CONSTRAINTS

SHUTTLE SYSTEM: TPS

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

No constraints identified to date

ORBITER MODIFICATIONS REQUIRED TO ACCOMMODATE EVA

EVA accommodations are provided by Orbiter. Orbiter would require addition of:

- MMU & supporting provisions
- TPS repair kit stowage

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (size, mass, C.G.)
• TPS repair kit • Portable lighting • Video/TV equipment • Crew/MMU stabilization unit	• Crew/MMU stabilization - Size: <.015 $m.^3$ (.5 $ft.^3$) - Mass: <10 kg. (22 lbs.) • TPS repair kit - Size: <.015 $m.^3$ (.5 $ft.^3$) - Mass: <9 kg. (20 lbs.)

FORCES REQUIRED FOR TASK	SI	CONVENTIONAL
• Maximum force on TPS tiles to avoid damage (tension)	<.3 kg/cm^2	<8 psi
• Linear	<11 kg.	<25 lbs.
• Torque (no tools)	<.45 kg-m.	<40 in-lbs.

SHEET NO. 3 of 4

SUPPLEMENTARY ORBITER EVA/AMU INFORMATION

SHUTTLE SYSTEM: TPS

WORKING GROUPS AND PERSONS CONTACTED

R. L. Dotts, JSC/ES3, (713) 483-2326

REFERENCE DOCUMENTS/DRAWINGS

VL70-009028 TPS Penetration Diagram - Double Delta, Lt. Wt. Orbiter, MCR 0200R5, 1-22-74

VL70-009030 Vertical Stabilizer TPS Configuration, MCR 200R5, 1-22-74

VL70-009026 TPS Definition and Boundary Control Diagram, MCR 200R5, 1-22-74

Shuttle Orbiter Thermal Protection System (TPS), North American Rockwell, (presentation), no date or document number

CURRENT ORBITER STATUS RELATIVE TO EVA REQUIREMENTS

Requirements under study

ADDITIONAL REMARKS/COMMENTS

Repair of the TPS to ensure safe reentry currently appears to require an MMU to access all Orbiter areas and the crewman's manipulative capability to effect repairs. Detail thermal protection studies and TPS tests are being conducted by Rockwell International. Since details of the TPS characteristics are too extensive to summarize in this analysis, the reader is referred to the above reference documents/drawings.

SHEET NO. 4 of 4

STRUCTURAL PENETRATIONS, 354 (INCLUDES 164 L.E. & ELEVON ACCESS PANELS)

TPS PENETRATIONS, 342 (EXCLUDES ANTENNAS)

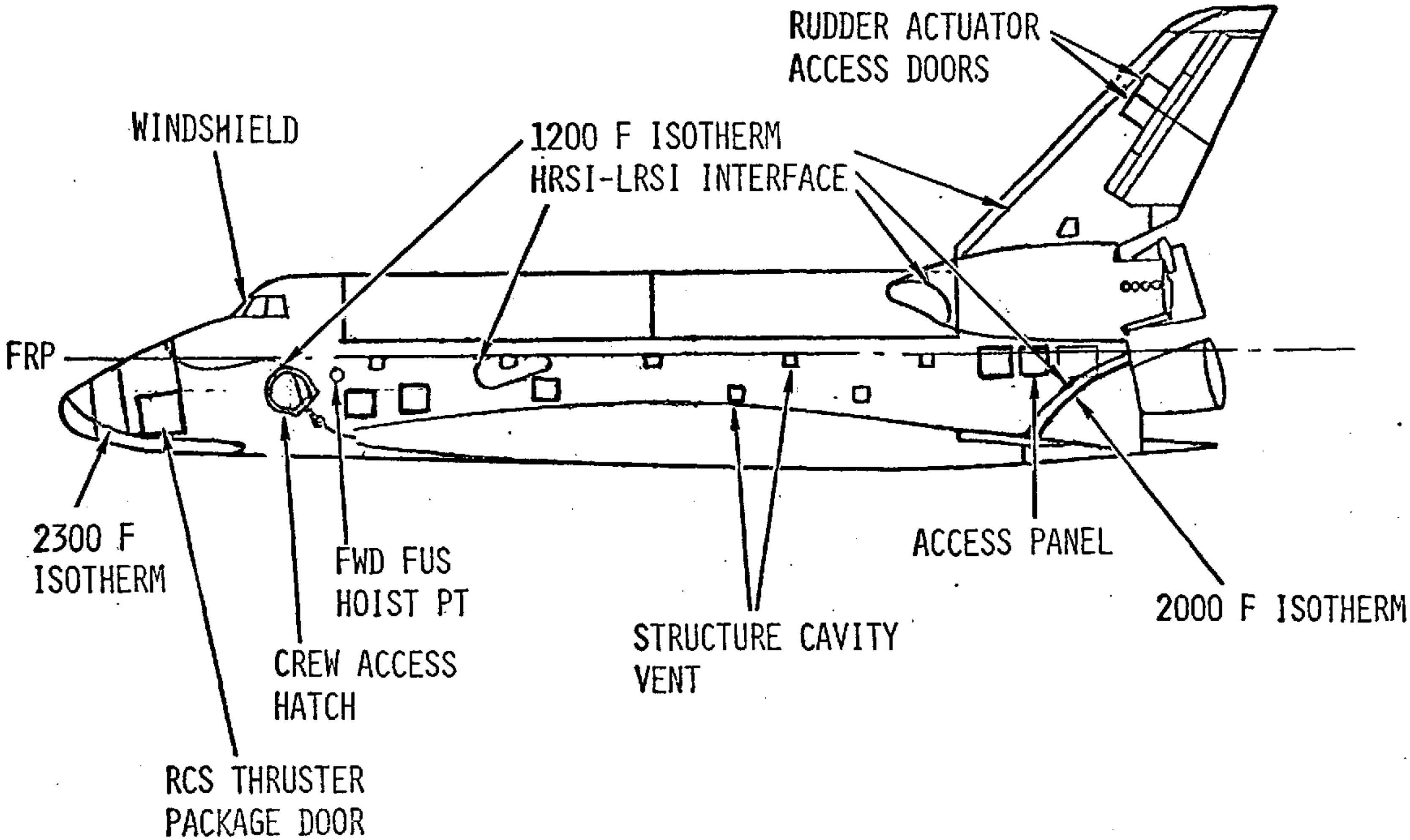


FIGURE B2.1: TPS Side Penetrations

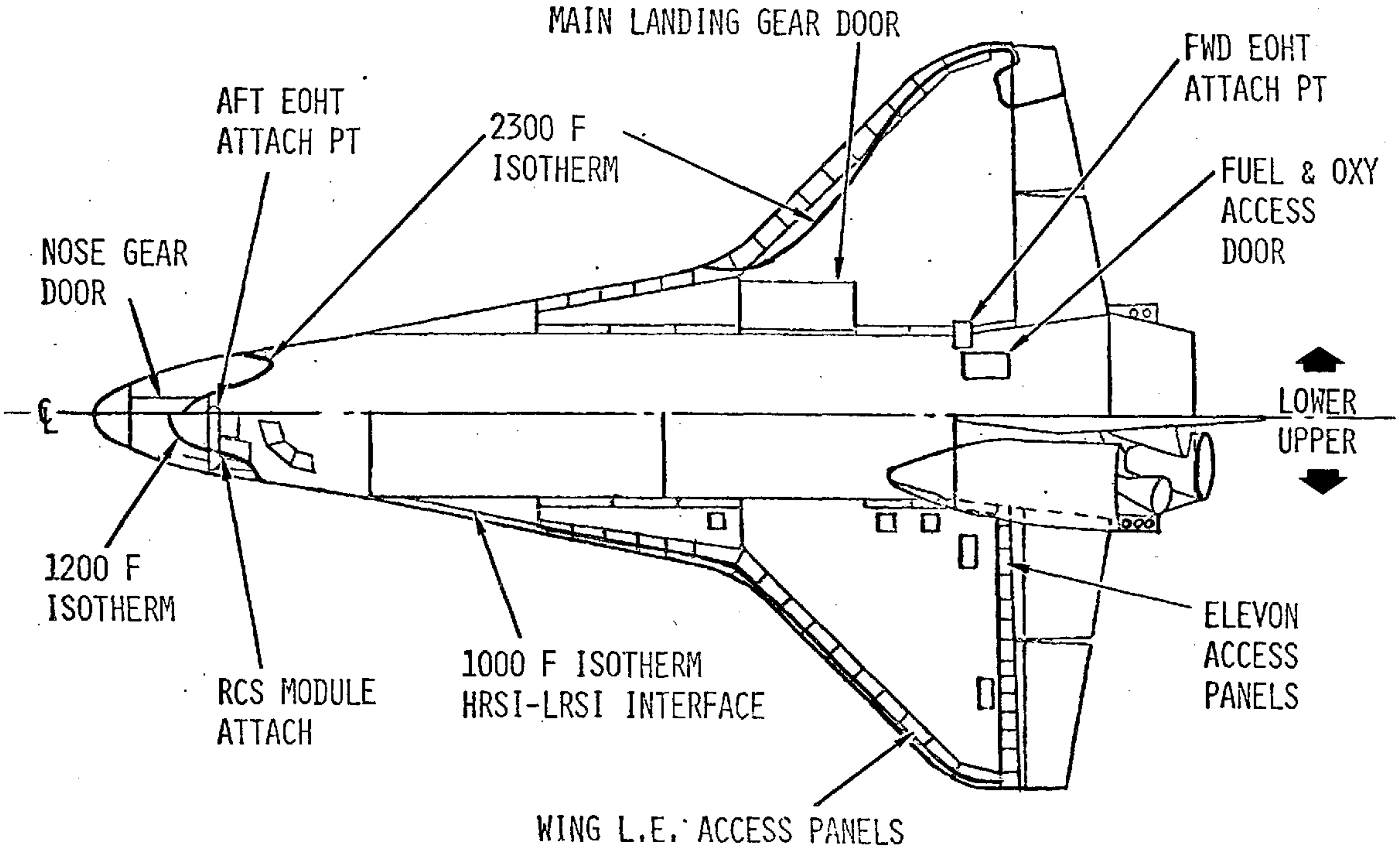
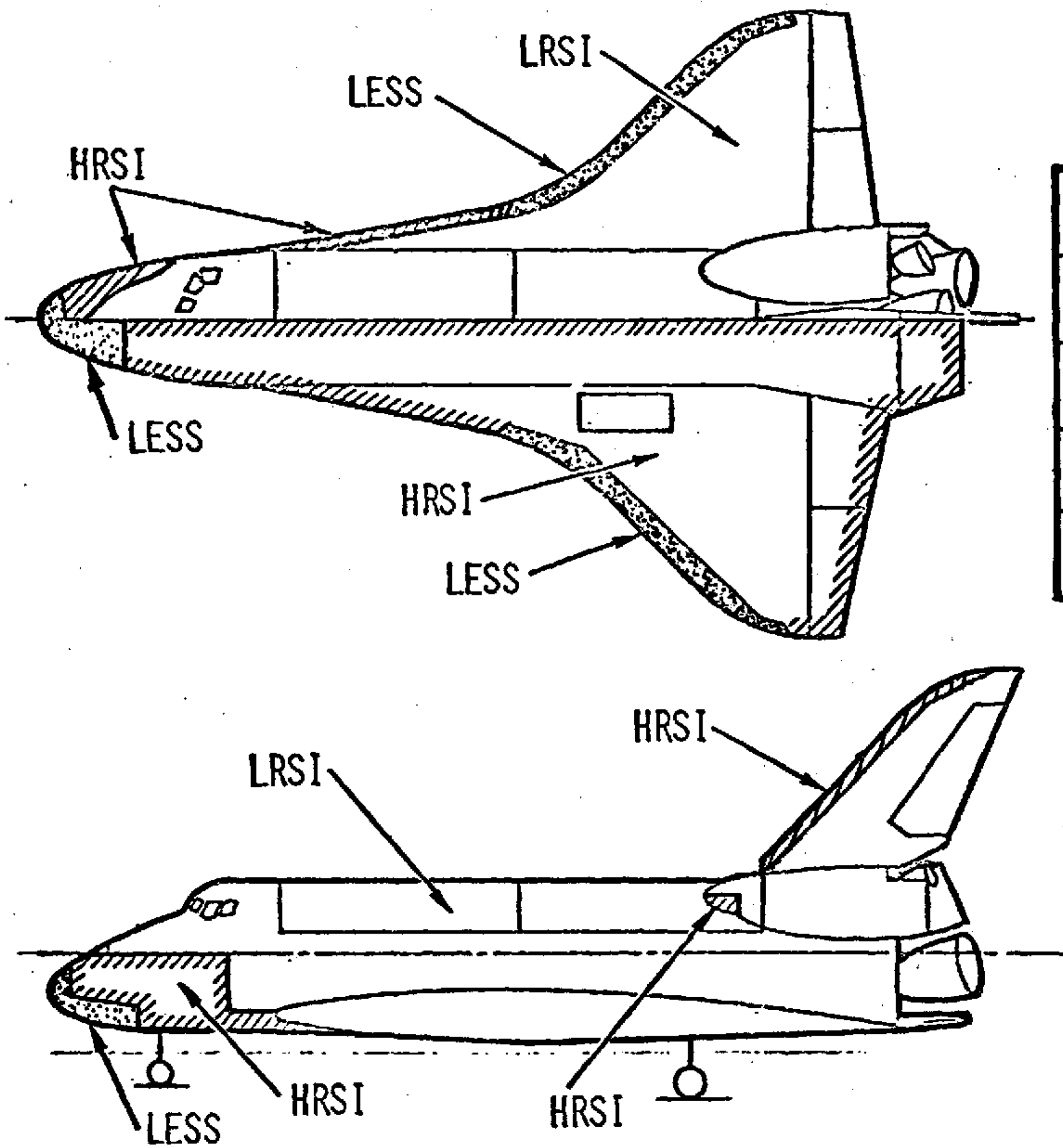


FIGURE B2.2: TPS Penetrations



140B CONFIGURATION
TRAJECTORY NOM NO. 89212

TPS	AREA	WT (LB)
LRSI	6,482 FT^2	4,547
HRSI	4,555 FT^2	10,685
RCC	563 FT^2	3,965
TOTAL	11,600 FT^2	20,747 *

LRSI - COATED SILICA

HRSI - COATED SILICA

RCC - REINFORCED CARBON-CARBON

SIP - NOMEX "E" FELT

* INCLUDES 1195 LB THERMAL SEALS
355 LB BASE HEAT SHIELD

FIGURE B2.3: TPS Description

TILE COUNT

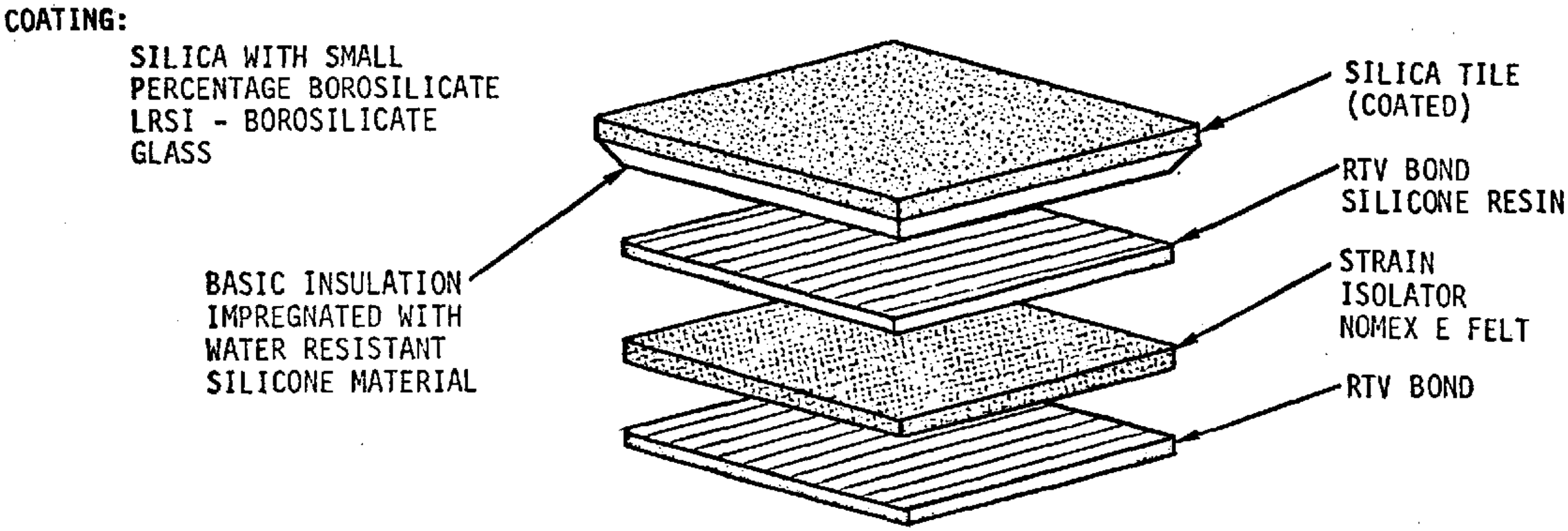
	SPECIAL	FLAT	SINGLE CURVE	DOUBLE CURVE	TOTAL
HRSI	5,220	5,044	3300	5700	19,264
LRSI	5,197	5,750	3450	1240	15,637
TOTAL	10,417	10,794	6750	6940	34,901

CONFIGURATION COUNT

	PREVIOUS BASELINE					CURRENT BASELINE (BUILDING BLOCK)				
	SPECIAL	FLAT	SINGLE CURVE	DOUBLE CURVE	TOTAL	SPECIAL	FLAT	SINGLE CURVE	DOUBLE CURVE	TOTAL
HRSI	2610	7820	3480	6090	20,000	2610	25	50	3000	5685
LRSI	—	—	—	—	*—	2600	25	50	620	3295
TOTAL	2610	7820	3480	6090	20,000	5210	50	100	3620	8980

*ELASTOMERIC MATERIAL

FIGURE B2.4: TPS Tile and Configuration Count



RSI REQUIREMENTS

BASIC INSULATION:

MAINTAIN AIRFRAME TEMPERATURE ≤ 350 F

HRSI $T_{MAX} \leq 2300$ F
LRSI $T_{MAX} \leq 1200$ F
FLOW ENVIRONMENT

INTERNAL INSULATION - LEADING EDGE SYSTEMS (RCC)
$T_{MAX} \leq 2500$ F - NONFLOW ENVIRONMENT

100 MISSION REUSABILITY
MINIMUM UNSCHEDULED MAINTENANCE

RSI $T_{MIN} \geq -240$ F

COMPATIBLE WITH COATING, WATER PROOFING MATERIAL & TPS ELEMENTS (ADHESIVE, STRAIN ISOLATION PAD, GAP FILLER MATERIALS)
DENSITY = 9 $\pm$ 1 PCF

FIGURE B2.5: HRSI and LRSI Tile Details

FIRST CRITICALITY - ORBITAL INSPECTION

DETERMINE IF TILE LOST AND WHERE

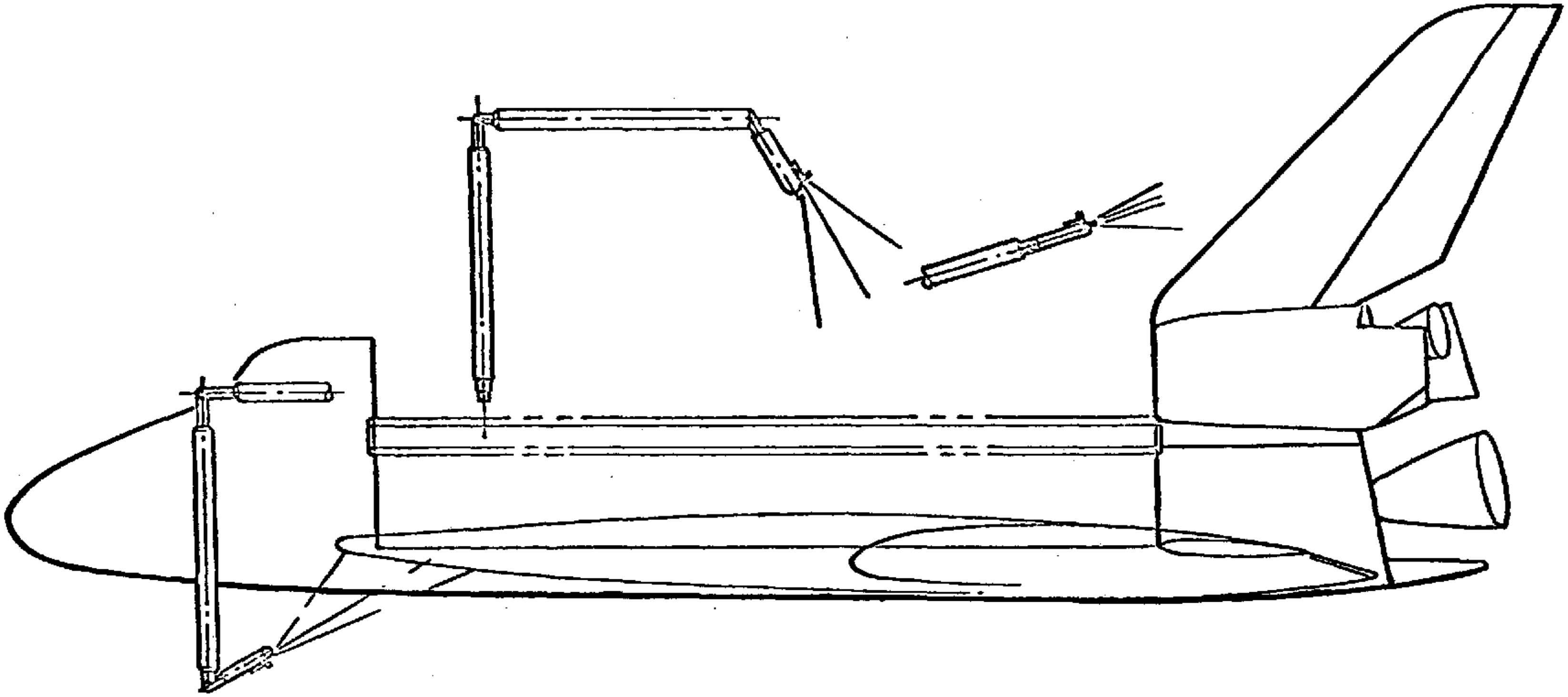
EARLY FLIGHTS

- VISUALLY INSPECT
  (A) LINE OF EYE SIGHT
  (B) REMOTE VISUAL AIDS
  (C) EVA
- ENVIRONMENT MONITORING

LATER FLIGHTS

- ENVIRONMENTAL MONITORING
  RAIN EXPOSURE
  LIGHTNING STRIKE
  ORBITAL COLD SOAK
  FLIGHT LOAD & STRUCTURAL DEFLECTION
  TEMPERATURE HISTORY
- VISUAL INSPECT FOR ADVERSE ENVIRONMENT EXPOSURE

FIGURE B2.6: TPS Tile Damage Failure Evaluation



IN ORBIT TPS VISUAL INSPECTION	
MODE	VISIBLE AREA
CREW CABIN	FWD UPPER NOSE & VERTICAL TAIL L/E
MANIPULATOR TV	TOTAL VEHICLE SURFACE EXCEPT AFT HEATSHIELD
EVA	LOCAL AREA VICINITY OF CARGO BAY (DOORS OPEN)
EVA/AMU	TOTAL VEHICLE AREA

IN ORBIT TPS REPAIR
• TPS MATERIAL & REPAIR TECHNIQUE REQUIRE DEVELOPMENT • EVA EQUIPMENT AND TECHNIQUES REQUIRE DEVELOPMENT

FIGURE B2.7: TPS External Viewing with Manipulator TV

ORBITER INSPECTION AND TPS REPAIR

Orbiter Inspection/TPS Repair Timeline

The typical MMU mission outlined in this appendix involves an inspection of the total Orbiter exterior for reentry status assessment and repair/replacement of a section of the Thermal Protection System (TPS) to ensure reentry capability. Photographic documentation of TPS damage, TPS repair status, and other areas relative to overall Orbiter reentry status are included as subtasks. Table B2-2 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task.

The MMU mission is assumed to be a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU. However, the task can be performed by one crewman with a slight increase in mission time. Crewman no. 2 (CM2) supports CM1 from the payload bay. CM1 performs the inspection tasks from a free-flying untethered MMU. TPS repairs are accomplished from a portable EVA crewman/restraint workstation attached to the Orbiter exterior. The MMU mission timeline does not include pre- and post-extravehicular activities and is initiated following airlock egress. The mission is completed following airlock ingress.

MMU Requirements for Orbiter Inspection/TPS Repair

A typical MMU translation route is shown in Figures B2.8 through B2.10. This route encompasses inspection of all critical reentry areas and subsystems plus repair of TPS tiles aft of the Orbiter main landing gear (right side). Table B2-3 shows the estimated travel distance for each major leg of the mission, estimated number of direction changes, and the delta velocity required.

Total ΔV Required

The translation ΔV required for the checkout, Orbiter inspection, and repair tasks is approximately 9 m/sec (30 ft/sec). From M509 on-orbit experience, it was found that the ΔV used for rotation is approximately equal to that required for translation. Therefore, the total ΔV required for both translation and rotation is approximately 18 m/sec (60 ft/sec) to perform the inspection and TPS repair tasks.

TABLE B2-2: Orbiter Inspection/TPS Repair Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
<u>INSPECTION TASKS</u>				
Egress airlock	X	X	--	2.0
Translate to MMU stowage area (assume stowage area on left side of forward bulkhead)	X	X	--	1.0
Checkout MMUs (2)	X	X		15.0
Don MMU and attach ancillary hardware			Portable lights, tethers, camera	15.0
MMU familiarization flight in payload bay with tether	X			5.0
Remove tether		X		1.0
Egress P/L over forward bulkhead, inspect star tracker and translate to ~6 m (20 ft) in front of Orbiter	X			5.0
Visually inspect forward area of Orbiter and photograph	X		Camera	4.0
Translate at wing level around left wing to wing tip (observe RCS door and wing leading edge RCC)	X		--	6.0
Translate at wing level to center line of Orbiter directly behind main engines (observe control surfaces, OMS, RCS, and main engines) and photograph	X		Camera	4.5
Translate at wing level to tip of right wing observing control surfaces	X		--	4.0
			TIME SUB TOTAL	62.5

TABLE B2-2: Orbiter Inspection/TPS Repair Timeline (continued)

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
Translate at wing level to right side forward RCS door and photograph	X		Camera	5.5
Translate toward underside of Orbiter ≈6.1 m (20 ft) below TPS (scan total underside)	X		--	3.0
Translate toward right main landing gear door, observe door and inspect TPS (report missing TPS tiles)	X		--	4.0
Translate to within 1.0 m (3.05 ft) of TPS missing tiles and inspect. Report repair items required to CM2 for preparation. Photograph damaged TPS area	X		Camera	6.0
Retrieve and prepare TPS repair kit for MMU transporting		X	TPS repair kit Workstation (W/S) W/S attachment kit W/S removal kit Tethers Tool kit	20.0*
Translate to U.S. flag emblem on right wing. Inspect general area including control surfaces	X		--	4.0
Translate toward left wing (underside), stop at center-line and inspect/observe aft direction, and proceed to vicinity of U.S.A. symbol on left wing	X		--	3.0
Translate toward nose of Orbiter near nose wheel door. Observe TPS, main landing gear door (left side) and nose wheel door area	X		--	4.0
			TIME SUB TOTAL	92.0

*Not included in total MMU time

TABLE B2-2: Orbiter Inspection/TPS Repair Timeline (continued)

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
Translate to left wing glove fairing area, inspect area and photograph	X		Camera	3.0
Translate to left payload bay door (midpoint on forward end) and inspect from ≈1.0 m (3.05 ft). Observe latching mechanisms and linkage systems	X		--	4.0
Translate length of left payload bay door near latching system to midpoint on aft P/L door end. Inspect top wing surface from aft end of door.	X		--	7.0
Translate along aft OMS/RCS shroud, observe launch umbilical door.	X			3.0
Translate to a point ≈3.0 m (10 ft) adjacent to and above the tip of the vertical stabilizer. Inspect left side of stabilizer and vehicle. Photograph area.	X		Camera	4.0
Translate across and ≈3.0 m (10 ft) beyond tip of vertical stabilizer to right side of vehicle. Inspect stabilizer and right side of vehicle. Photograph area.	X		Camera	5.0
Translate to right side of OMS/RCS shroud. Observe shroud and surrounding systems.	X		--	3.0
Translate to right payload bay door (midpoint on aft end) and inspect from ≈1.0 m (3.05 ft). Observe latching mechanisms and linkage system. Inspect top wing surface from aft end of door.	X		--	7.0
			TIME SUB TOTAL	128.0

TABLE B2-2: Orbiter Inspection/TPS Repair Timeline (continued)

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
Translate length of right payload bay door near latching system to midpoint on forward P/L door end. Inspect latching system.	X		--	4.0
Translate into payload bay to TPS repair equipment stowage	X		--	2.0
---- END INSPECTION TASK ----			SUB TOTAL	113.0
<u>Note:</u> If required, recharge MMU propellant tank or doff MMU 1 and don MMU 2	X	X	--	15.0
<u>TPS REPAIR TASK</u>				
Retrieve, attach and secure TPS repair kit and other hardware to MMU	X	X		10.0
Translate from P/L bay to underside of vehicle near right side main landing gear (assume curved translation path in contrast to start-stop pattern used during inspection task).	X			3.0
Remove workstation-to-Orbiter attachment kit/unit from MMU temporary stowage. Connect workstation attachment unit to Orbiter/worksite.	X		Workstation attachment kit	5.0
			TIME SUB TOTAL	167.0

TABLE B2-2: Orbiter Inspection/TPS Repair Timeline (continued)

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
Remove EVA/MMU portable workstation/restraint from stowage. Secure workstation to attachment unit.	X			4.0
Deploy and ingress EVA workstation.	X			1.0
Place MMU controls in specified "worksite" mode	X			--
Prepare damaged TPS area for repair	X			5.0
Retrieve TPS repair kit from MMU temporary stowage and set up for repair operations	X			3.0
Perform TPS repairs	X			20.0
Retrieve TPS repair equipment and stow on MMU	X			3.0
Place MMU controls in operational mode	X			--
Photograph repaired area and egress workstation	X		Camera	3.0
Remove workstation attachment unit using removal kit/system and stow on MMU	X		Workstation attachment kit/unit	4.0
Translate from TPS worksite to P/L bay MMU equipment stowage area	X			3.0
Stow TPS repair equipment	X	X		4.0
			TIME SUB TOTAL	202.0

TABLE B2-2: Orbiter Inspection/TPS Repair Timeline (continued)

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	ESTIMATED TIME (min.)
Doff and stow MMU	X	X		6.0
Translate to and ingress airlock	X	X		3.0
			TOTAL TIME	212.0

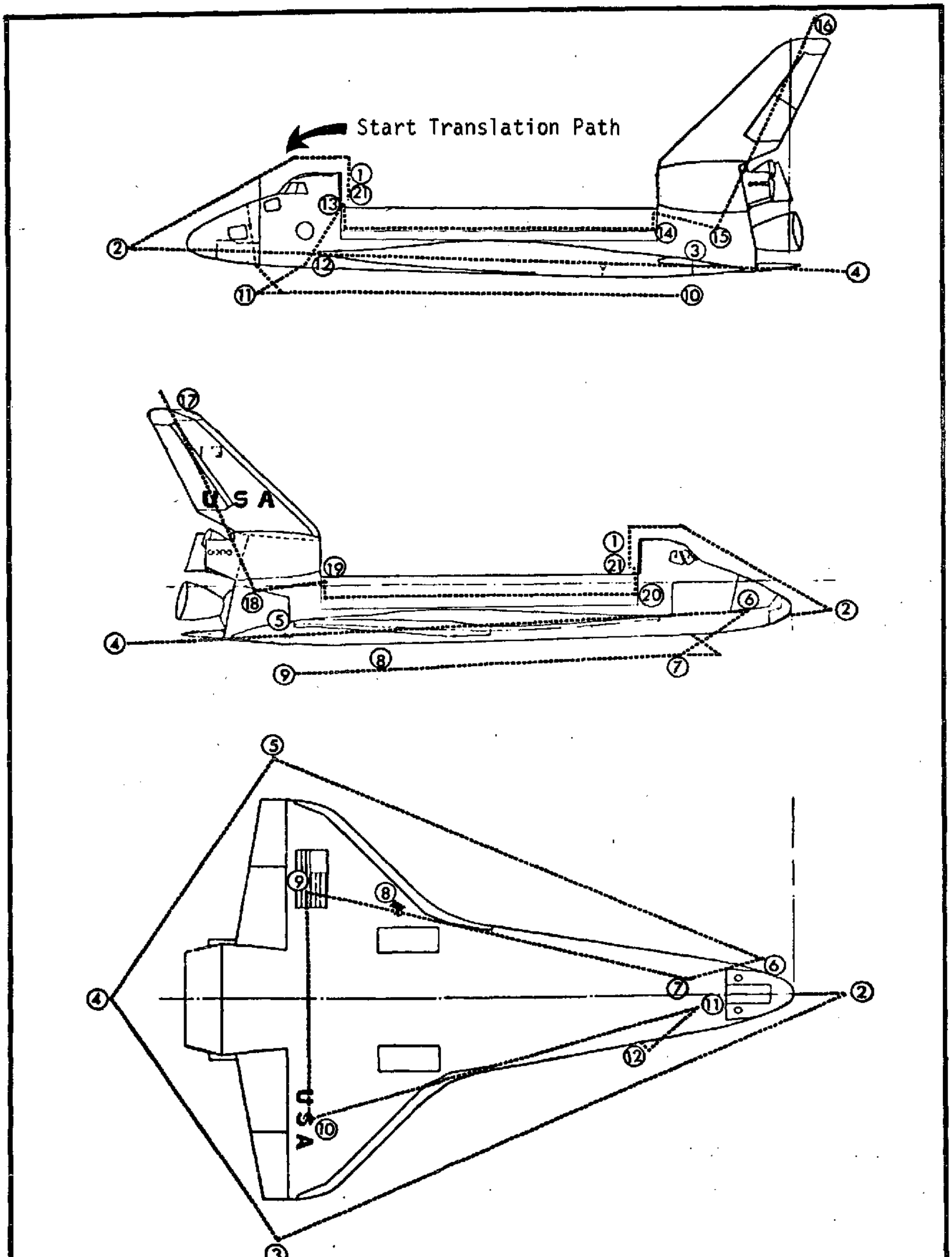


FIGURE B2.8: Orbiter Exterior Inspection--MMU Translation Route (One-Dimensional Views)

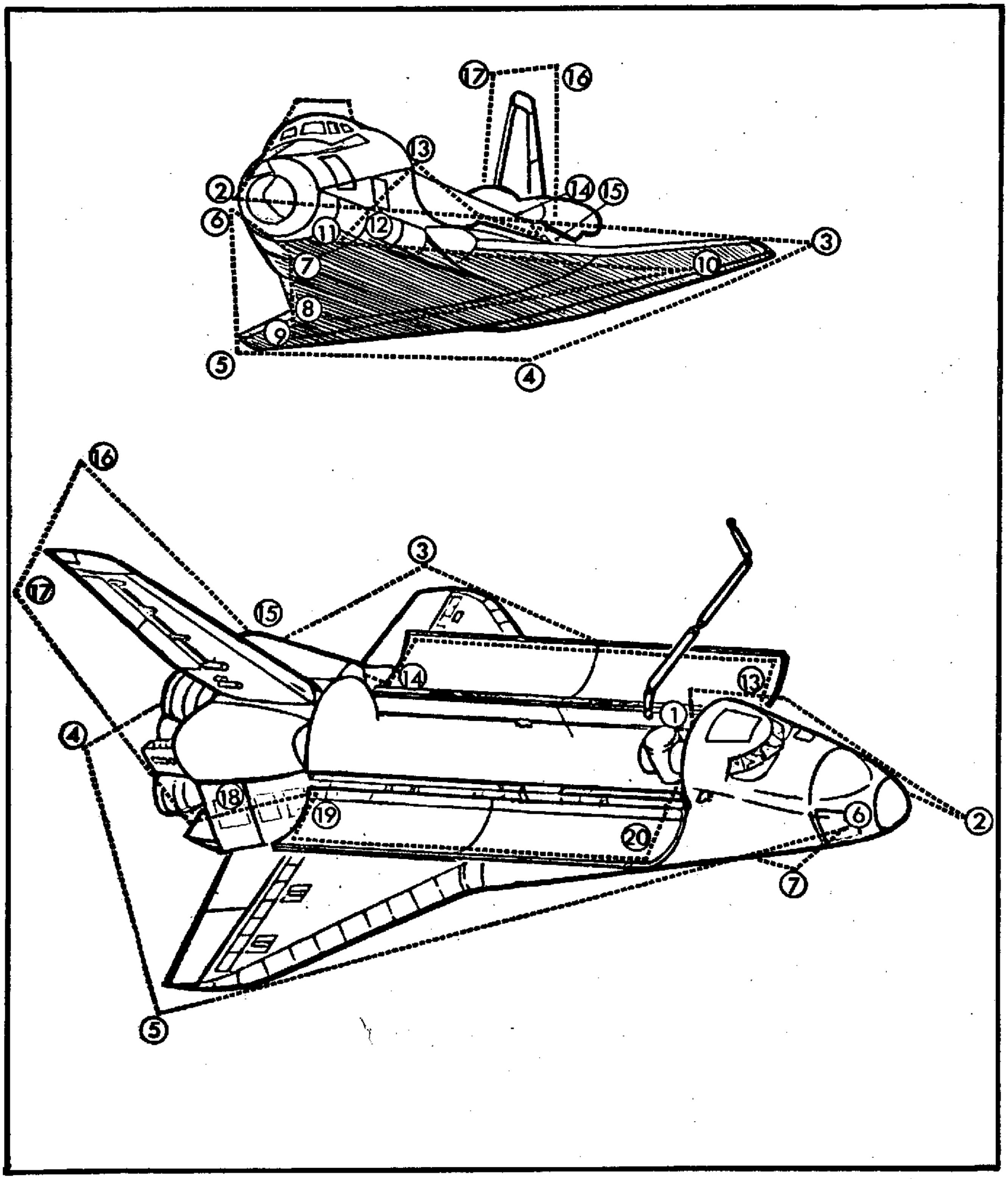


FIGURE B2.9: Orbiter Exterior Inspection--MMU Translation Route
(Three-Dimensional Views)

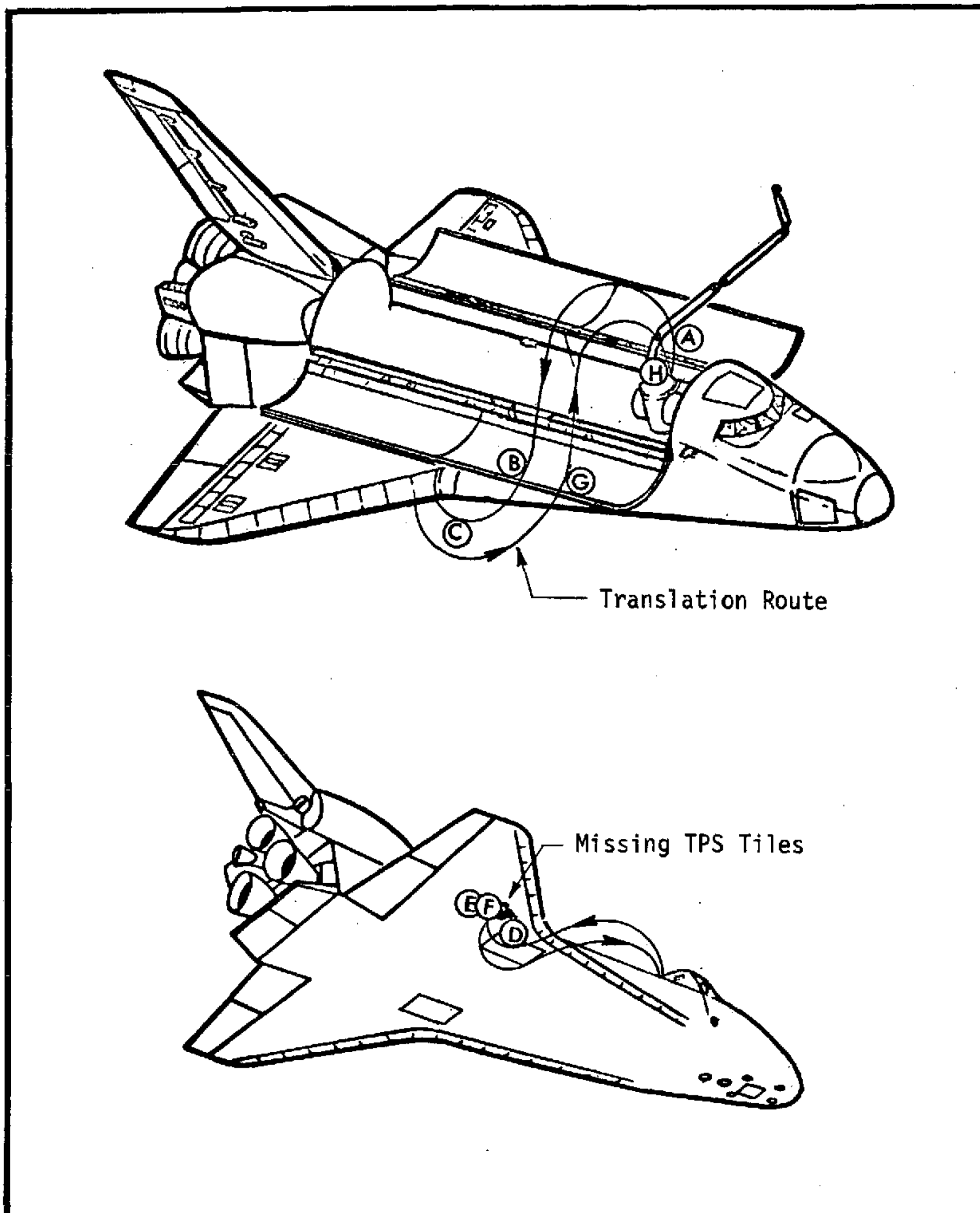


FIGURE B2.10: MMU TPS Repair--Translation Route

TABLE B2-3: MMU Requirements for Orbiter Inspection/TPS Repair

TRAVEL DISTANCE			DIRECTION CHANGES 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	roll	pitch	yaw	starts/ stops	m/sec	ft/sec	m/sec	ft/sec
CHECKOUT	46.0	150	360	360	360	15	.09	(.3)	1.35	(4.5)
INSPECTION TASK - ORBITER EXTERIOR										
1 to 2: Over cabin to forward of nose and stop	22.9	75		30	360	5	.12	(.4)	.60	(2.0)
2 to 3: around left side at wing level	36.6	120		15	45	2	.15	(.5)	.30	(1.0)
3 to 4: left wing tip to center line aft of main engines	18.3	60		10	60	2	.15	(.5)	.30	(1.0)
4 to 5: aft center line to right wing tip	18.3	60			30	2	.15	(.5)	.30	(1.0)
5 to 6: right wing to right RCS door	33.5	110		10	45	2	.15	(.5)	.30	(1.0)
6 to 7: RCS downward to underside	6.1	20		30	15	4	.09	(.3)	.36	(1.2)
7 to 8: fwd. underside to aft of right landing gear door (inspect RCS)	21.3		20			4	.15	(.5)	.60	(3.0)

TABLE B2-3: MMU Requirements for Orbiter Inspection/TPS Repair (continued)

TRAVEL DISTANCE			DIRECTION CHANGES 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	roll	pitch	yaw	starts/ stops	m/sec	ft/sec	m/sec	ft/sec
8 to 9: right landing gear door to flag symbol on wing	6.1	20		10		2	.09	(.3)	.18	(0.6)
9 to 10: flag to left wing USA symbol (stop at center line)	13.7	45	90			2	.15	(.5)	.3	(1.0)
10 to 11: left wing to nose wheel door	21.3	70	90			2	.12	(.4)	.24	(0.8)
11 to 12: nose wheel to glove fairing (left wing)	7.6	25		30	15	4	.09	(.3)	.36	(1.2)
12 to 13: glove fairing to P/L door	9.1	30		60	90	2	.09	(.3)	.18	(0.6)
13 to 14: along P/L door	24.4	80			90	4	.09	(.3)	.36	(1.2)
14 to 15: along aft left RCS shroud	7.5	25	180	60		5	.09	(.3)	.45	(1.5)
15 to 16: RCS shroud to top of vert. stabilizer	15.2	50				2	.09	(.3)	.18	(0.6)
16 to 17: across vert. stabilizer	7.6	25	180	30		2	.09	(.3)	.18	(0.6)

TABLE B2-3: MMU Requirements for Orbiter Inspection/TPS Repair (continued)

TRAVEL DISTANCE			DIRECTION CHANGES 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	roll	pitch	yaw	starts/ stops	m/sec	ft/sec	m/sec	ft/sec
17 to 18: top vert. stabilizer to right RCS shroud	15.2	50		30		2	.15	(.5)	.3	(1.0)
18 to 19: right RCS shroud to right P/L door	7.6	25		90		5	.09	(.3)	.45	(1.5)
19 to 20: along right P/L door	24.4	80			180	4	.09	(.3)	.36	(1.2)
20 to 21: right P/L door into P/L bay	6.1	20	90	90	180	5	.09	(.3)	.15	(0.5)
SUB TOTAL (Inspection Task)	368.9	1210	1010	855	1470	52	N/A	N/A	7.8	(26.5)
TPS REPAIR TASK										
A to B: P/L bay MMU stowage to right side P/L door	18.3	60				3	.18	(.6)	.54	(1.8)
B to C: right P/L door downward to underside of Orbiter	4.6	15				1	.12	(.4)	.12	(0.4)
C to D: underside to worksite area near right side landing gear door	9.1	30		90	90	3	.15	(.5)	.15	(0.5)

TABLE B2-3: MMU Requirements for Orbiter Inspection/TPS Repair (continued)

TRAVEL DISTANCE			DIRECTION CHANGES 3-axes (degrees)			TRANSLATION LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	roll	pitch	yaw	starts/ stops	m/sec	ft/sec	m/sec	ft/sec
D to E: workstation placement and ingress at worksite			60	10	5	4				
E to F: workstation egress and removal at worksite			60	10	5	4				
F to G: worksite area to P/L bay door	13.7	45				1	.18	(.6)	.18	(0.6)
G to H: P/L bay door to P/L bay stowage area	18.3	60		90	270	3	.18	(.6)	.54	(1.8)
SUB TOTAL (TPS Repair Task)									1.53	(5.1)
TOTAL (Inspection and Repair)	432.9	1420	1130	1055	1840	71	N/A	N/A	9.03	(30.1)
TRANSLATION ΔV + ROTATION ΔV →									18.06	60.2

MMU PERFORMANCE AND CONTROL REQUIREMENTS

TPS INSPECTION/REPAIR

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE) (MAX.)	610 m.	2000 ft.
TOTAL VELOCITY CHANGE CAPABILITY	18.6 m/sec*	60.2 ft/sec*
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±3°	±3°
- ATTITUDE RATE PRECISION	±2°/sec	±2°/sec
ACCELERATION		
- TRANSLATION (2)	$\leq$.09 m/sec^2	$\leq$.3 ft/sec^2
- ROTATION	>6°/sec^2	>6°/sec^2
FORCE APPLICATIONS		
- LINEAR (3)	22.2 N	5 lbs.
- TORQUE (2)		

REMARKS

(1) Estimated accuracy required to install a portable workstation.

(2) Not critical for inspection/TPS repair operations.

(3) Estimated force required to install/remove a portable workstation.

* MMU design driver from applications analysis.

APPENDIX B3

ORBITER DOOR SYSTEMS

SHUTTLE ORBITER SYSTEM GENERAL INFORMATION

SHUTTLE SYSTEM: External Doors

SHUTTLE ORBITER SYSTEM			
Orbiter External Doors			
SUBSYSTEM OR COMPONENT			
• Payload Bay Doors • Star Tracker Door • RCS Doors • External Tank Attachment Doors • Fuel and O_2 Access Doors			
LOCATION ON ORBITER			
See Figure 1			
SUBSYSTEM--WBS MANAGER/LOCATION			
R. D. Langley, JSC/EW (713) 483-3375			
MMU/EVA REQUIREMENTS	PLANNED EVAs	TASK	None defined to date
		NO./MISSION	
		DURATION (hrs.)	
	CONTINGENCY EVAs	PROBABLE TASK	Inspect and correct door jam
		DURATION (hrs.)	2+ (est.)

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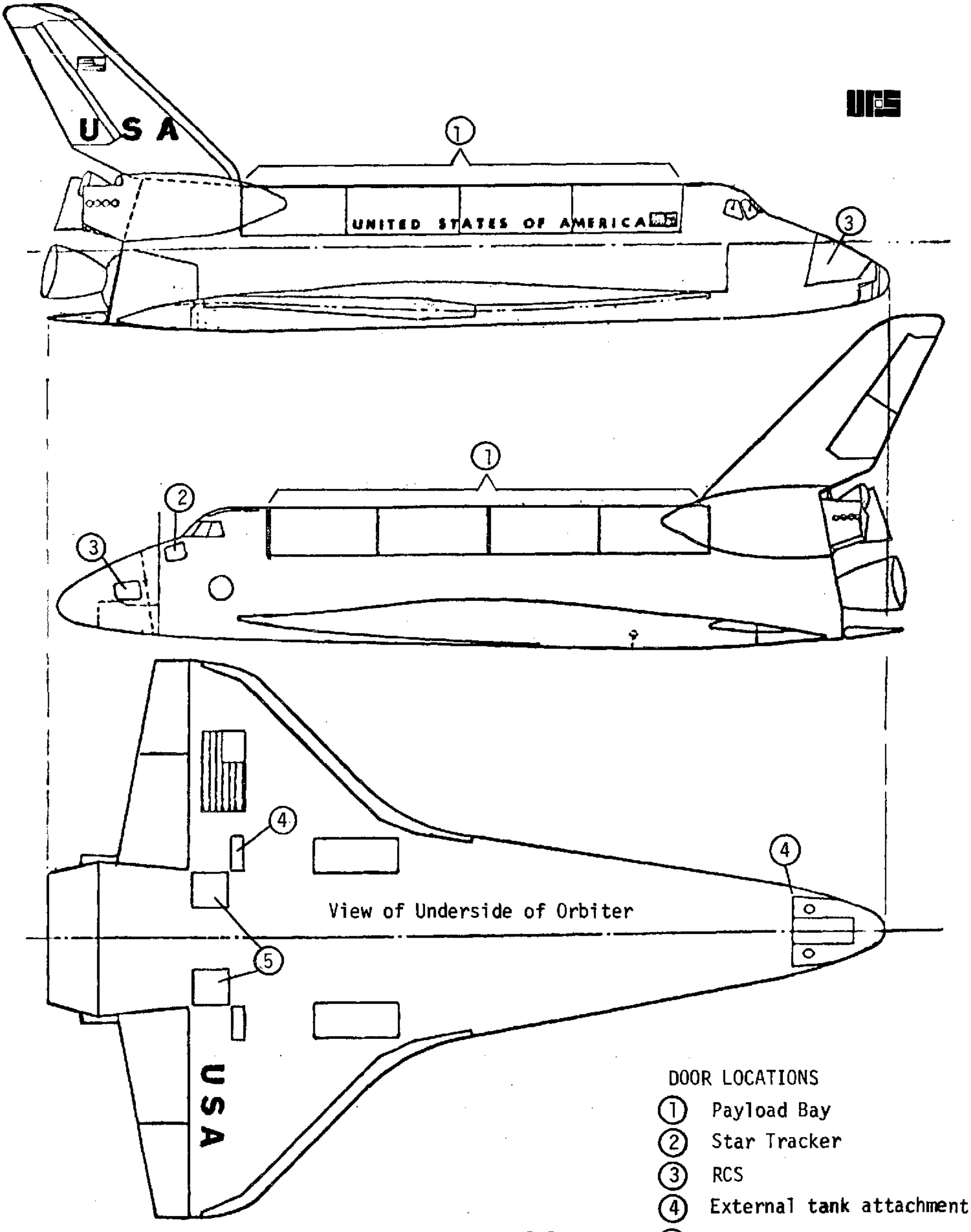

FIGURE B3.1: Shuttle External Doors

EVA TASK DESCRIPTION

SHUTTLE SYSTEM: External Doors

TASK OBJECTIVE

Inspect doors, remove foreign material, or disconnect linkage to allow door closure for reentry

EVA/MMU TASK DESCRIPTION

- Prepare for EVA, egress airlock, don MMU, attach general purpose tool kit, lights and cameras
- Maneuver to problem area, inspect and photograph
- Determine approach for correcting anomaly
- Attach stabilization/restraint device to worksite, if required
- Remove foreign material, if possible
- Request crew inside cabin to initiate door closure
- Manually assist door closure, if required (at present there are no provisions for manual operation of the doors)
- Inspect door seal area to assure proper closure
- Remove stabilization/restraint device (design of device is TBD)
- Return to MMU donning station
- Stow ancillary equipment
- Doff MMU, ingress airlock, end EVA

UNIQUE TASKS OR HAZARDOUS CONDITIONS TO EVA CREW

Hazards are thruster impingement and mechanical systems, other hazards are not identified at this time.

SHEET NO.3 of 5

ORBITER REQUIREMENTS AND CONSTRAINTS

SHUTTLE SYSTEM: External doors

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

- Constraints on EVA in vicinity of Star Tracker: TBD
- At present, no constraints have been identified in the door areas.

ORBITER MODIFICATIONS REQUIRED TO ACCOMMODATE EVA

Orbiter provides handrails for access to payload bay door hinge line along the rim of the bay. To work in any area outside of the bay, the Orbiter may require addition of:

- MMU and supporting provisions
- Tool stowage
- Crew stabilization/restraint provisions at the worksite (MMU may be adequate for this requirement)

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (size, mass, C.G.)
• Prying, cutting, impact tools • Cameras, lights • Crew/MMU stabilization unit	Tool kit - TBD Cameras, lights - TBD Crew/MMU stabilization unit Size: <.015 m^3 (.5 ft^3) Mass: <10 kg. (22 lbs.)

FORCES REQUIRED FOR TASK	SI	CONVENTIONAL
• Prying	TBD	
• Cutting	TBD	
• Impact	TBD	
Note: Avoid damage to TPS - tiles are fragile. Reference information sheets on TPS system for allowable TPS force parameters		

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SUPPLEMENTARY ORBITER EVA/AMU INFORMATION

SHUTTLE SYSTEM: External Doors

WORKING GROUPS AND PERSONS CONTACTED

R. D. Langley, JSC/EW (713) 483-3375

REFERENCE DOCUMENTS/DRAWINGS

North American Rockwell drawings

CURRENT ORBITER STATUS RELATIVE TO EVA REQUIREMENTS

Requirements under study

ADDITIONAL REMARKS/COMMENTS

A door jam, due to foreign material or linkage failure, is a likely failure mode. At present, the MMU provides the only method for accessing all of the external doors on the Orbiter. It is felt that the MMU should be considered an essential equipment item on all Orbiter flights.

SHEET NO. 5 of 5

ORBITER DOOR CLOSURE

Orbiter Door Closure Timeline

The typical MMU mission outlined in this appendix involves a contingency door closure to ensure reentry capability of the Orbiter. Table B3-1 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task.

The MMU mission is assumed to be a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU (one-man MMU operations can be performed, if required). Crewman no. 2 (CM2) supports CM1 from the payload bay. CM1 performs the required tasks from a free-flying untethered MMU. Door closure is accomplished in a free-flying mode or from a portable EVA workstation attached to the Orbiter exterior. The MMU mission is initiated following airlock egress and terminates with airlock ingress.

MMU Requirements for Orbiter Door Closure

A typical MMU translation route is shown in Figure B3.2. Closure of the external tank attachment door was chosen since it is not within RMS reach capability. Table B3-2 shows the estimated travel distance for the mission, direction changes, number of starts/stops, estimated velocity and Δvelocity requirements.

Total ΔV Required

The translation ΔV required for this particular MMU mission is approximately 3.17 m/sec (10.4 ft/sec). From M509 on-orbit experience, it was found that the ΔV used for rotation is approximately equal to that required for translation. Therefore, the total ΔV for both translation and rotation is approximately 6.34 m/sec (20.8 ft/sec).

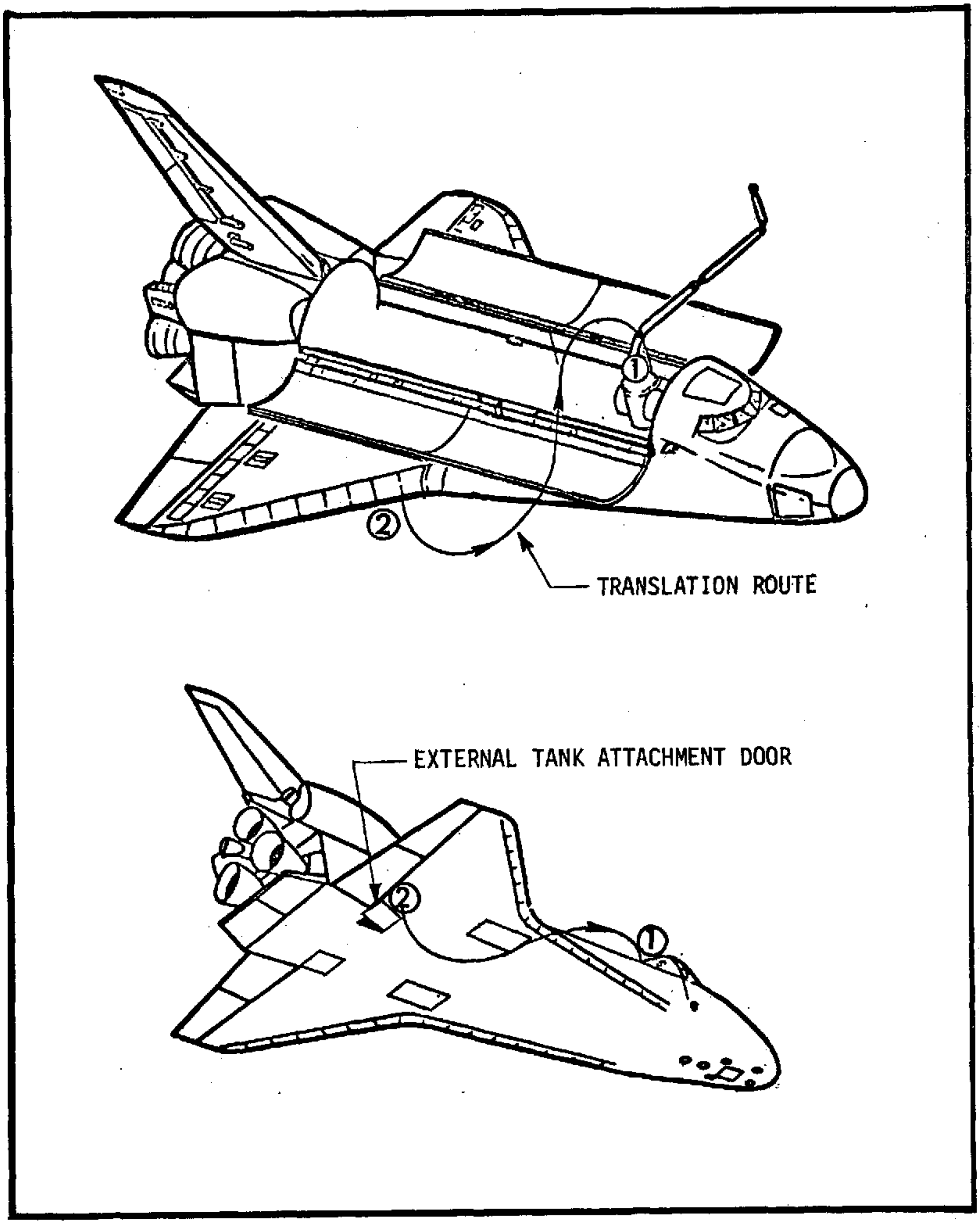


FIGURE B3.2: MMU Translation Route for Door Closure

TABLE B3-1: Orbiter Door Closure Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		2.0
Checkout MMU	X			15.0
Don MMU	X			15.0
Flight check MMU (first use of MMU on mission)	X			15.0
Attach ancillary hardware	X	X	tools, lights, camera, portable workstation	5.0
Remove MMU tether	X			1.0
Translate to malfunctioning door	X			5.0
Attach workstation, close door *	X			20.0
Remove workstation	X			5.0
Translate to MMU stowage area	X			5.0
Doff and stow MMU and ancillary hardware	X	X		5.0
Ingress airlock	X	X		2.0
End EVA	X	X		
*see MMU Performance and Control Requirements sheet--this task				
			TOTAL TIME	97.0

TABLE B3-2: MMU Requirements for Orbiter Door Closure

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
Contingency Door Closure	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
MMU flight check	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
1 to 2 translate to jammed door	32	(105)	--	90	90	7	.15	(.5)	1.07	(3.5)
Fasten workstation in place	--	--	60	10	5	4				
Remove workstation	--	--	60	10	5	4				
2 to 1 translate to MMU stowage area	32	(105)	--	90	270	4	.18	(.6)	.73	(2.4)
TOTAL	110	(360)	480	560	730	34			3.17	(10.4)
TRANSLATION ΔV + ROTATION ΔV									6.34	(20.8)

MMU PERFORMANCE AND CONTROL REQUIREMENTS

EXTERNAL DOORS

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE) (MIN.)	110 m.	360 ft.
TOTAL VELOCITY CHANGE CAPABILITY	6.34 m/sec	20.8 ft/sec
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±2°	--
- ATTITUDE RATE PRECISION	±1°/sec*	--
ACCELERATION (2)		
- TRANSLATION	$\leq$.09 m/sec^2	$\leq$.3 ft/sec^2
- ROTATION	>6°/sec^2	--
FORCE APPLICATIONS		
- LINEAR (3)	22.2 N	5 lbs.
- TORQUE (2)		

REMARKS

(1) Estimated accuracy required to remove a pin or foreign material from the door mechanism. (Accuracy required if restraints are not available.

(2) Not critical for external door repair.

(3) Estimated force required to install/remove a portable workstation.

* Special case for door repair without attaching MMU to Orbiter.

APPENDIX B4

REMOTE MANIPULATOR SYSTEM (RMS)

(The general information in this appendix was excerpted from JSC 07700, Vol. 14, Space Shuttle System Payload Accommodations)

Remote Manipulator System

The Remote Manipulator System (RMS) is shown in Figure B4.1. The RMS is located in the payload bay as shown in Figure B4.2.

The Orbiter provides a manipulator 15.24 m. (50 ft.) in length on the left side of the vehicle. In orbit, the manipulator is specified capable of removing and installing a 4.57 m. (15 ft.) diameter, 18.29 m. (60 ft.) long, 29,510 kg. (65,000 lb.) payload. The RMS is stowed outside the payload envelope and is charged to Orbiter weight. The installation of the RMS is illustrated in Figure B4.3.

The manipulator system is specified capable of deploying a 14,528 kg. (32,000 lb.) payload in no more than seven minutes from release of payload tiedown to the fully deployed position 7.62 m. (25.0 ft.) above the Orbiter horizontal centerline, $Z_0 = 400$, and on the Orbiter vertical centerline at $X_0 = 710$. The manipulator is specified capable of retracting a 14,528 kg. (32,000 lb.) payload in less than seven minutes from start of initial retracting motion to initiation of payload tiedown.

The manipulator provides a light (TBD) for payload illumination and a TV camera (TBD) for remote payload viewing. Locations on the manipulator are TBD.

The RMS may be removed if not required for a particular mission. In addition, a second manipulator arm (Figure B4.3) can be installed, if required. The weight of the second manipulator is chargeable to the payload.

Functional Capability

The RMS has the following basic operational requirements which form the basis for performance characteristics:

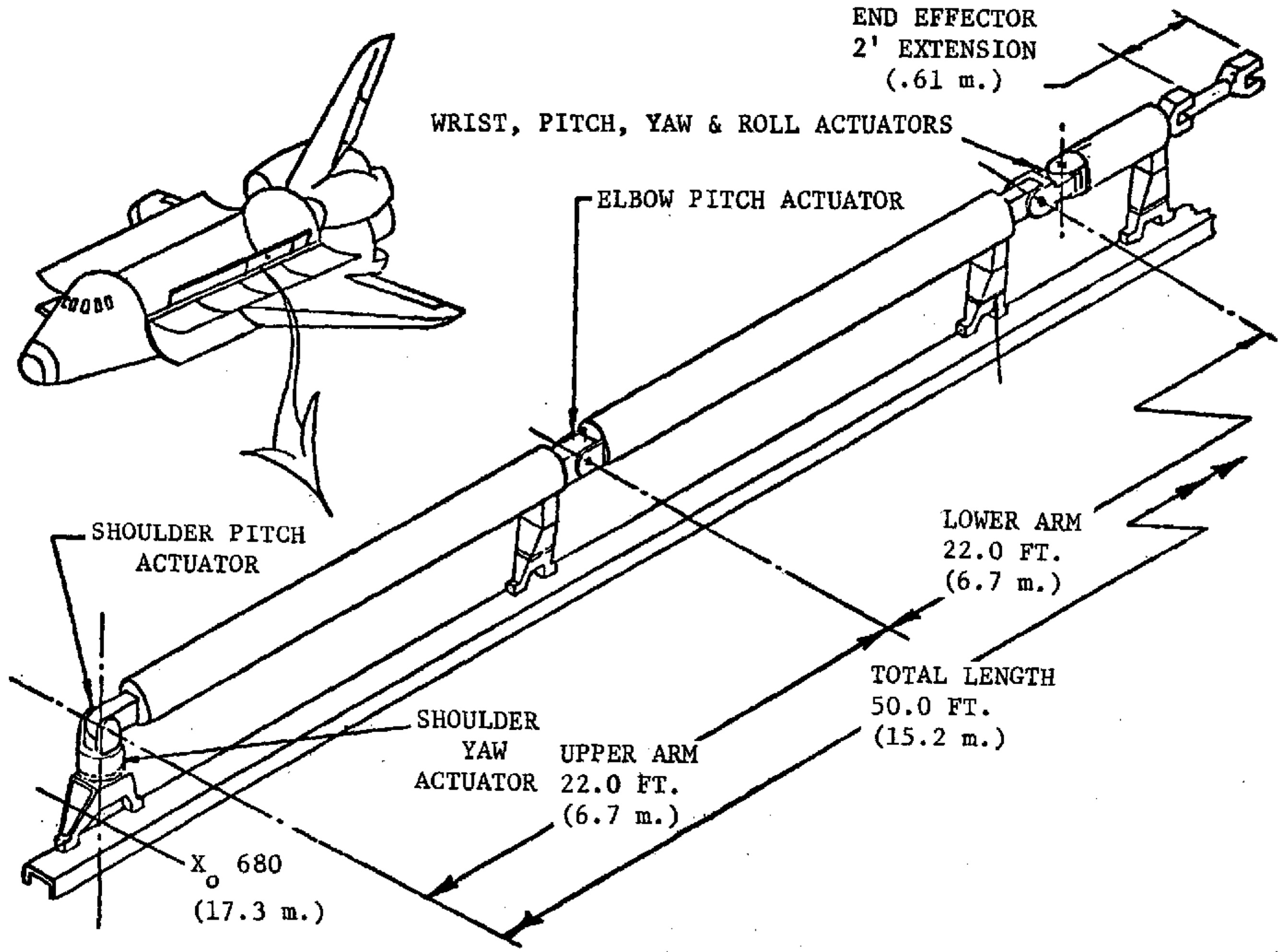


FIGURE B4.1: Orbiter Remote Manipulator System

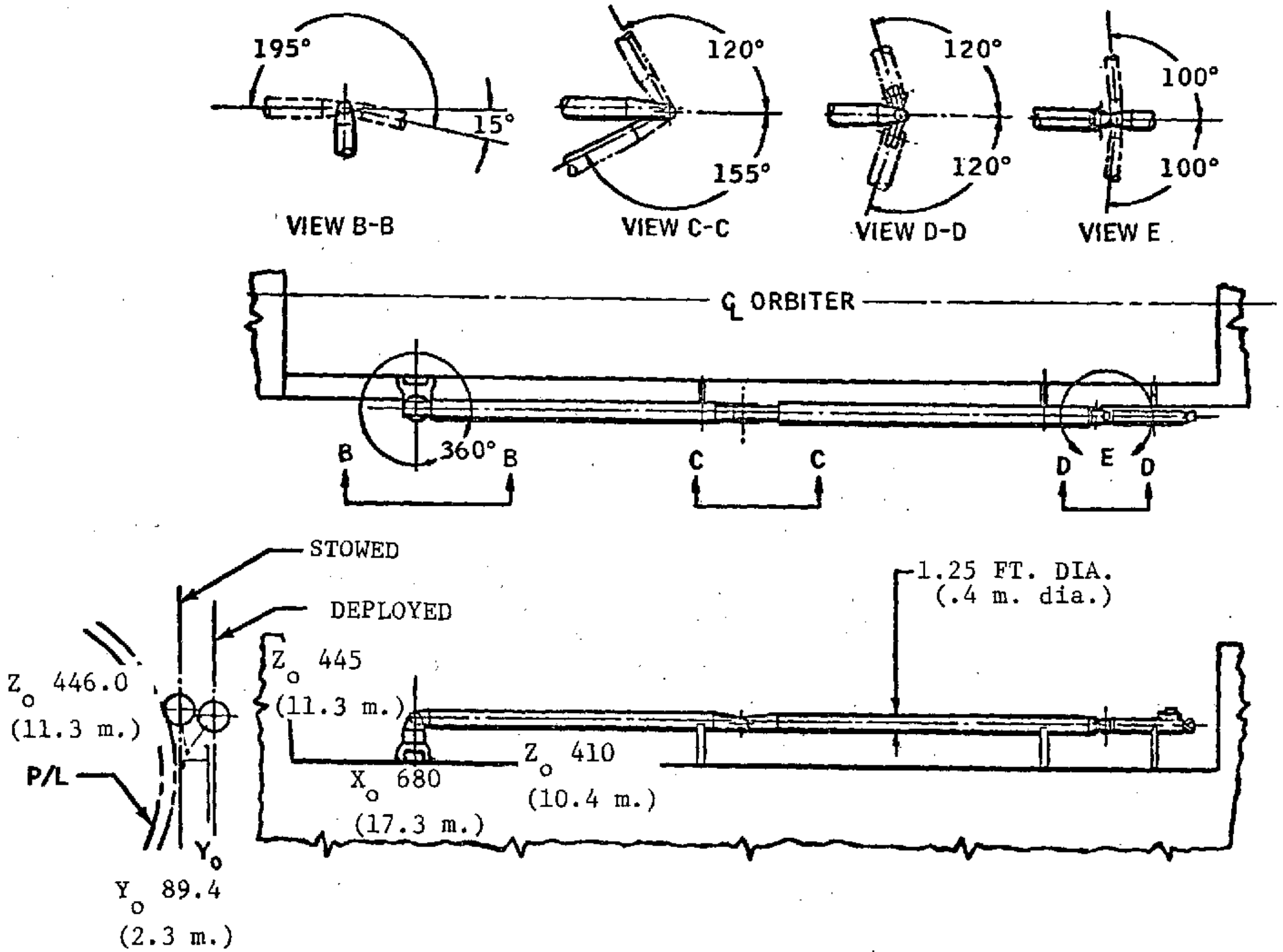


FIGURE B4.2: RMS Location

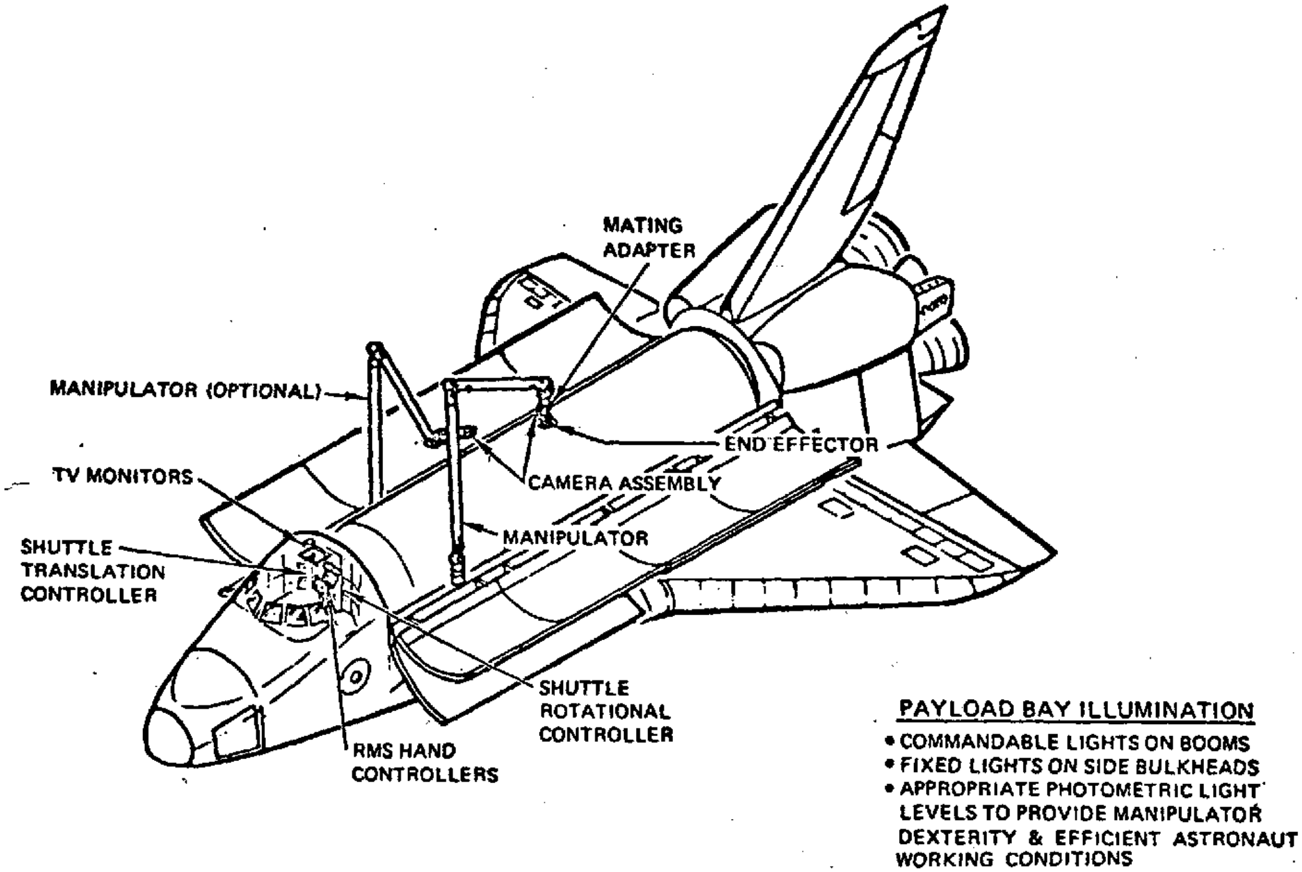


FIGURE B4.3: Deployment/Retrieval System

- Payload deployment, handling and storage
- Payload retrieval
- Payload servicing
- Docking payloads to the Orbiter and other stabilized elements
- Inspection
- EVA support

RMS Performance

The RMS will be used only in zero g for handling of payloads. The RMS performance characteristics and limitations are given in Table B4-1. Within the reach limit of the deployment mechanism, the Orbiter vehicle will have the capability to deploy and retrieve single or multiple payload elements on-orbit during a single mission, including placement (such as docking of payloads) to a stabilizied body. Payload furnished adaptors shall provide suitable attach points.

This mechanism will deploy the payload clear of the Orbiter vehicle mold line. In payload retrieval, the RMS will provide the capability of aligning the payload in the payload bay, and with the aid of the payload retention mechanisms, accomplish stowage of the payload.

The manipulator system will also be used to inspect payloads using CCTV, both in the Orbiter bay and in space, before it attaches to them. It will also be used to inspect the exterior of the Orbiter and other spacecraft. Manipulator attachment to payloads in orbit will require visual knowledge of the payload's orientation and location. A television camera mounted near the end of the manipulator will provide a view of distant points and will provide viewing of points hidden from the direct view of the operator. For these reasons, a television camera (TBD) mounted on the manipulator will be used for close inspections and also to aid in attaching the RMS to payloads. Locations of other television cameras are TBD.

TABLE B4-1: Remote Manipulator Performance

PAYLOAD ATTACHED TO MANIPULATOR		PERFORMANCE CHARACTERISTIC	
Maximum Torques:			
RM Shoulder	- Pitch	6000	in-lb (677.9 N.m)
	- Yaw	6000	in-lb (677.9 N.m)
RM Elbow	- Pitch	3600	in-lb (406.7 N.m)
RM Wrist	- Roll	2400	in-lb (271.2 N.m)
	- Pitch	2400	in-lb (271.2 N.m)
	- Yaw	2400	in-lb (271.2 N.m)
RM Wrist Extension/Retraction Force		10 lb @ 24 inch stroke (44.5 N @ .69 m.)	
Holding force		200 lb (brakes locked) (890 N)	

Manipulator reach and viewing capability: This is illustrated in Dwg. VL 70-004145, Figures B4.4 and B4.5 for various X, Y and Z locations.

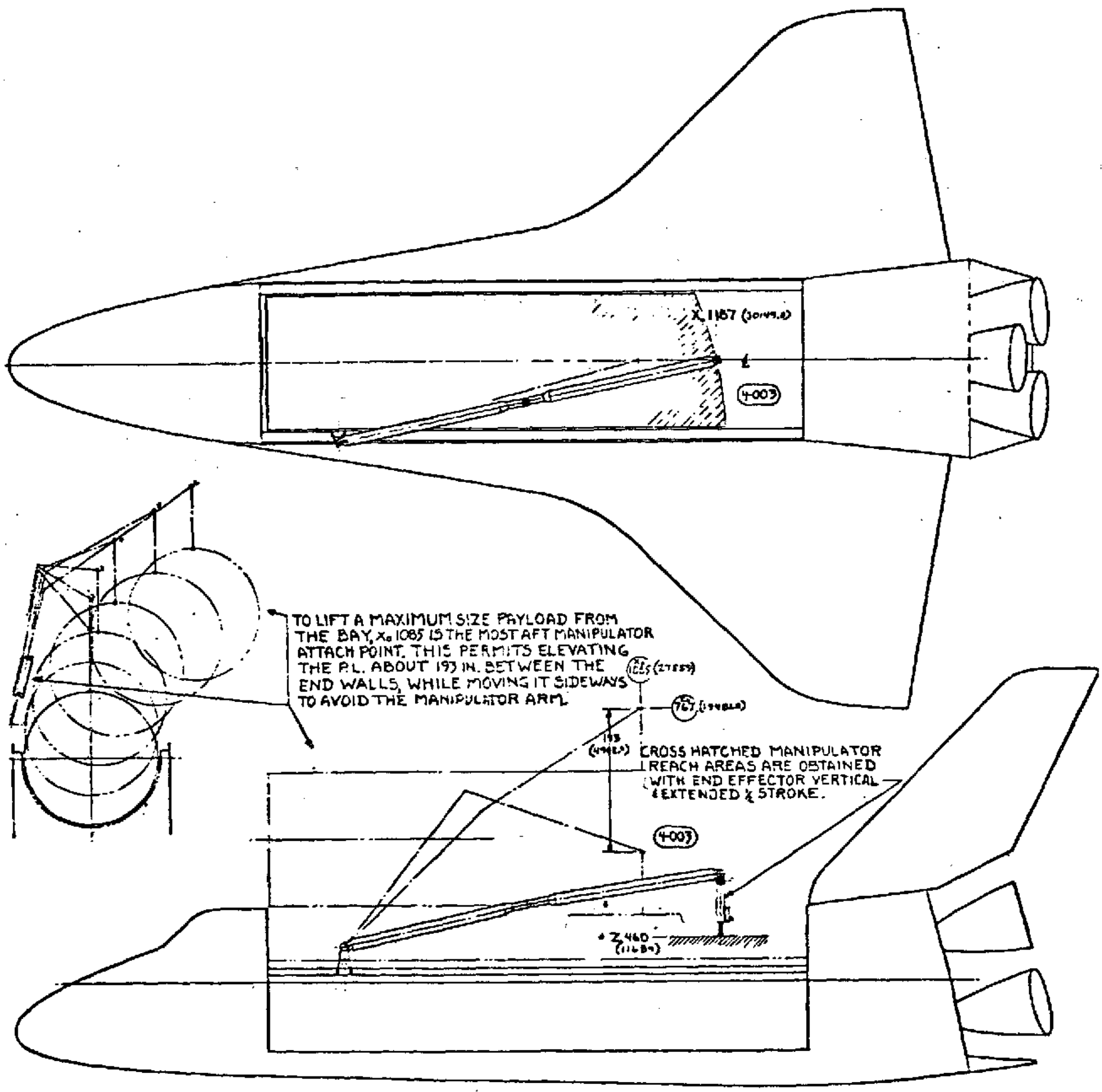


FIGURE B4.4: RMS Reach Inside Payload Bay

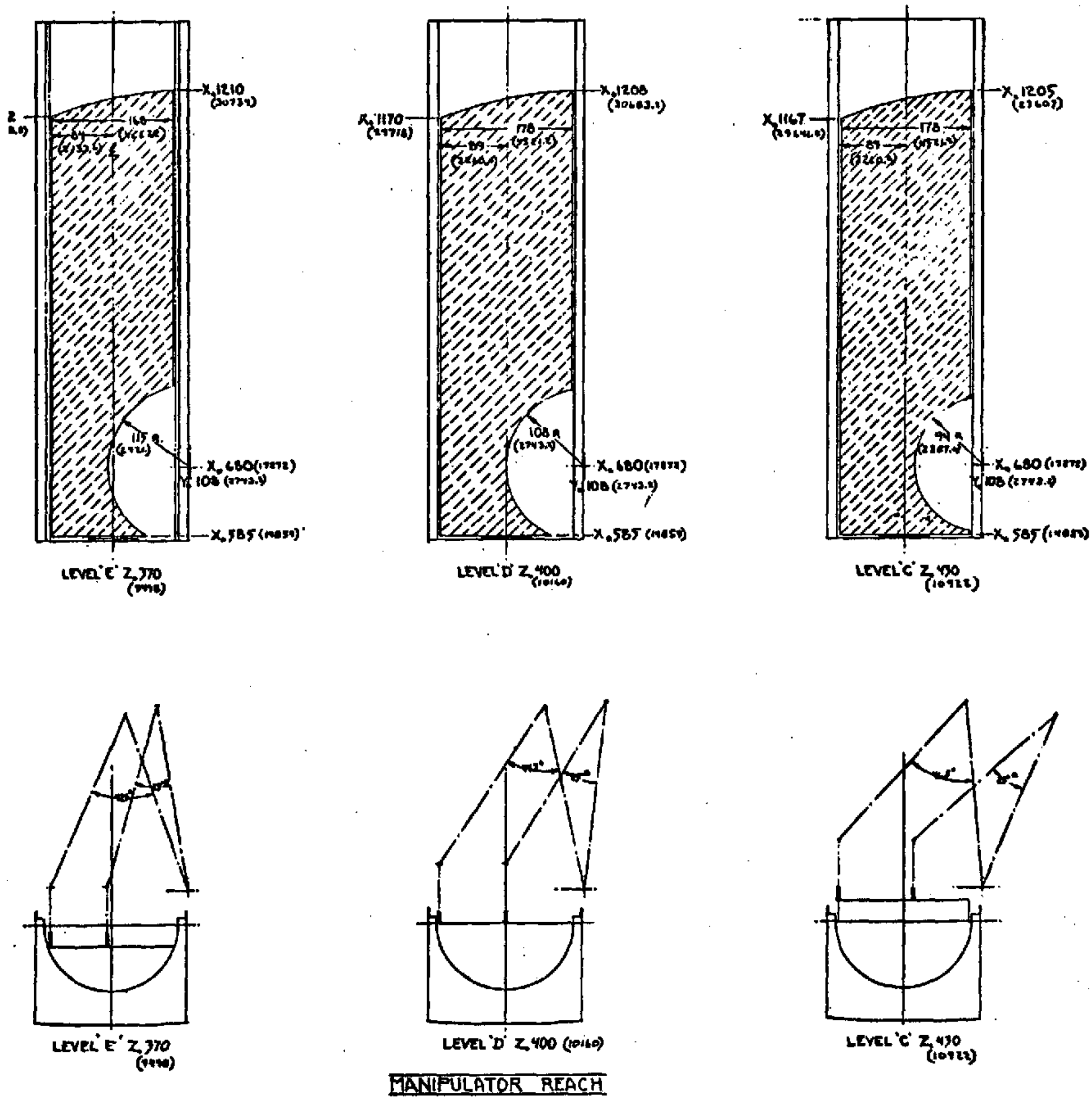


FIGURE B4.4: RMS Reach Inside Payload Bay (continued)

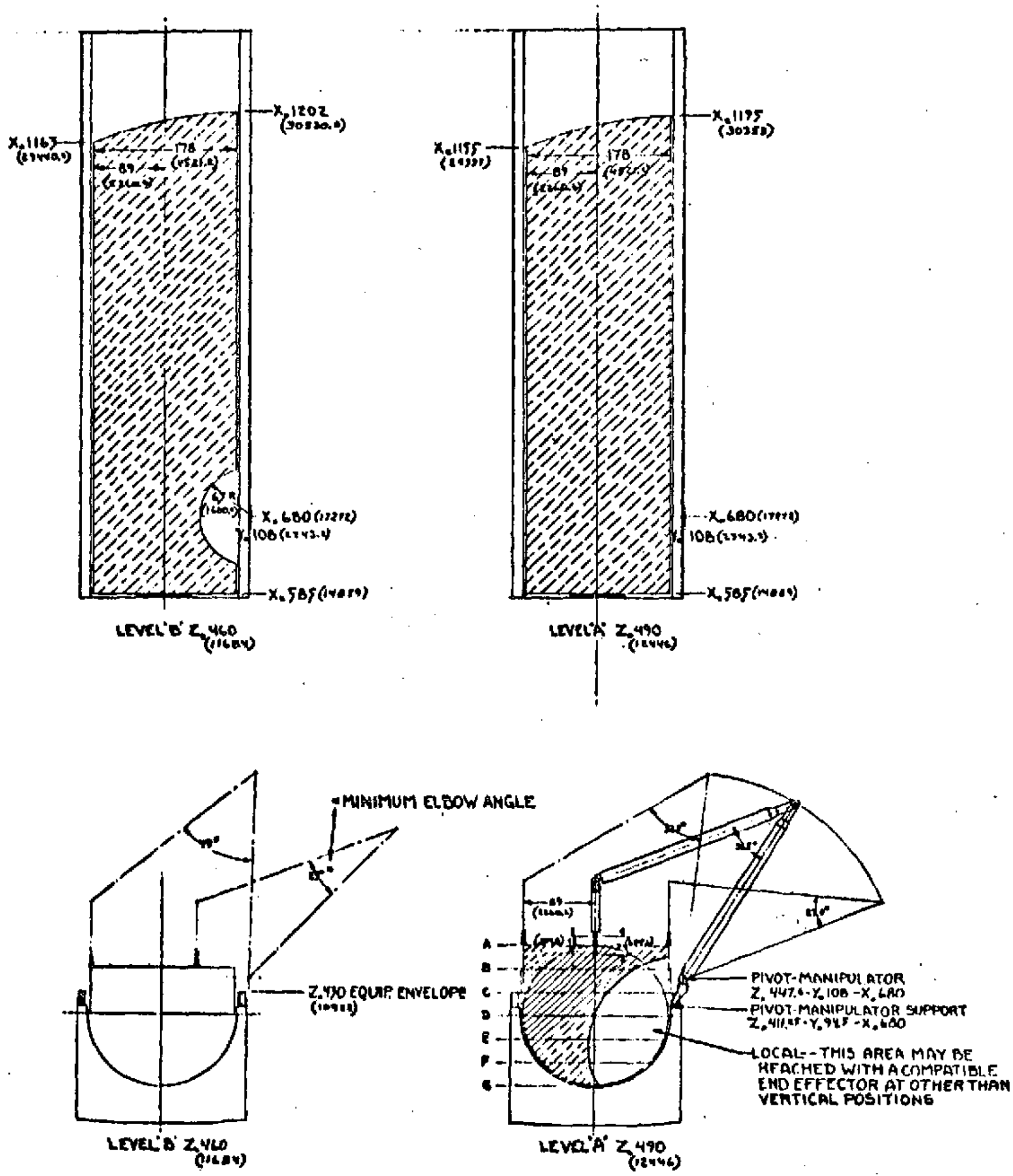


FIGURE B4.4: RMS Reach Inside Payload Bay (continued)

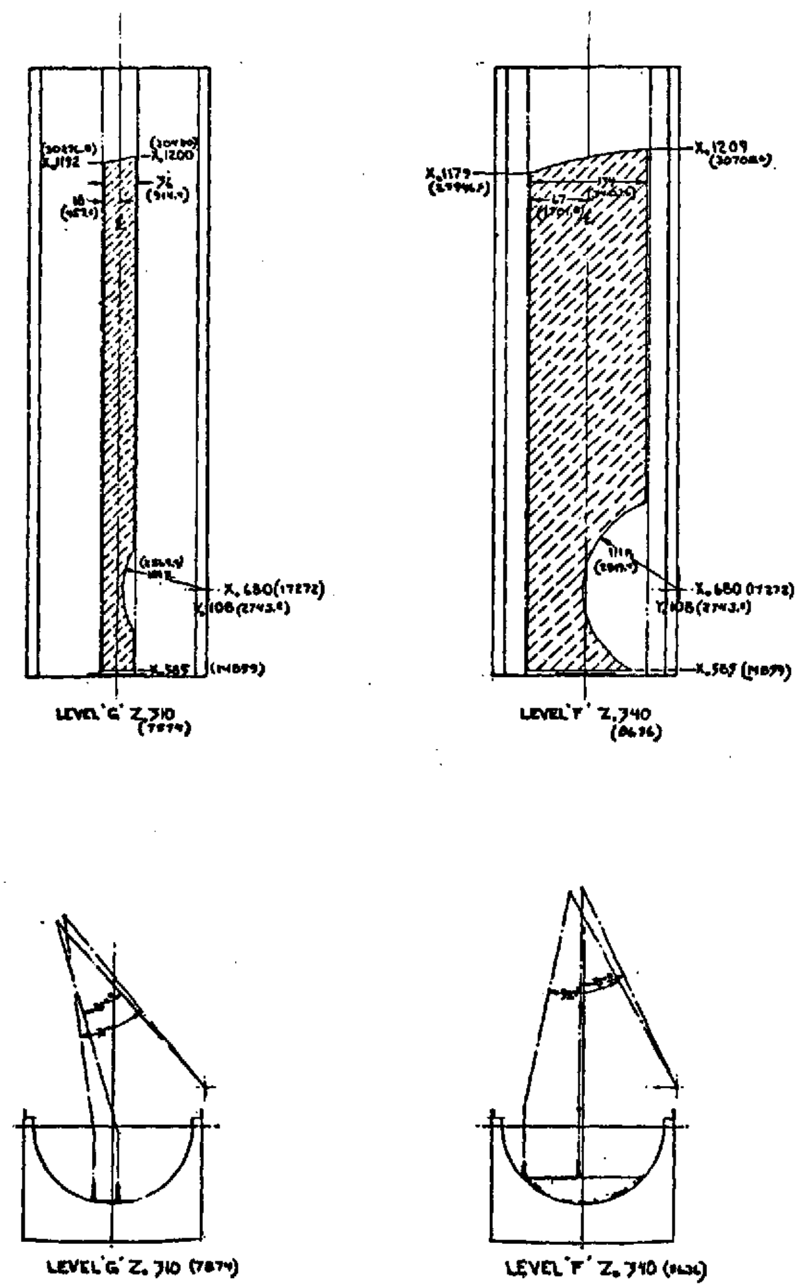


FIGURE B4.4: RMS Reach Inside Payload Bay (continued)

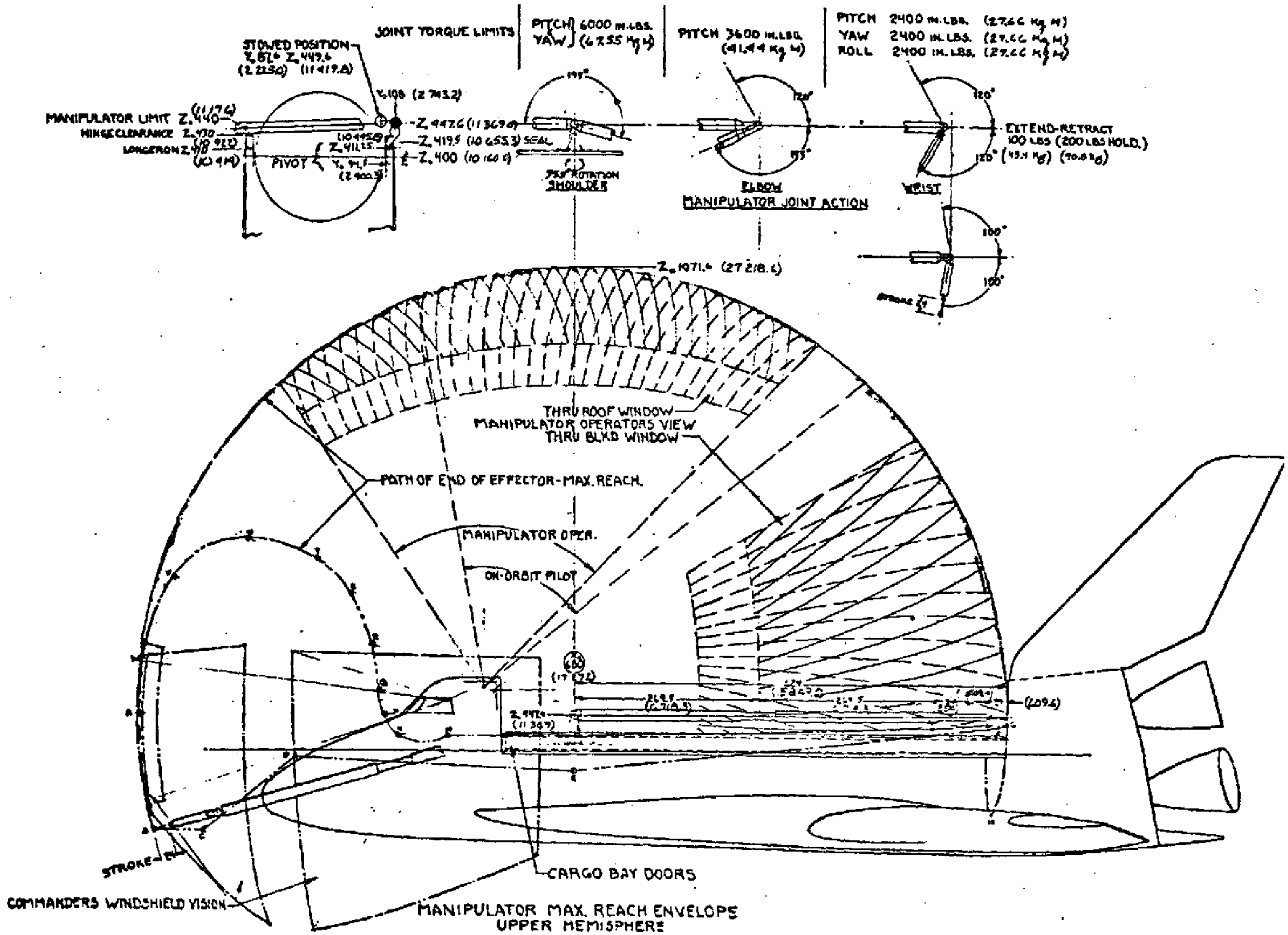


FIGURE B4.5: RMS Reach Envelope Orbiter Exterior

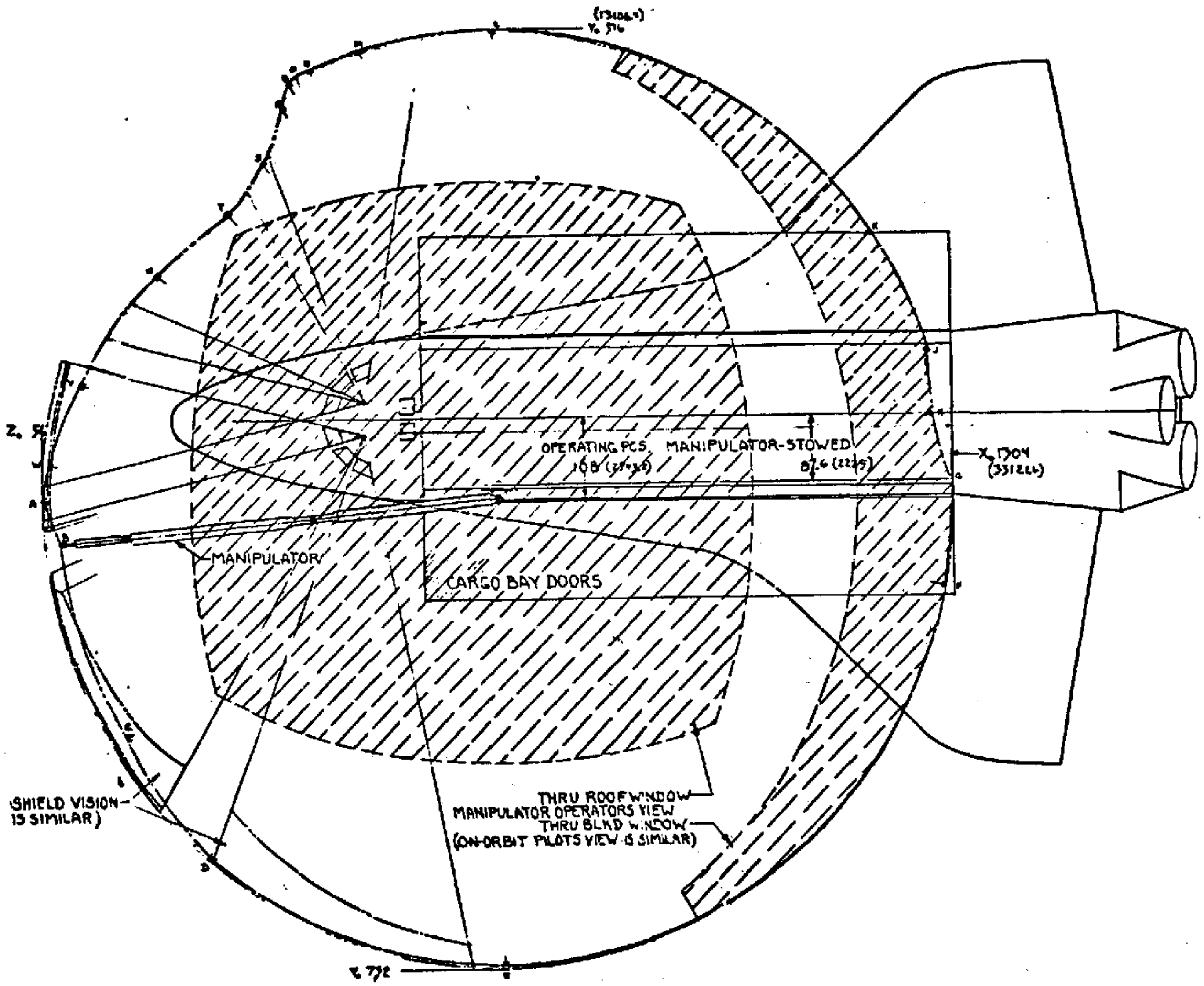
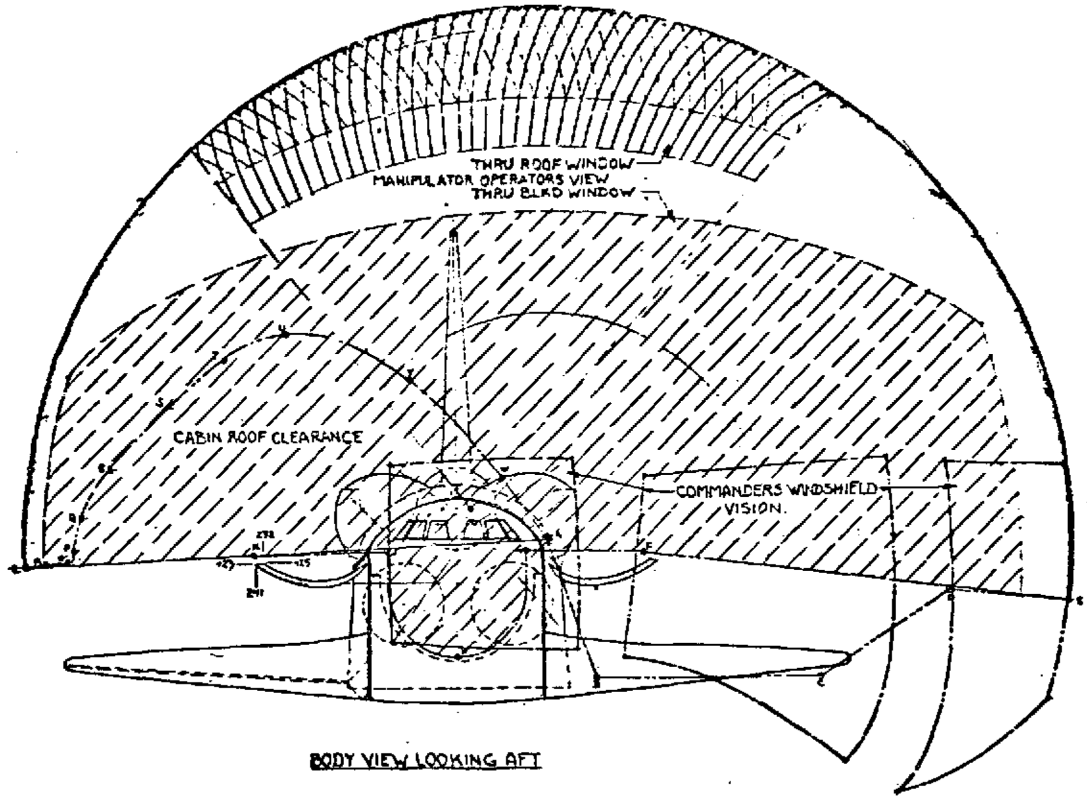
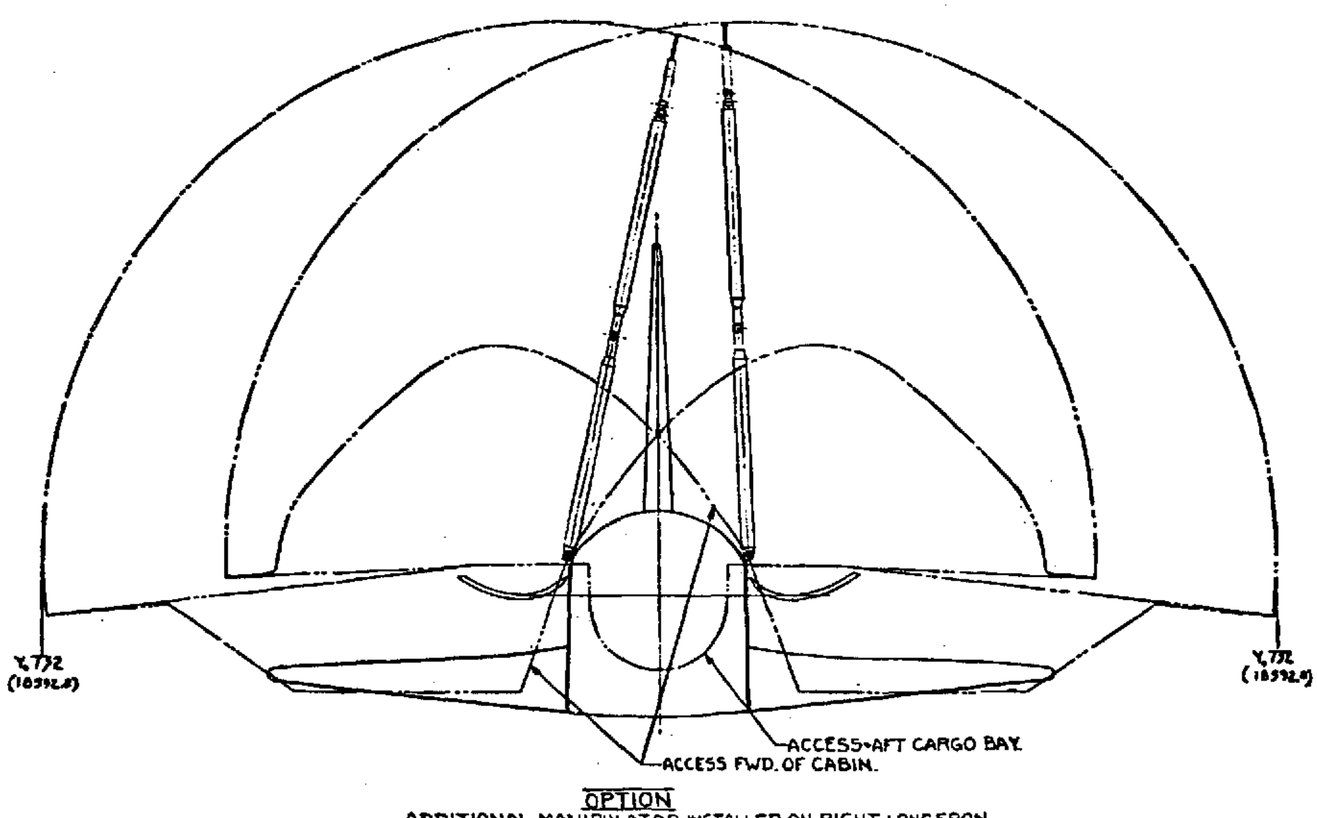


FIGURE B4.5: RMS Reach Envelope Orbiter Exterior (continued)



BODY VIEW LOOKING AFT



OPTION
ADDITIONAL MANIPULATOR INSTALLED ON RIGHT LONGERON.

FIGURE B4.5: RMS Reach Envelope Orbiter Exterior (continued)

RMS Physical and Dynamic Characteristics

The RMS physical and dynamic characteristics are as follows:

A. Physical Parameters

1. Longeron attachment locations:
   a. Primary Manipulator = X_o 680 (17,272.0 mm.), Y_o -108 (-2,743.2 mm.), Z_o 445 (11,304 mm.) deployed position
   b. Operational Manipulator = X_o 680 (17,272.0 mm.), Y_o 108 (2,743.2 mm.), Z_o 445 (11,304 mm.) deployed position
2. Manipulator arm and end effector total length = 15.240 m. (50 ft.).
3. Manipulator arm diameter = 381.0 mm. (15.0 in.) max.
4. Manipulator weight = TBD
5. Stowage location = X_o 680 (17,272.0 mm.), Y_o -89.4 (2,270.8 mm.), Z_o 446.0 (11,328.4 mm.).
6. Reach characteristics = X_o 580 (14,732.0 mm.), X_o -1180 (29,972.0 mm.)--in payload bay
7. Manipulator station end effector viewing limits = TBD

B. Maximum Payload Release Errors (Inertial)

1. Linear tip-off motion = TBD
2. Angular tip-off rate = TBD

C. Allowable Manipulator Arm Rates at Payload Contact

1. Maximum closing rate at contact = TBD
2. Maximum angular rate at contact = TBD

D. Allowable Orbiter Dynamics With Payload Attached to Arm

1. Orbiter limit cycle/rates =
   a. Roll ±1 deg
   b. Pitch ±1 deg
   c. Yaw ±1 deg
   d. Roll Rate ±.075 deg/sec
   e. Pitch Rate ±.075 deg/sec
   f. Yaw Rate ±.075 deg/sec
2. Orbiter maximum allowable accelerations =
   a. Roll TBD

b. Pitch TBD

c. Yaw TBD

E. Allowable Payload Dynamics Prior to Retrieval

1. Maximum limit cycle (inertial) = ± 1 deg about any axis
2. Maximum limit cycle rates (inertial) = ± 0.4 deg/sec about any axis
3. Allowable attach point or docking ring motion (relative) = ± 76.2 mm. (±3.0 in.)

F. End Effector Linear and Angular Position Capability TBD

Payload Deployment and Retrieval

For deployment the payload must provide (TBD)-type attach points for the manipulator located ± TBD inches from the payload c.g. Visual aids must be provided to facilitate mating of the payload attach points and the manipulator end effector.

For retrieval the payload must provide (TBD)-type attach points located ± TBD inches from the payload c.g. The payload shall be inertially or local vertically stabilized with maximum limit cycle rates of ±0.1 deg/sec. about any axis within a limit cycle which results in ±76 mm. (±3 in.) or less motion of the attach point.

The manipulator reach and viewing capabilities are illustrated in greater detail in Dwg. VL70-004145 for various X, Y and Z locations.

REMOTE MANIPULATOR SYSTEM FAILURE

RMS Failure Flow Chart

Figure B4.6 presents a logic diagram relative to an RMS failure. Since a jettison capability is required for the manipulator system, RMS failures must be considered. There are currently no backup systems to the RMS in the Shuttle Program. (Both the MMU and FFTS are viable candidates.) This logic diagram shows the possible role of an MMU in support of the RMS.

Typical MMU Mission Outline

The typical MMU mission outlined in this appendix involves a backup operation to the RMS for payload deployment and stowage of a failed RMS in the payload bay. Table B4-2 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task. Numerous payload servicing tasks can also be performed by the MMU while being restrained by the RMS. The MMU mission is baselined as a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU. Crewman no. 2 (CM2) supports CM1 from the payload bay. The MMU mission is initiated following airlock egress and terminated following ingress.

Translation Route and Travel Distance

A typical MMU translation route is shown in Figure B4.7. Table B4-3 shows the estimated travel distance for the mission, as well as direction changes, number of starts/stops, estimated velocity and Δvelocity requirements.

Total ΔV Required

The translation ΔV required for this particular MMU mission is approximately 6.36 m/sec (20.9 ft/sec). From M509 on-orbit experience, it was found that

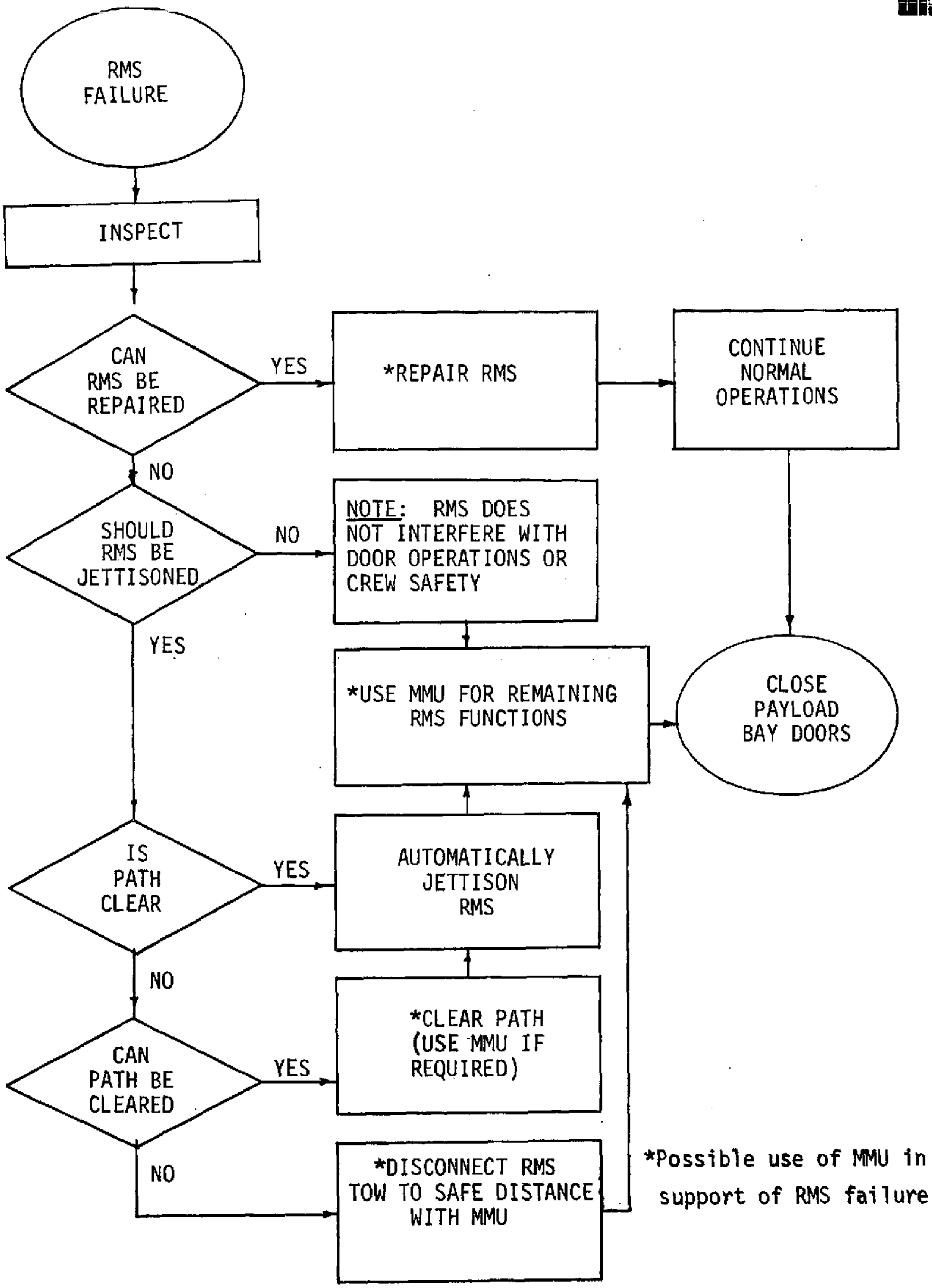


FIGURE B4.6: Flow Diagram of RMS Failure

TABLE B4.2: RMS Failure - MMU Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage	X	X		2.0
Checkout MMU	X			15.0
Don MMU and attach ancillary hardware	X	X	lights, tethers, cables, tools	15.0
Flight check MMU in bay on tether	X			15.0
Remove tether	X			1.0
Translate to payload attach point, attach cable*	X			5.0
Translate to RMS attach point, attach cable & release RMS	X			5.0
Maneuver payload safe distance from Orbiter	X			20.0
Position payload in proper orientation for operation	X			10.0
Release cable from payload	X			3.0
Return to RMS	X			5.0
Unlock each joint	X			15.0
Secure RMS in normal location for reentry	X	X		20.0
Translate to MMU stowage area	X	X		3.0
Doff and stow MMU and ancillary equipment	X	X		5.0
Ingress airlock - End EVA	X	X		2.0
*see MMU Performance and Control Requirements sheet-- this task				
			TOTAL TIME	143.0

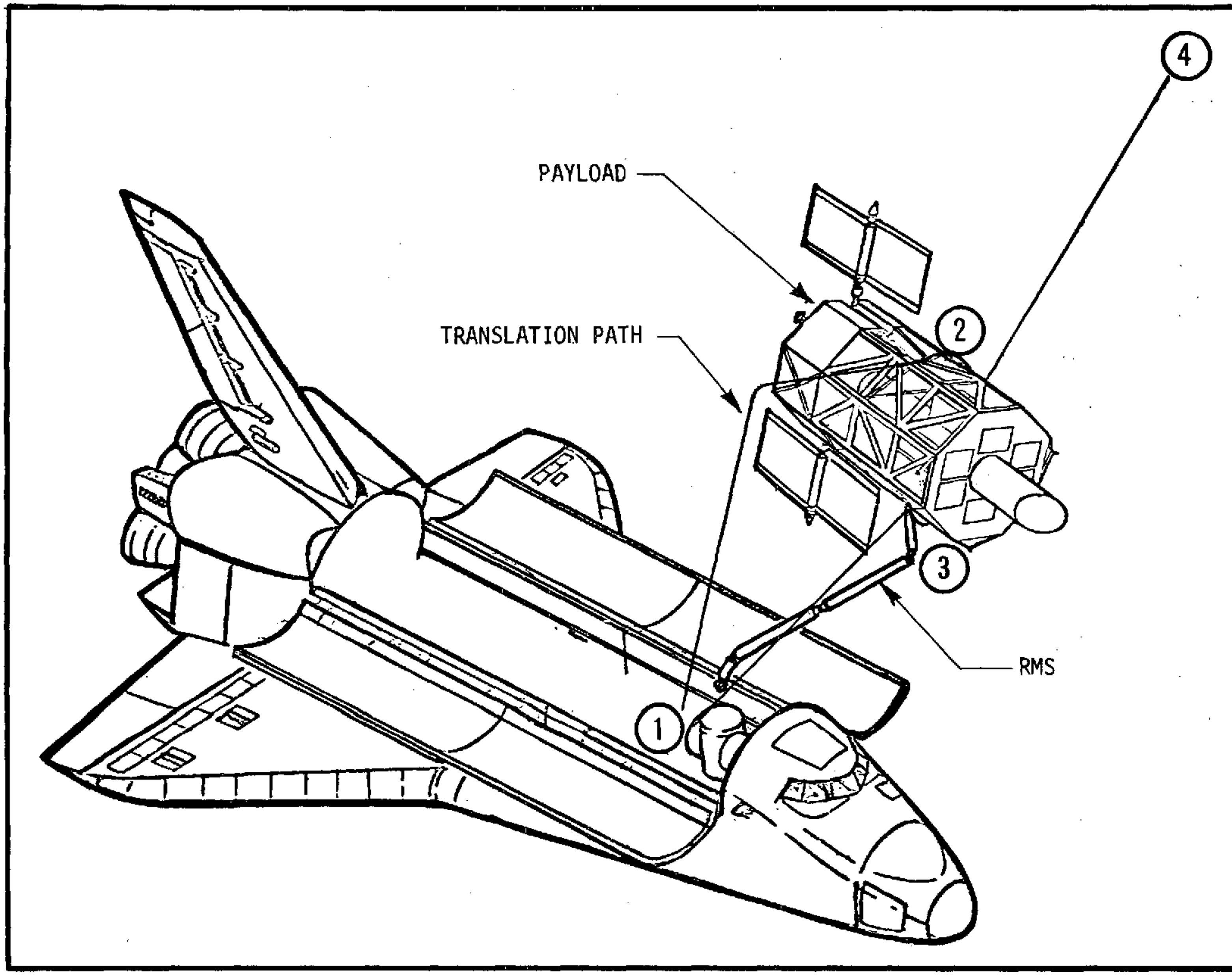


FIGURE B4.7: MMU Translation Route for RMS Failure

TABLE B4.3: MMU Requirements for RMS Failure

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
Flight check MMU	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
1 to 2 translate to payload cable attach point	18	(60)	15	30	120	4	.12	(.4)	.48	(1.6)
2 to 3 translate to RMS/ payload attachment point	12	(40)	90	180	90	2	.09	(.3)	.18	(0.6)
3 to 4 maneuver payload into operate position	92	(300)	30	90	120	4	.15	(.5)	.61	(2.0)
4 to 3 translate to RMS	92	(300)	15	90	180	2	.18	(.6)	.37	(1.2)
Unlock RMS joints	15	(50)	180	270	360	6	.09	(.3)	.55	(1.8)
Secure RMS in stowage location	15	(50)	80	160	160	6	.12	(.4)	.73	(2.4)
Translate to MMU stowage area	15	(50)	--	15	90	2	.12	(.4)	.24	(0.8)
	Assume Additional ΔV 6 ft/sec for Payload Maneuvering								1.83	(6.0)
TOTAL	305	1000	770	1195	1480	41	--	--	6.36	(20.9)
TRANSLATION ΔV + ROTATION ΔV →									12.72	(41.8)

the ΔV used for rotation is approximately equal to that required for translation. Therefore, the total ΔV for both translation and rotation is approximately 12.72 m/sec (41.8 ft/sec).

MMU PERFORMANCE AND CONTROL REQUIREMENTS

RMS SUPPORT

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	305 m.	1000 ft.
TOTAL VELOCITY CHANGE CAPABILITY	12.72 m/sec	41.8 ft/sec
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±3°	--
- ATTITUDE RATE PRECISION	±3°/sec	--
ACCELERATION (2)		
- TRANSLATION	$\leq .09$ m/sec^2	$\leq .3$ ft/sec^2
- ROTATION	>6°/sec^2	--
FORCE APPLICATIONS		
- LINEAR (3)	22.24 N	5 lbs.
- TORQUE (2)		

REMARKS

(1) Estimated accuracy required to allow a crewman to attach a cable to a payload interface point.

(2) Not critical for RMS support.

(3) This force may be required to deploy solar arrays, antennae and for service to the payloads. Exact forces are not available since payload hardware designs are not firm.

APPENDIX B5

PERSONNEL RESCUE

PERSONNEL RESCUE FROM SHUTTLE ORBITER

The orbital condition necessitating personnel rescue is simply one in which the Shuttle Orbiter is disabled and cannot safely reenter the earth's atmosphere. A second Orbiter vehicle will be launched in a rescue capacity to rendezvous and receive the transferring crew members from the disabled vehicle. The disabled Orbiter vehicle rescue hardware inventory will contain hardware and provisions to equip two crewmen, trained in EVA operations, with spacesuits and life support systems for conducting EVA transfer. The inventory will also contain rescue enclosures to ensure viable transfer of all additional crew members aboard the disabled vehicle.

Rescue via extravehicular activity may be accomplished from the Orbiter airlock or from the side hatch. The side hatch will be used only if the Orbiter payload bay doors cannot be opened. The Orbiter must be depressurized to use the side hatch. If the payload bay doors are operational, the preferred EVA rescue mode would utilize the Orbiter airlock with egress directly from the airlock or the EVA egress module, depending on the payload being carried.

Shuttle Orbiter Personnel Rescue Provisions

The Shuttle Orbiter provides EVA and rescue equipment and expendables for the basic 4-man crew plus additional expendables for 96 hours while awaiting rescue. Additional equipment and expendables for crew members in excess of 4 are made available by the payloads utilizing the Space Shuttle system.

The personnel rescue provisions carried aboard the Orbiter consist of the following: (1) systems to support nominal two-man EVAs, not dedicated to rescue operations; and (2) additional contingency systems for transferring crewmen externally between vehicles, dedicated to rescue support. The personnel equipment consists of the following:

- Spacesuits and support equipment--2 per Orbiter vehicle
- Liquid Cooling Garments--2 per Orbiter vehicle

- Extravehicular Life Support Systems--2 per Orbiter vehicle
- Personnel Rescue Systems--one for each crew member above 2

Shuttle Rescue Baseline

The primary on-orbit personnel rescue operation is considered one of transferring crewmen from a disabled Orbiter vehicle to another rescuing Orbiter. The method and systems used depend upon the status of the disabled Orbiter. If the disabled vehicle is stable, the rescue will be via extravehicular (EV) transfer using a transfer system connected between the disabled and rescue vehicles (e.g., transfer tethers, life line, RMS). If the disabled Orbiter is unstable to the extent that a transfer system cannot be connected between the vehicles, a "bail-out" free-space pickup or one using MMUs may be required.

EVA Rescue Support Systems and Techniques

A number of techniques which will utilize equipment being developed for Shuttle Program applications and also systems unique to personnel rescue are being considered for EVA rescue support. Equipment and systems currently being studied include the following:

- Orbiter remote manipulator system
- Transfer system deployed between vehicles
- Manned Maneuvering Units (Figure B5.1).

In utilizing each of the systems and techniques, two crewmen from the disabled Orbiter will have a full complement of spacesuit and life support provisions. The additional crew members will be transferred while contained in the personnel rescue systems (PRS). Concepts for utilizing the MMU in a rescue support capacity include the following:

(1) Towing the PRS units between Orbiter vehicles, either in a free-flying mode or utilizing a tether line for control and safety. The concept is depicted in Figure B5.2.

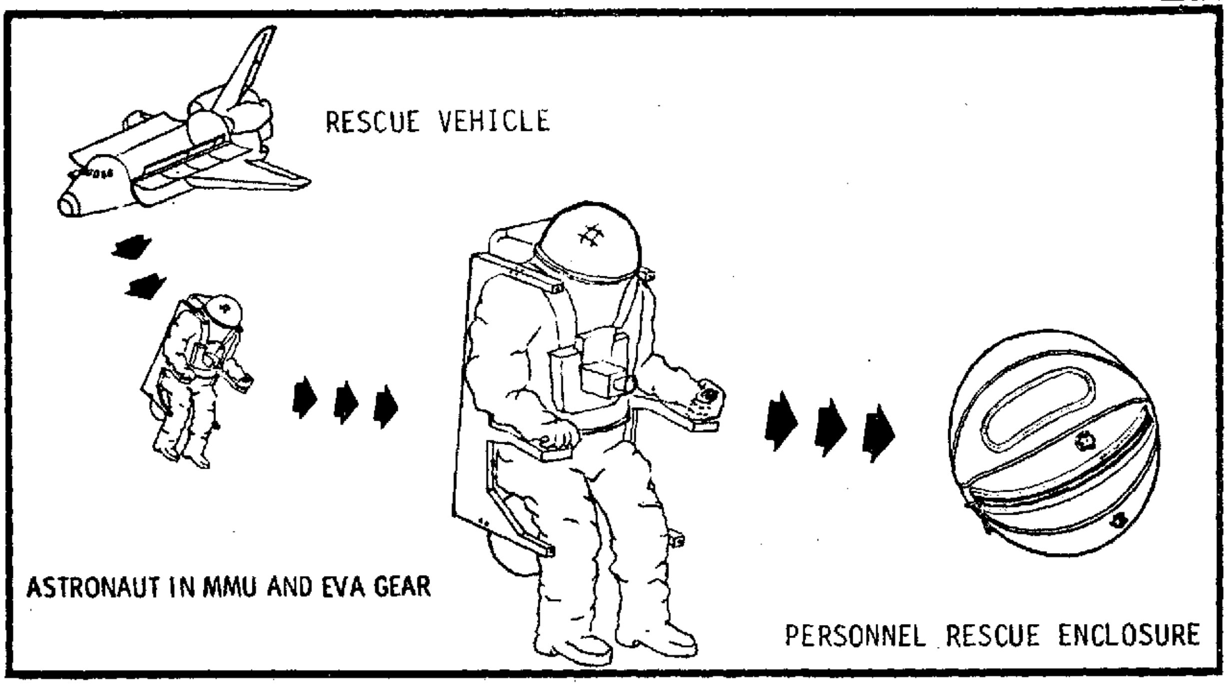


FIGURE B5.1: Artist's Concept of Manned Maneuvering Unit Shuttle Rescue Application

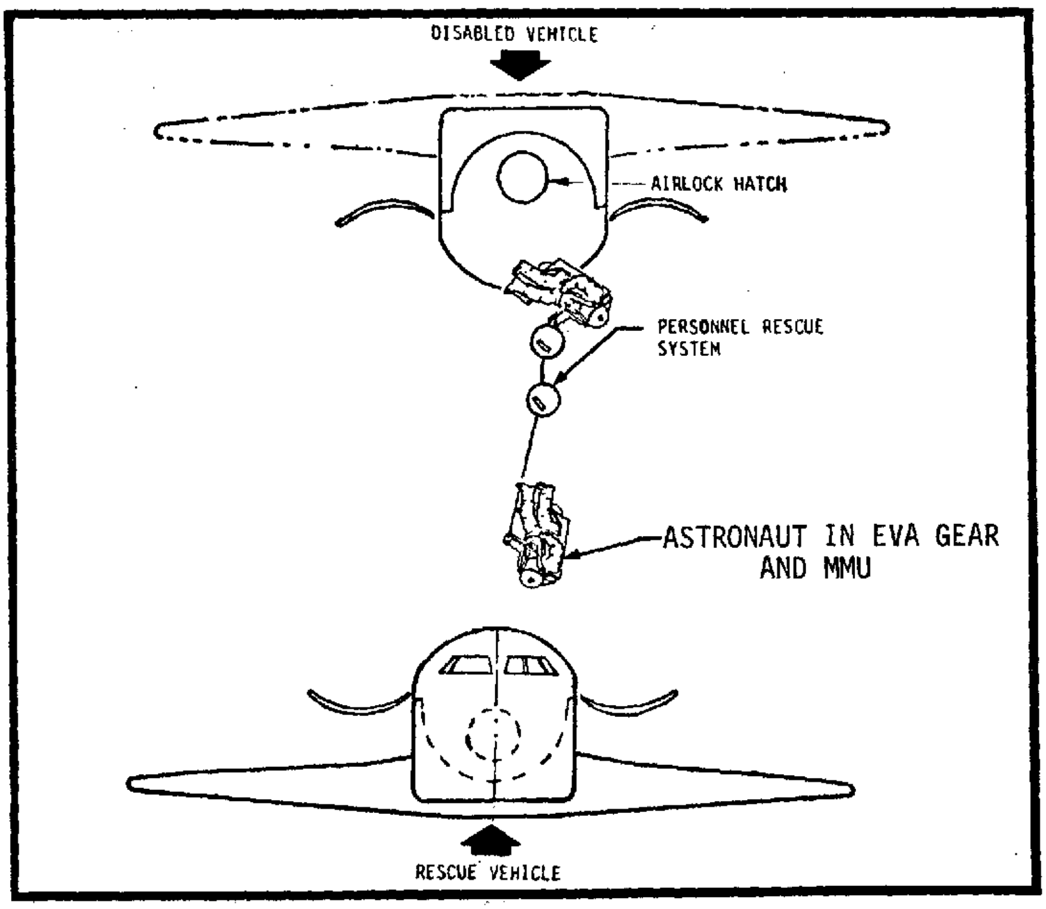


FIGURE B5.2: Manned Maneuvering Unit/PRS Rescue Technique

(2) MMU retrieval of crewman from stable disabled Orbiter side or airlock hatches.

(3) Free space pickup of spacesuited crewmen and PRS units from an unstable Orbiter following bail-out operations. The MMU may be the only method of retrieving personnel escaping from a disabled Orbiter in a situation where the Orbiter requires a bail-out procedure due to uncontrollable vehicle perturbations. If the disabled vehicle perturbations are of a magnitude which inhibits "controlled" bail-out, the MMU may be required to perform random retrieval operations. A free space pickup rescue concept is shown in Figure B5.3, and a representative bail-out rescue scenario provided.

The free space personnel pickup rescue technique represents a more critical mode relative to precise and timely rescue operations, and the probability of success may be reduced when compared to other concepts. However, it is a viable technique when the disabled Orbiter is too unstable to effect transfer via other methods.

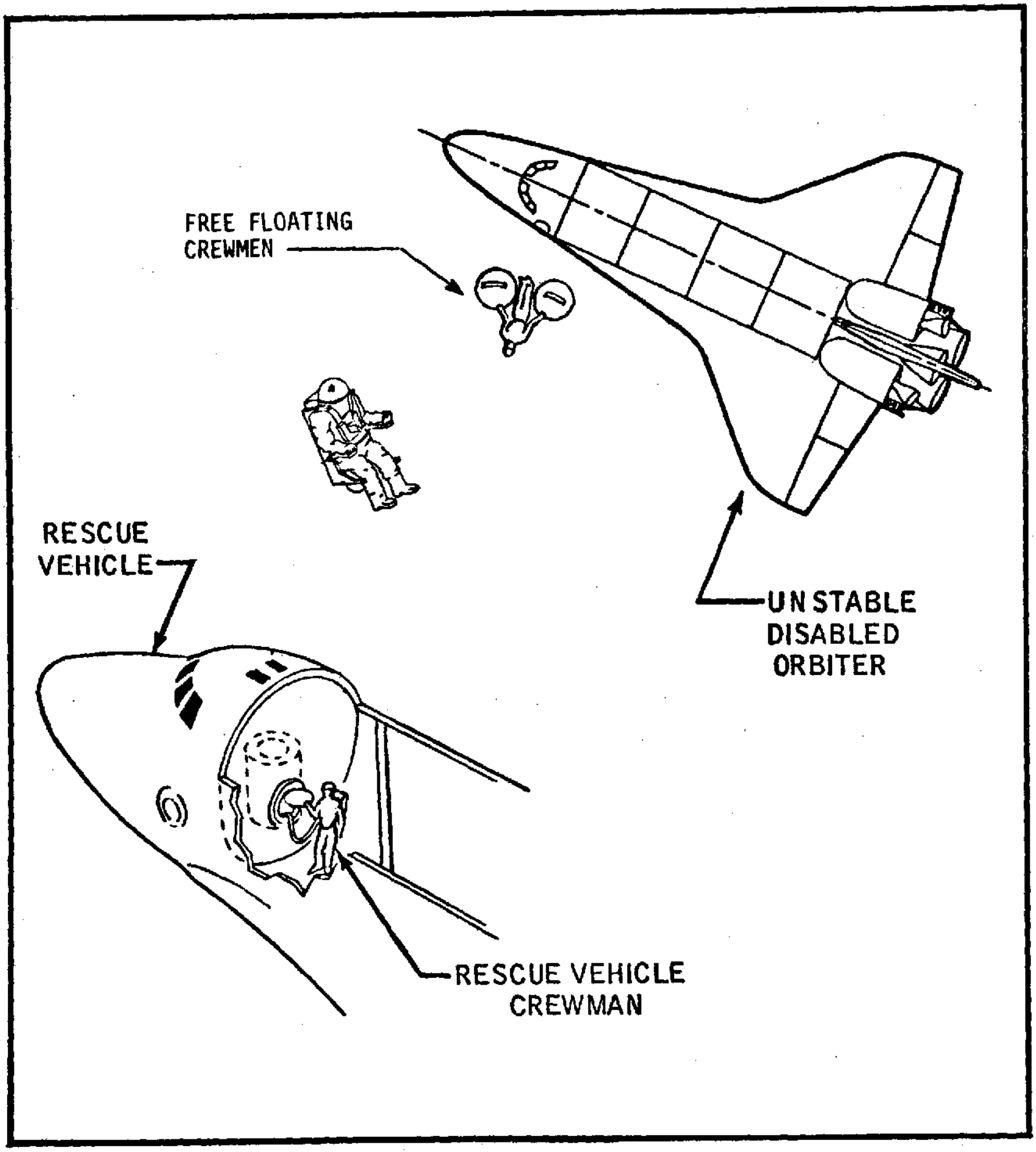


FIGURE B5.3: Translation Route for MMU Rescue

PERSONNEL RESCUE

MMU Personnel Rescue Scenario

A representative MMU personnel rescue scenario is presented based on a "worst case" condition in which the disabled Orbiter is unstable to the extent that a bail-out mode is mandatory. The MMU crewman from the rescue vehicle is awaiting rescue operations with all preparatory tasks completed. The scenario with quantitative data is provided.

MMU/EVA Rescue Timeline

The typical MMU mission outlined in this appendix involves a rescue of crewmen from a disabled Orbiter vehicle. Table B5-1 contains a sequenced description of the tasks/operations, equipment required and estimated time requirements for each task.

The MMU mission is baselined as a two-EVA crewman operation. It is recommended that two MMUs be used for bail-out rescue missions. MMU utilization during rescue missions in which the two Orbiter vehicles are connected via a tether or lifeline may require only one MMU.

Translation Route and Travel Distance

A typical MMU translation is shown in Figure B5.3. Table B5-2 shows the estimated travel distance and other parameters associated with MMU requirements, including direction changes, number of starts/stops, velocity and Δvelocity.

Total ΔV Required

The translation ΔV required for this mission is approximately 7.60 m/sec (25.0 ft/sec). From M509 on-orbit experience, it was found that the ΔV used for

TABLE B5-1: MMU/EVA Rescue Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		2.0
Checkout MMUs (2)	X			15.0
Don MMU	X	X		15.0
Flight check MMU in payload bay	X			15.0
Egress payload bay and translate from Orbiter toward PRS	X			5.0
Translate to PRS**	X			2.4
Capture PRS or EMU clad crewman (assume single capture)	X			1.0
Return rescued crewmen to airlock of rescue vehicle				8.4
Recharge or change-out propellant tank (as required)	X	X		15.0
Repeat above procedure to accomplish safe transfer of 4 crewmen	X			35.4*
Translate to MMU stowage area	X			3.0
Doff and secure MMU and support hardware	X	X		5.0
Ingress airlock - end EVA	X	X		2.0
**see MMU Performance and Control Requirements sheet--this task				
			TOTAL TIME	126.2

*Add 11.8 min. for an additional 3 rescue sequences

TABLE B5-2: MMU Requirements for Rescue

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
Note: Assume all MMU checkouts have been completed and the rescue MMU has a full supply of propellant										
Translate to PRS	296	(970)		30	360	2	3.1	(10.0)	4.88	(16.0)
Capture PRS/EMU crewman	24	(80)	45	30	120	5	.06	(0.2)	.61	(2.0)
Return to airlock with crewman	320	(1050	30	30	180	2	.61	(2.0)	2.14	(7.0)
Note: MMU propellant supply may require re-charge between rescues. Repeat procedure for remaining crewmen rescue										
TOTAL	640	2100	660	720	3000	66	--	--	7.63	(25.0)
					TRANSLATION ΔV + ROTATION ΔV →				15.26	(50.0)*

*Required for each PRS rescue attempt

rotation is approximately equal to that required for translation. Therefore, the total ΔV for both translation and rotation is approximately 15.26 m/sec (50.0 ft/sec).

MMU PERSONNEL RESCUE SCENARIO

The MMU personnel rescue scenario developed below is based on the following simplified conditions and orbital mechanics:

> A disabled Orbiter is unstable to an extent that rescue equipment cannot be connected between the Orbiter vehicles. A "bail-out" mode is the only rescue possibility. The personnel being rescued occupy personnel rescue systems (PRS) and are "ejected" from the disabled vehicle at a velocity of 1.2 m/sec (4.0 ft/sec). The PRS is 122 m (400 ft) from the rescuing MMU and traveling away from the rescuing Orbiter.

For safety considerations the MMU is assumed not to exceed 3.05 m/sec (10.0 ft/sec) during rescue operations. The MMU will accelerate to 3.05 m/sec (10.0 ft/sec) at maximum thrust, maintain 3.05 m/sec (10.0 ft/sec) until near the PRS, decelerate to 1.2 m/sec (4.0 ft/sec), capture and stabilize the PRS, and decelerate the MMU-PRS combination to zero velocity. The MMU conducts a visual inspection of the PRS and reports on personnel status prior to returning to the rescue Orbiter. The MMU-PRS will accelerate at .15 ft/sec^2 until a velocity of 2.0 ft/sec is reached. The MMU with crewman and complete support equipment is assumed to weigh 2380 N (535 lbs) and to be equipped with translational thrusters (in three axes) of 19.3 N (4.75 lbf) capacity.

<u>Under the above conditions</u>:

Maximum acceleration is given by:

$$F = ma \qquad \text{where} \quad m = \frac{W}{g} \quad \text{or} \quad m = \frac{535}{32.2} \; = \; 16.6 \text{ slug-ft}^2$$

$$\therefore \; a = \frac{4.75}{16.6} \; = \; .286 \text{ ft/sec}^2.$$

The MMU reaches a velocity of 10 ft/sec in:

$$v = at \qquad \text{or} \qquad t = \frac{10}{.286} \; = \; 35 \text{ sec.}$$

and has traveled $s = \frac{1}{2} at^2 = \frac{.286\ (35)^2}{2} = 175$ ft.

The PRS has traveled in 35 sec: $s = vt = 4(35) = 140$ ft. The distance now separating the MMU and PRS is $(400 + 175 - 140) = 365$ ft.

The distance for the MMU to reach the PRS is given by:

$s_1 = v_1 t_1$ and $s_2 = v_2 t_2$ where the subscript $_1$ refers to the MMU and the subscript $_2$ refers to the PRS.

At this point, $t_1 = t_2 = \frac{s_1}{v_1}$; $s_2 = s_1 - 365$; $s_1 = v_2 \frac{s_1}{v_1} + 365$; $s_1 = \frac{3650}{6} = 608$ ft.

The time required is $t_1 = 60.8$ sec.

The time required to decelerate at .286 ft/sec^2 from 10 ft/sec to 4 ft/sec is given by:

$v_2^2 = v_1^2 + 2as$; $s = \frac{84}{2\ (.286)} = 147$ ft. The time is derived from

$s = \frac{1}{2} at^2$; $t = 32.0$ sec.

Now assume 20 seconds to position and capture the PRS which will take 80 ft. at 4 ft/sec constant velocity. The MMU must now decelerate the MMU-PRS system from 4 ft/sec. Given the total mass of the MMU-PRS system to be 740 lbs., the deceleration capability is

$$a = \frac{F}{m} \quad \text{where} \quad m = \frac{740}{32.2} = 23.0 \text{ slug-ft}^2$$

$$a = \frac{4.75}{23.0} = .207 \text{ ft/sec}^2 \text{ (deceleration)}$$

$v^2 = v_0^2 + 2as$; $s = \frac{16}{2\ (.207)} = 39$ ft.; $t = \frac{v}{a} = 19.3$ sec.

Therefore, the time and distance required to rendezvous, capture and decelerate the PRS are:

$$\text{Distance} = s = (175 + 608 + 147 + 80 + 39) = 1049 \text{ ft.}$$

$$\text{Time} = t = (35.0 + 60.8 + 32.0 + 20.0 + 19.3) = 167.1 \text{ sec.}$$

Assume the MMU crewman expends 90 seconds to inspect the PRS and report the content status, followed by an acceleration of .15 ft/sec^2 until a velocity of 2.0 ft/sec is attained for the return trip to the rescue vehicle. The time to accelerate to 2.0 ft/sec is

$$v = at \quad \text{or} \quad t = \frac{2}{.15} = 13.3 \text{ sec.}$$

and the distance traveled is

$$s = \frac{1}{2} at^2 = 13.3 \text{ ft.}$$

The remaining distance to reach the rescue Orbiter is 1049 - 13.3 ≈ 1016 ft. at a rate of 2.0 ft/sec. (Assume the same deceleration of .15 ft/sec^2 at the rescue Orbiter to give a total travel distance at 2.0 ft/sec of 1002 ft.) The time required to travel 1002 ft. is

$$s = vt \quad \text{or} \quad t = \frac{1002}{2} = 501.0 \text{ sec.}$$

Finally, the total time and distance required to rescue the PRS crewman under the above assumed conditions are

$$\text{Distance} = s_{tot} = (1049 + 1049) \approx 2100 \text{ ft.}$$

$$\text{Time} = t_{tot} = 167.1 + 13.3(2) + 501.0 = 694.7 \text{ sec.}$$

CONCLUSION:

Design of the MMU thruster system capable of .5 to .6 ft/sec^2 acceleration would enhance the PRS/EMU rescue attempts through a more rapid access capability. This capability should be considered relative to MMU systems impact (e.g., weight, thrusters, propellant, controls) for Space Shuttle application. The design of systems for future use, such as the assembly and maintenance of large structures in space, may require 3 - 4 crewmen outside the spacecraft separated by distances in excess of 1/2 mile. An MMU thruster system malfunction may necessitate rescue from a second MMU. The capability to rapidly accelerate and decelerate would be advantageous under such conditions. A manually actuated emergency system to regulate (increase) the pressure to the thrusters for use only in contingency situations should be considered.

MMU PERFORMANCE AND CONTROL REQUIREMENTS

	RESCUE	
PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	640 m.	2100 ft.
TOTAL VELOCITY CHANGE CAPABILITY	15.3 m/sec	50.0 ft/sec
STATION KEEPING ACCURACY ①		
- TRANSLATION HOLD PRECISION	±.03 m.	±.1 ft.*
- VELOCITY PRECISION	±.015 m/sec	±.05 ft/sec*
- ATTITUDE HOLD PRECISION ④	±4°	--
- ATTITUDE RATE PRECISION	±1°/sec*	--
ACCELERATION ②		
- TRANSLATION	$\geq$15 m/sec^2	$\geq$.5 ft/sec^2
- ROTATION	$\geq$10°/sec^2	--
FORCE APPLICATIONS ③		
- LINEAR		
- TORQUE		

REMARKS

① Estimated accuracy required to capture and stabilize a PRS.

② To reduce timeline and enhance rescue operations in the bail-out mode.

③ Not critical for this task.

④ Precision may be required to deactivate controls on an unstable MMU from a second MMU during free-space rescue attempts.

* MMU design drivers from applications analysis

APPENDIX B6

GENERAL INFORMATION

(Portions of this appendix are excerpted from NASA JSC 07700, Vol. 14, Space Shuttle System Payload Accommodations Document)

PAYLOAD CONTAMINATION

CONTAMINANT MODES:

- DEPOSITION ON SENSORS
- CONTAMINATION OF LOCAL ENVIRONMENT
- SCATTERING
- ADSORPTION/EMISSION

CONTAMINANT TYPES:

- PARTICLES
- WATER VAPOR
- EVA LEAKAGE
- OUTGASSING

CONTAMINANT SOURCES*

PARTICLES

- Payload - 600 particles/in^2/day--due to dust fall (clean class 10,000)
- Orbiter - Large, complex surface area--exposed to particles and dust during ground operations
- Payload Deployment - From operation of cargo bay doors and manipulator
- EVA Crewman - Minimal surface area approximately 1/500 of Orbiter

WATER

- EVA Leakage - 5.4×10^{-4} lb/hr
- Venting PLSS - 1.72 lb/hr
- Cabin Leakage - .0185 lb/hr
- Shuttle ACPS - 50 lb/hr (includes NH_3 & H_2O)

GASSES

- EVA Leakage - .016 lb/hr
- Cabin Leakage - .4 lb/hr

*INFORMATION FROM SPACE SHUTTLE EVA CONTAMINATION STUDY, HAMILTON STANDARD, PRESENTATION TO NASA-MSC, FEBRUARY 1973

TABLE B6-1: Contaminant/Mode Summary*

	DEPOSITION	LOCAL CONTAMINATION	SCATTERING	ABSORPTION EMISSION
PARTICLES	LOW ENERGY SENSORS-	NO PROBLEM CLEAR IN ~3 MIN.	LOW ENERGY SENSORS- CLEAR IN 1-35 HR	LOW ENERGY SENSORS- CLEAR IN 1-35 HR
WATER VAPOR	SENSORS < 150°K	NO PROBLEM CLEAR IN ~1/2 HR	NO PROBLEM CLEAR IN ~1/2 HR	NO PROBLEM CLEAR IN 1/2 HR
EVA LEAKAGE	NO PROBLEM APART FROM ORBITER	NO PROBLEM	NO PROBLEM	NO PROBLEM
OUTGASSING	NO PROBLEM APART FROM WATER VAPOR	NO PROBLEM	NO PROBLEM	NO PROBLEM

*INFORMATION FROM SPACE SHUTTLE EVA CONTAMINATION STUDY, HAMILTON STANDARD, PRESENTATION TO NASA-MSC, FEBRUARY 1973.

TABLE B6-1: Contaminant/Mode Summary (continued)

CONCLUSIONS*

- AN H_2O VENTING PLSS AND EVA LEAKAGE OF 100 SCC/MIN IS A USABLE COMBINATION FOR PERFORMING SHUTTLE EVA.
- ON 7 SHUTTLE FLIGHTS THE PAYLOAD CONTAMINANT SHIELDS MUST BE CLOSED DURING EVA TO PROTECT SENSORS AT ~4°K, REGARDLESS OF EVA SYSTEM TYPE.
- ON 81 SHUTTLE FLIGHTS THE SHIELDS MUST BE CLOSED DURING EVA TO PROTECT THE INSTRUMENTS FROM PARTICLE DEPOSITION FROM EVA EQUIPMENT.
- THE SHIELDS MUST ALSO REMAIN CLOSED DURING THE TIME THE PAYLOAD SHEDS PARTICLES AND THE ORBITER SHEDS PARTICLES AND OTHER EFFLUENTS.
- ON 8 OF THE 81 FLIGHTS. A WAIT OF 1-35 HOURS MAY BE REQUIRED FOR PARTICLES TO DISAPPEAR IF MEASUREMENTS ARE TO BE MADE THROUGH THE PARTICLE WAKE.

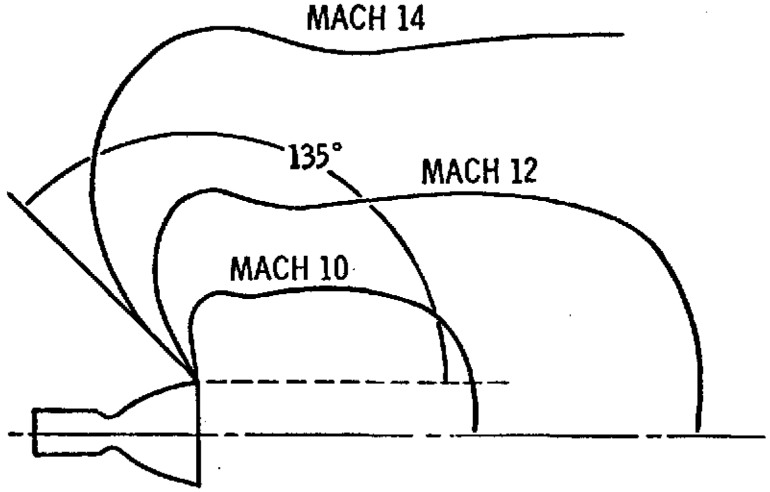
*INFORMATION FROM <u>SPACE SHUTTLE EVA CONTAMINATION STUDY</u>, HAMILTON STANDARD, PRESENTATION TO NASA-MSC, FEBRUARY 1973

ORBITER PLUME ENVELOPE AND CONSTITUENTS

Reaction Control System Plume Environment: The Reaction Control System (RCS) employs bipropellant thrusters using monomethylhydrazine (MMH) as the fuel and nitrogen tetroxide (N_2O_4) as the oxidizer. Two thruster sizes are used: (1) main RCS engine operating at a rated vacuum thrust of 950 pounds to provide attitude control and translational capability; and (2) vernier RCS operating at a rated vacuum thrust of 25 pounds to provide more precise attitude hold capability.

Main RCS Thruster Plume: There are 14 main engines located in the forward RCS modules and 24 in the OMS pods. Figure B6.1 shows the gas plume flow field and constituents of the combustion products for a main engine. The mass fraction, major constituents, sizes and potential contamination are listed on the right of the figure. Figure B6.2 shows the 95 percent streamline of the gaseous phase plume. Figure B6.3 shows the RCS thruster 95 percent plume geometry.

Vernier RCS Thruster Plume: The vernier RCS consists of six 25 pound thrust engines. Two are located in the forward RCS module adjacent to the main RCS thrusters (one on each side) and fire in the down (-z) direction. Four (two on each side) are located aft on the OMS pods. Two fire sideways, one in the +y and one in the -y direction, the other two fire in the downward (-z) direction. Figure B6.4 shows the vernier thruster 95 percent plume geometry.



COMBUSTION PRODUCTS

MASS FRACTION = 90.5%
MAJOR CONSTITUENTS: N_2, H_2O, CO, CO_2, H_2, ETC
SIZE - MOLECULAR (10^{-4} MICRONS)
POTENTIAL CONTAMINATION - CONDENSATES, HEAT, PRESSURE

UNBURNED VAPOR

MASS FRACTION = .02%
SIZE = 1 - 2 MICRONS
POTENTIAL CONTAMINATION - SMOKE-LIKE DEPOSITS

- TYPICAL 900 LB (409 Kb) RCS ENGINE
- COLD STARTS
- GAS VELOCITY = 11,000 FPS (335.3 M/S)

FIGURE B6.1: RCS Gas Plume Flow Field and Constituents

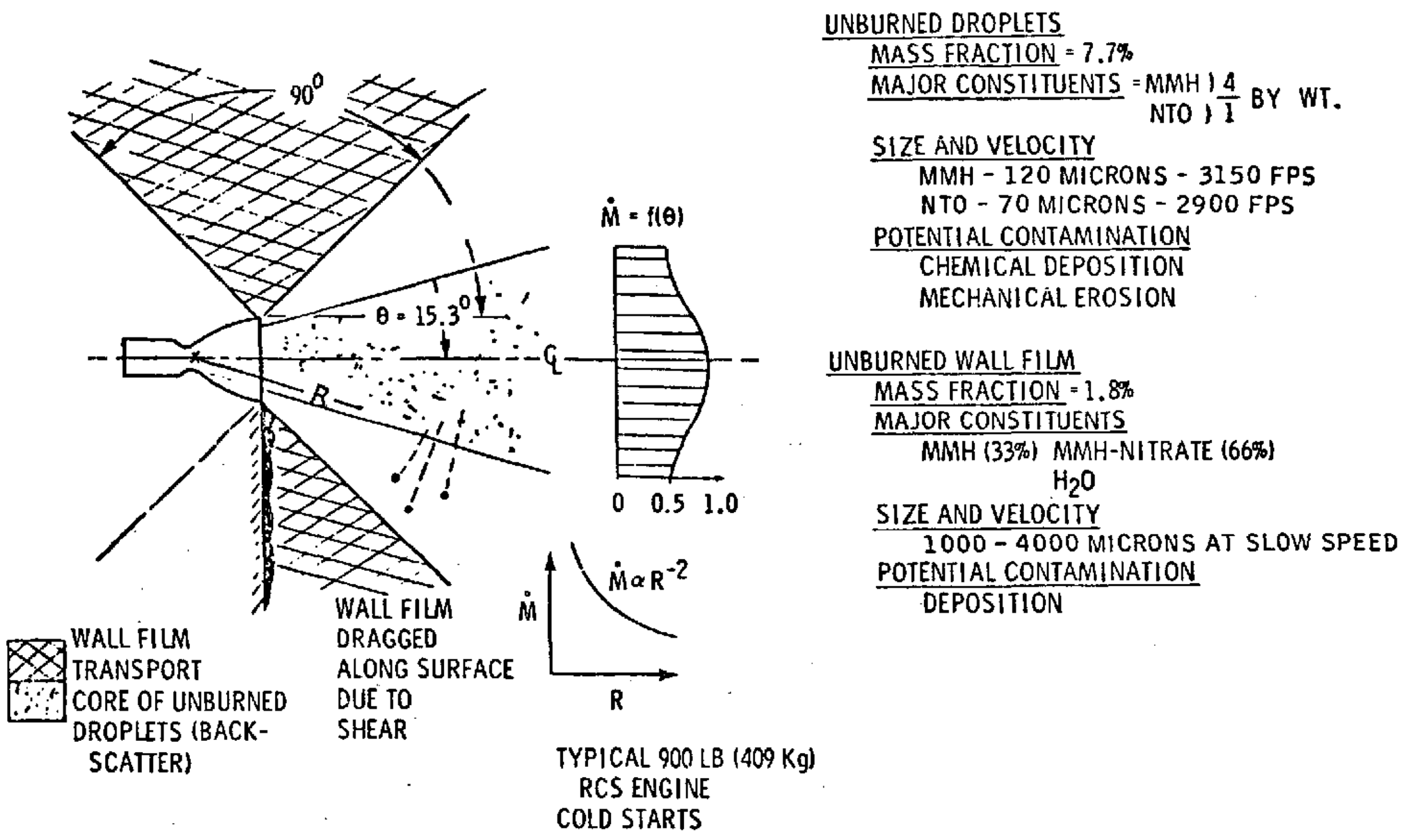


FIGURE B6.2: RCS 95% Streamline of the Gaseous Phase Plume

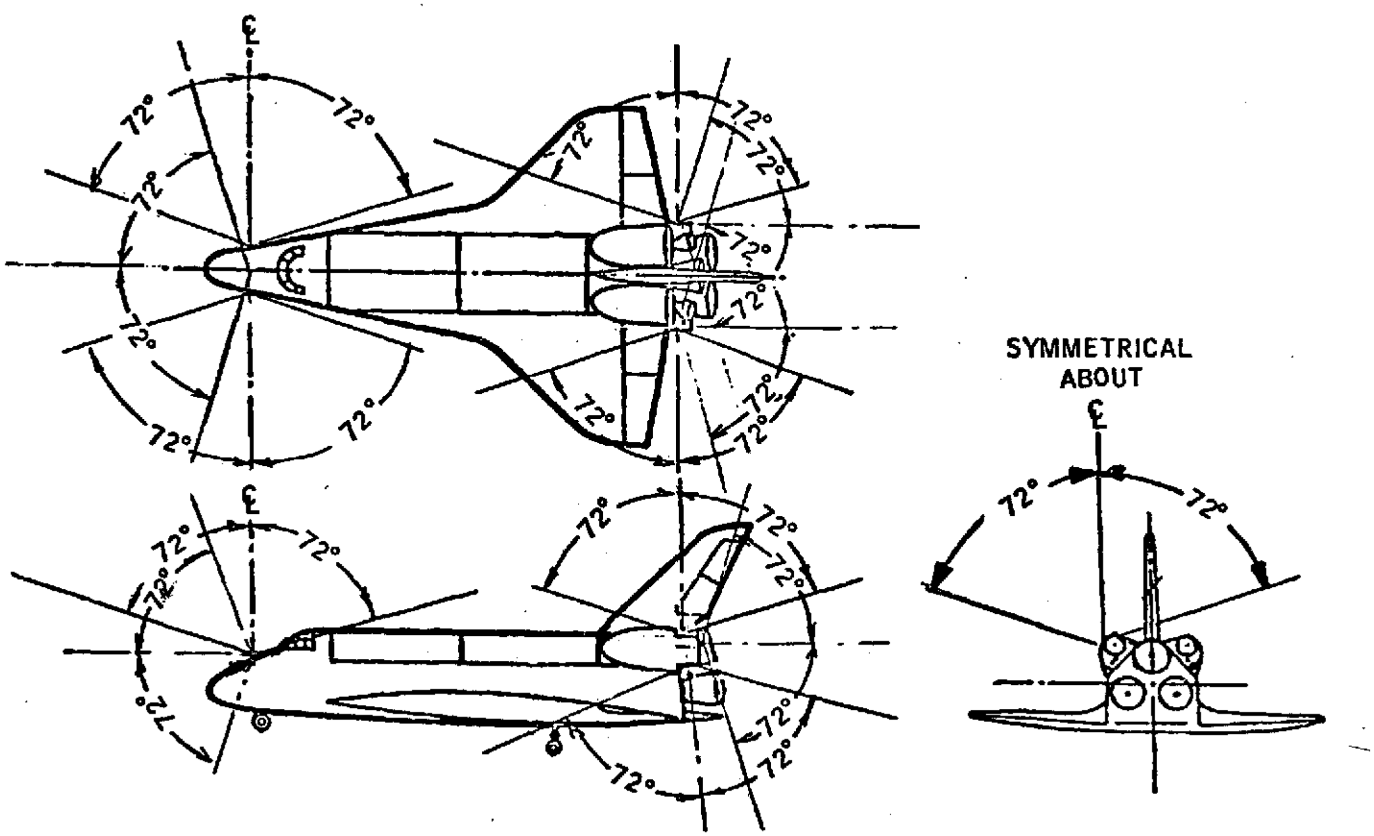


FIGURE B6.3: RCS 95% Gas Phase Plume Envelope

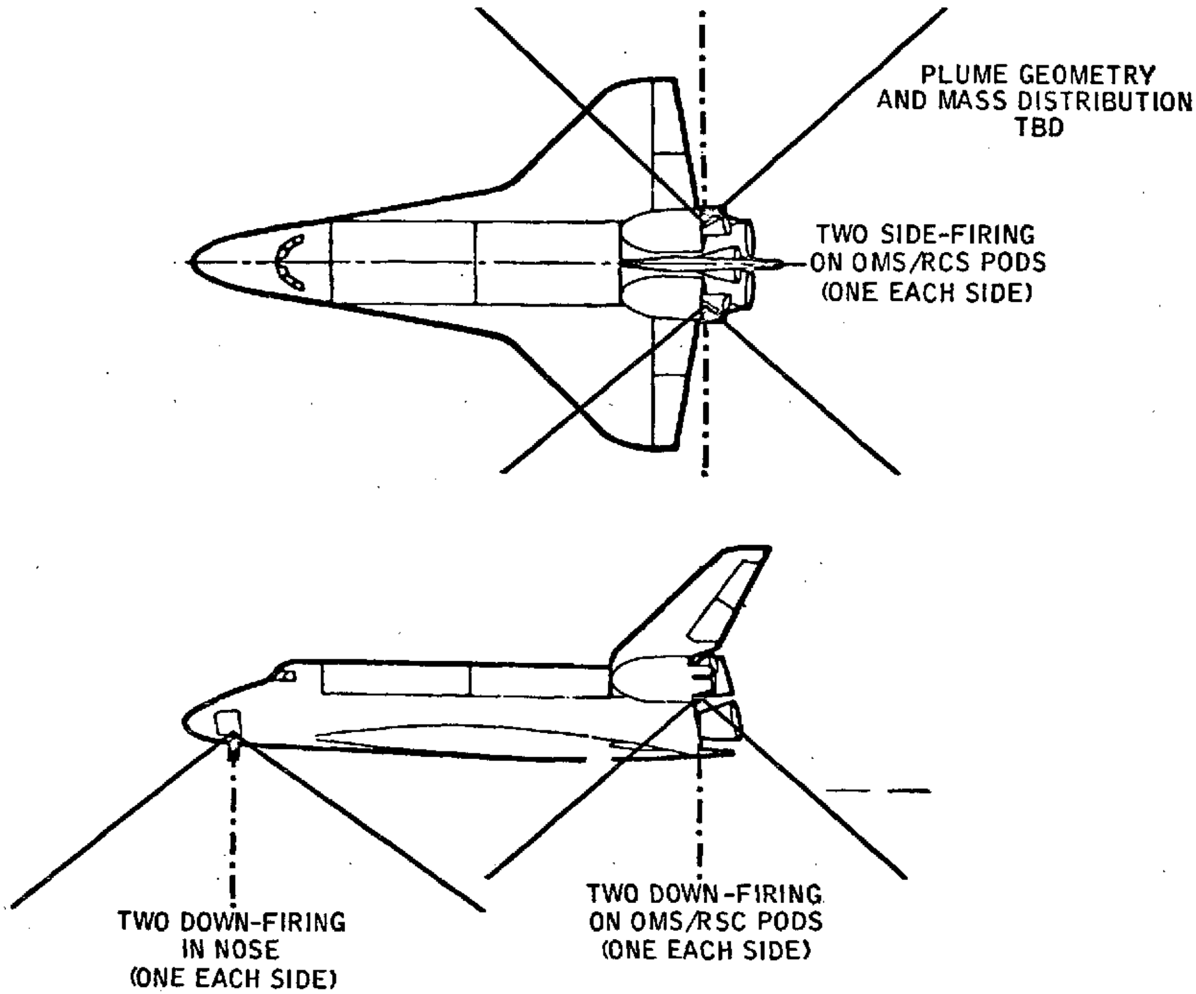


FIGURE B6.4: Vernier RCS 95% Gas Phase Plume Envelope

TABLE B6-2: Effect of Orbital Altitude on RCS Vernier Propellant Usage For Payload Pointing with Various Orbiter Orientations (per axis deadband of ±0.1 deg)

Orientation	Propellant Usage, lbs/Orbit (KG/Orbit)		
	100 NMI(185KM)	200 NMI(370KM)	500 NMI(926KM)
Y-Pop Z-Local Vertical	0.7 (0.318)	0.6 (0.272)	0.6 (0.272)
Y-Pop Inertial	4.2 (1.92)	3.9 (1.77)	3.6 (1.63)
Z-Pop Inertial	13.6 (7.16)	5.4 (2.45)	4.6 (2.09)
X-Pop Inertial	13.7 (6.21)	1.0 (.453)	0.8 (.363)

TABLE B6-3: RCS Propellant Usage for Orbiter Single Axis and Sequential Three-Axis Automatic Maneuvers as a Function of Maneuver Rate with the 950 lb. RCS Thruster

Maneuver Rate, Deg/Sec	Propellant, lbs			
	Roll	Pitch	Yaw	Total
0.25	2.9	5.1	7.2	15.2
0.5	5.1	10.7	13.4	29.2
0.75	7.3	13.8	19.1	40.2
1.0	9.5	17.5	25.3	52.3

TABLE B6-4: RCS Propellant Usage for Orbiter Single Axis and Sequential Three-Axis Automatic Maneuvers with the 25 lb Vernier Thrusters

Maneuver (1)		Single Axis Prop Usage, lb			Total Sequential 3 Axis (IB)
Rate Deg/Sec	ARC (1) (Deg)	Roll	Pitch	Yaw	
.001	.5	0.14	0.18	0.22	0.54
.01	5	.28	.38	.28	.94
.033	5	.76	.92	1.02	2.70

Note:

(1) The propellant usage at these small maneuver rates varies with the maneuver ARC as well as with rate because of the effects of gravity gradient torque with time. These values, therefore, apply to very small maneuver arcs.

TABLE B6-5: Distribution of RCS Propellants for Rotational Maneuvers

Maneuver Axis	Aft, %	Forward, %
Roll	100	0
Pitch	50	50
Yaw	50	50

APPENDIX C

AUTOMATED PAYLOAD ANALYSES

APPENDIX C

TABLE OF CONTENTS

APPENDIX C INTRODUCTION

Appendix C contains informal data used in identifying and supporting the potential MMU missions selected by the contractor as representative MMU applications to the automated payloads. Initially, a review of 81 automated payloads was conducted (see Table C-1). Three automated payloads were selected for detailed applications analysis. Supporting data are provided for these representative MMU missions and include:

- Automated payloads analysis sheets
- Preliminary mission description and timelines
- MMU mission scenarios including delta velocity requirements
- Performance and control requirements charts
- Calculations for supporting MMU performance and control requirements

In developing the typical MMU scenarios, each mission was based on two crewmen for conducting EVAs; however, the MMU systems and supporting hardware will be designed for operation by a single suited crewman, and one-man EVAs may be allowed, if necessary, for contingency situations.

APPENDIX C1

LIST OF AUTOMATED PAYLOADS

AND THEIR MMU APPLICATIONS

LIST OF AUTOMATED PAYLOADS REVIEWED

ASTRONOMY

AS-01-A — Large Space Telescope
AS-02-A — Extra Coronal Lyman Alpha Explorer
AS-03-A — Cosmic Background Explorer
AS-05-A — Advanced Radio Explorer
AS-07-A — 3m Ambient Temperature IR Telescope
AS-11-A — 1.5m IR Telescope
AS-13-A — UV Survey Telescope
AS-14-A — 1.0m UV-Optical Telescope
AS-16-A — Large Radio Observatory Array (LROA)
AS-17-A — 30m IR Interferometer

HIGH ENERGY ASTROPHYSICS

HE-01-A — Large X-Ray Telescope Facility
HE-03-A — Extended X-Ray Survey
HE-05-A — High Latitude Cosmic Ray Survey
HE-07-A — Small High Energy Satellite
HE-08-A — Large High Energy Observatory A (Gamma Ray)
HE-09-A — Large High Energy Observatory B (Magnetic Spectrometer)
HE-10-A — Large High Energy Observatory C (Nuclear Calorimeter)
HE-11-A — Large High Energy Observatory D (1.2m X-Ray Telescope)
HE-12-A — Cosmic Ray Laboratory

SOLAR PHYSICS

SO-02-A — Large Solar Observatory
SO-03-A — Solar Maximum Mission

ATMOSPHERIC AND SPACE PHYSICS

AP-10-A — Upper Atmosphere Explorer
AP-02-A — Medium Altitude Explorer
AP-03-A — High Altitude Explorer
AP-04-A — Gravity and Relativity Satellite - LEO
AP-05-A — Environmental Perturbation Satellite - Mission A
AP-06-A — Gravity and Relativity Satellite - Solar
AP-07-A — Environmental Perturbation Satellite - Mission B
AP-08-A — Heliocentric and Interstellar Spacecraft

LIST OF AUTOMATED PAYLOADS REVIEWED (continued)

EARTH OBSERVATIONS

EO-07-A — Advanced Synchronous Meteorological Satellite
EO-08-A — Earth Observatory Satellite
EO-09-A — Synchronous Earth Observatory Satellite
EO-10-A — Applications Explorer (Special Purpose Satellite)
EO-12-A — TIROS 'O'
EO-56-A — Environmental Monitoring Satellite
EO-57-A — Foreign Synchronous Meteorological Satellite
EO-58-A — Geosynchronous Operational Meteorological Satellite
EO-59-A — Geosynchronous Earth Resources Satellite
EO-61-A — Earth Resources Survey Operational Satellite
EO-62-A — Foreign Synchronous Earth Observatory Satellite

EARTH AND OCEAN PHYSICS

OP-01-A — GEOPAUSE
OP-02-A — Gravity Gadiometer
OP-03-A — Mini-LAGEOS
OP-04-A — GRAVSAT
OP-05-A — Vector Magnetometer Satellite
OP-06-A — Magnetic Field Monitor Satellite
OP-07-A — SEASAT - B
OP-51-A — Global Earth & Ocean Monitor System

SPACE PROCESSING APPLICATIONS

SP-01-A — Space Processing Free-Flyer

LIFE SCIENCES

LS-02-A — Biomedical Experiment Scientific Satellite

SPACE TECHNOLOGY

ST-01-A — Long Duration Exposure Facility

LIST OF AUTOMATED PAYLOADS REVIEWED (continued)

PLANETARY

PL-01-A — Mars Surface Sample Return
PL-02-A — Mars Satellite Sample Return
PL-03-A — Pioneer Venus Multiprobe
PL-07-A — Venus Orbital Imaging Radar
PL-08-A — Venus Buoyancy Probe
PL-09-A — Mercury Orbiter
PL-10-A — Venus Large Lander
PL-11-A — Pioneer Saturn/Uranus Flyby
PL-12-A — Mariner Jupiter Orbiter
PL-13-A — Pioneer Jupiter Probe
PL-14-A — Saturn Orbiter
PL-15-A — Uranus Probe/Neptune Flyby
PL-16-A — Ganymede Orbiter/Lander
PL-18-A — Encke Rendezvous
PL-19-A — Halley Comet Flyby
PL-20-A — Asteroid Rendezvous
PL-22-A — Pioneer Saturn Probe

COMMUNICATIONS/NAVIGATION

CN-51-A — INTELSAT
CN-52-A — U.S. DOMSAT 'A'
CN-53-A — U.S. DOMSAT 'B'
CN-54-A — Disaster Warning Satellite
CN-55-A — Traffic Management Satellite
CN-56-A — Foreign Communications Satellite A
CN-58-A — U.S. DOMSAT 'C'
CN-59-A — Communications R&D/Prototype Satellite
CN-60-A — Foreign Communications Satellite B

LUNAR

LU-01-A — Lunar Orbiter
LU-02-A — Lunar Rover
LU-03-A — Lunar Halo Satellite
LU-04-A — Lunar Sample Return

TABLE C-1: List of Automated Payloads and Their MMU Applications

PAYLOAD NO.	INSPECT/CHECK	P/L DEPLOY/RETRIEVE	CONTINGENCY EQP DATA RETRIEVAL	SYSTEMS DEPLOY/RETRACT	SYSTEMS SERVICE/REPAIR	MODULE REPLACEMENT	SATELLITE STABILIZE	JETTISON			PLANNED EVA	CONTINGENCY EVA
ASTRONOMY												
AS-01-A	●	●	●	●	●	●	●	●				X
AS-02-A			●		●	●		●				X
AS-03-A	●	●		●	●	●	●	●				X
AS-05-A			●		●			●				X
AS-07-A	●	●	●		●	●	●	●				X
AS-11-A	●	●	●		●	●	●	●				X
AS-13-A	●	●	●		●	●	●	●				X
AS-14-A	●	●	●		●	●	●	●				X
AS-16-A			●		●			●				X
AS-17-A	●	●	●	●	●	●	●	●			X	X
HIGH ENERGY ASTROPHYSICS												
HE-01-A	●	●	●	●	●	●	●	●				X
HE-03-A	●	●	●	●	●	●	●	●				X
HE-05-A	●	●	●		●			●				X
HE-07-A	●	●		●	●			●				X
HE-08-A	●	●	●	●	●	●	●	●				X
HE-09-A	●	●	●	●	●	●	●	●			X	X
HE-10-A	●	●	●	●	●	●	●	●				X
HE-11-A	●	●	●	●	●	●	●	●				X
HE-12-A	●	●	●	●	●	●	●	●				X
											X	X
SOLAR PHYSICS												
SO-02-A	●	●			●	●	●	●			X	X
SO-03-A	●	●		●	●		●	●				X
ATMOSPHERIC AND SPACE PHYSICS												
AP-01-A								●				
AP-02-A								●				
AP-03-A								●				
AP-04-A	●	●		●	●			●				X
AP-05-A								●				
AP-06-A								●				
AP-07-A								●				
AP-08-A					●			●				X
EARTH OBSERVATIONS												
EO-07-A			●		●			●				X
EO-08-A	●	●			●	●	●	●				X
EO-09-A			●		●			●				X
EO-10-A	●	●			●			●				X
EO-12-A					●			●				X
EO-56-A					●			●				X
EO-57-A			●		●			●				X
EO-58-A			●		●			●				X
EO-59-A			●		●			●				X
EO-61-A	●	●			●			●				X
EO-62-A			●		●			●				X
EARTH AND OCEAN PHYSICS												
OP-01-A					●			●				X
OP-02-A	●	●			●			●				X
OP-03-A	●	●						●				
OP-04-A	●	●	●		●			●				X
OP-05-A	●	●			●			●				X
OP-06-A					●			●				X
OP-07-A	●	●			●			●				X
OP-51-A	●	●						●				

●- MMU POTENTIAL APPLICATION X- EVA STATUS

TABLE C-1: List of Automated Payloads and Their MMU Applications (continued)

PAYLOAD NO.	INSPECT/CHECK	P/L DEPLOY/ RETRIEVE	CONTINGENCY EOP	DATA RETRIEVAL	SYSTEMS DEPLOY/ RETRACT	SYSTEMS SERVICE/ REPAIR	MODULE REPLACEMENT	SATELLITE STABILIZE	JETTISON		PLANNED EVA	CONTINGENCY EVA
SPACE PROCESSING APPLICATIONS												
SP-01-A	●	●		●	●			●				X
LIFE SCIENCES												
LS-02-A	●	●		●	●		●	●				X
SPACE TECHNOLOGY												
ST-01-A	●	●	●		●		●	●				X
PLANETARY												
PL-01-A								●				
PL-02-A								●				
PL-03-A					●			●				X
PL-07-A								●				
PL-08-A								●				
PL-09-A								●				
PL-10-A								●				
PL-11-A					●			●				X
PL-12-A								●				
PL-13-A								●				
PL-14-A								●				
PL-15-A								●				
PL-16-A								●				
PL-18-A								●				
PL-19-A								●				
PL-20-A								●				
PL-22-A								●				

PAYLOAD NO.	INSPECT/CHECK	P/L DEPLOY/ RETRIEVE	CONTINGENCY EOP	DATA RETRIEVAL	SYSTEMS DEPLOY/ RETRACT	SYSTEMS SERVICE/ REPAIR	MODULE REPLACEMENT	SATELLITE STABILIZE	JETTISON		PLANNED EVA	CONTINGENCY EVA
COMMUNICATIONS/NAVIGATION												
CN-51-A					●			●				X
CN-52-A					●			●				X
CN-53-A					●			●				X
CN-54-A					●			●				X
CN-55-A					●			●				X
CN-56-A					●			●				X
CN-58-A					●			●				X
CN-59-A					●			●				X
CN-60-A					●			●				X
LUNAR												
LU-01-A								●				
LU-02-A								●				
LU-03-A								●				
LU-04-A								●				

APPENDIX C2

LARGE SPACE TELESCOPE (LST)

(AS-01-A AND REVISIT)

AUTOMATED PAYLOAD GENERAL INFORMATION

PAYLOAD NO. AS-01-A

PAYLOAD NAME: Large Space Telescope		INITIAL LAUNCH: 1980		NO. LAUNCHED: 3			
				NO. RETRIEVED: 2			
TOTAL NO. PAYLOADS: 1		ORBIT: LEO (611 km., 330 mi.)		PAYLOAD LAUNCHED BY:			
				ORBITER	RMS	TUG	
NO. P/L SERVICED: 9		STABILITY: CMG/cold gas		X	X		

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	UNITS / PARAMETER	SI	CONV.
	DIAMETER OR WIDTH	4.27 m.	14.0 ft.
	LENGTH OR HEIGHT	12.7 m.	41.7 ft.
	MASS	11,340 kg.	25,100 lbs.
	C.G.	4.71 m. -x axis 0.025 m. z axis	15.5 ft. 0.08 ft.

ORBIT CHECKOUT	X	CONTAM. COVER	X	THRUSTERS	X	LOUVERS	X
REFURBISH	X	SOLAR ARRAYS	X	ANTENNA		PYROTECHNICS	
DOCKING	X	SUN SHIELD	X	STAR TRACKER	X	OTHER	

MMU/EVA REQUIREMENTS			
	PLANNED EVAs	TASK	Repair/exchange system components or scientific instruments
		NO./MISSION	1 (for on-orbit servicing)
		DURATION (hrs.)	3+
	CONTINGENCY EVAs	PROBABLE TASK	Repair, replace, reconfigure, backup nominal operations
		ESTIMATED DURATION (hrs)	3+ hrs.

COGNIZANT SCIENTIST OR PI--LOCATION: C. R. O'Dell, NASA/MSFC (205) 453-0162	DEVELOPMENT AGENCY: MSFC/GSFC
	SHEET NO. 1 of 7

EVA TASK DESCRIPTION

PAYLOAD NO. AS-01-A

OBJECTIVE

1. Replace system components and/or scientific instruments
2. Repair system components including stabilization
3. Aid deployment/retrieval of payload

EVA/MMU TASK DESCRIPTION

Large Space Telescope--Figures C2.1 thru C2.3

1. Nominal on-orbit servicing (replace system components and/or scientific instruments)
   - Prepare for EVA and egress airlock
   - Don MMU - check out
   - Maneuver to LST worksite with replacement components (portable work-station may be required)
   - Ingress workstation
   - Replace failed payload components or reconfigure experiment
   - Egress LST workstation
   - Doff MMU
   - Ingress airlock

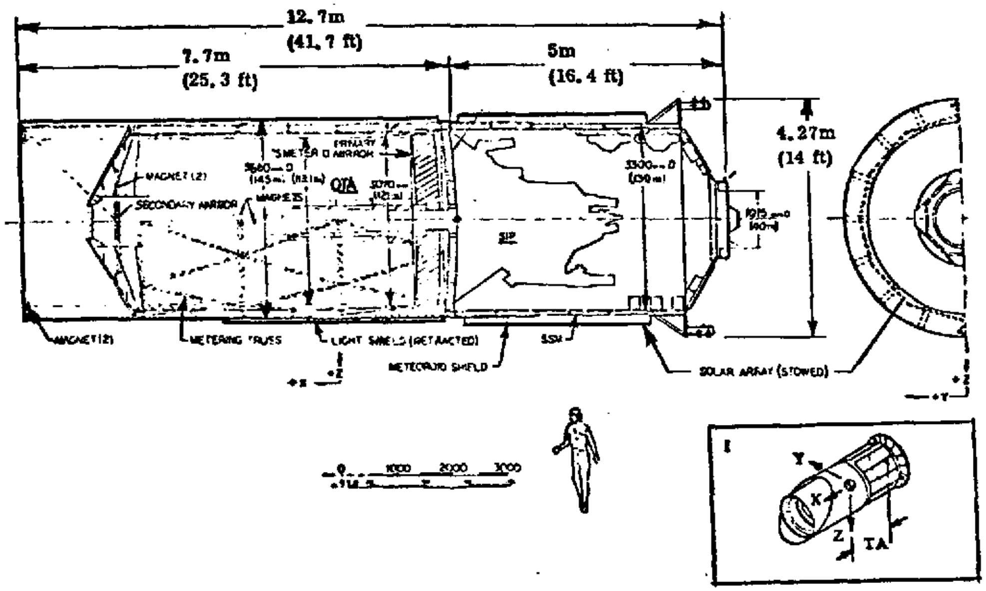
2. Repair system components

   Typical failures may include:
   - Stuck thruster / Malfunctioning CMG } Payload becomes unstable--MMU is used to bring payload under control for retrieval by Orbiter RMS.
   - Damaged or partially deployed solar array--MMU is used to free stuck array or to make repair
   - Damaged thermal protection system--MMU allows EVA crewman to repair the TPS

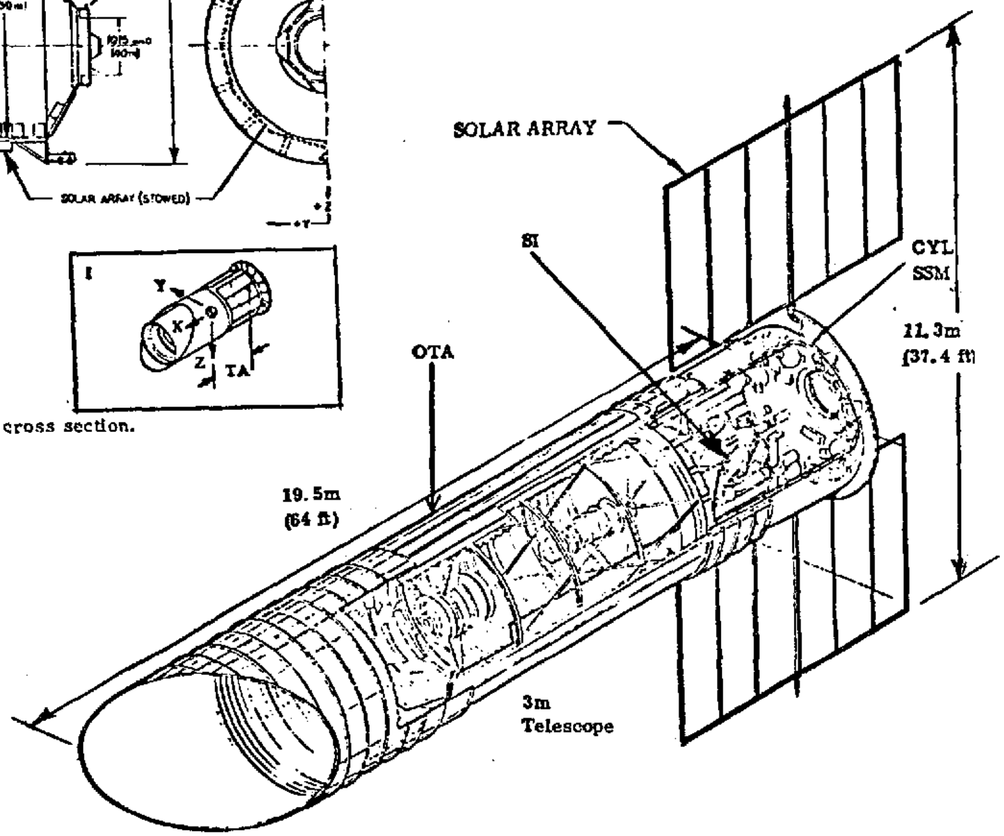
3. Aid deployment/retrieval of payload (TBD)

   MMU may be required because of:
   - Uncontrollable payload
   - Manipulator malfunction
   - Inability of Orbiter to capture payload due to thruster impingement, excessive contamination to payload, excessive use of Orbiter propellents for docking maneuvers, etc.

SHEET NO. 2 of 7



LST reference design longitudinal cross section.



Launch Weight, kg (lb) 9,946 (21,931)
Retrieval Weight, kg (lb) 9,924 (21,557)

C.G. Location, m (ft) 4.71 m (15.5 ft), X-axis
C.G. Location, m (ft) 0.025 m (0.08 ft) Z-axis

Moments of Inertia, kg m^2 (slug ft^2) Includes 20% contingency

I_{xx} 19,318 (14,200)

I_{yy} 123,703 (91,000)

I_{zz} 126,839 (93,400)

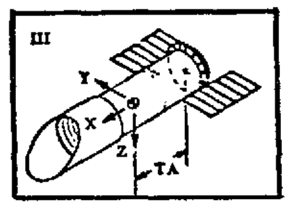


FIGURE C2.1: Large Space Telescope (LST) Configuration (Preliminary)

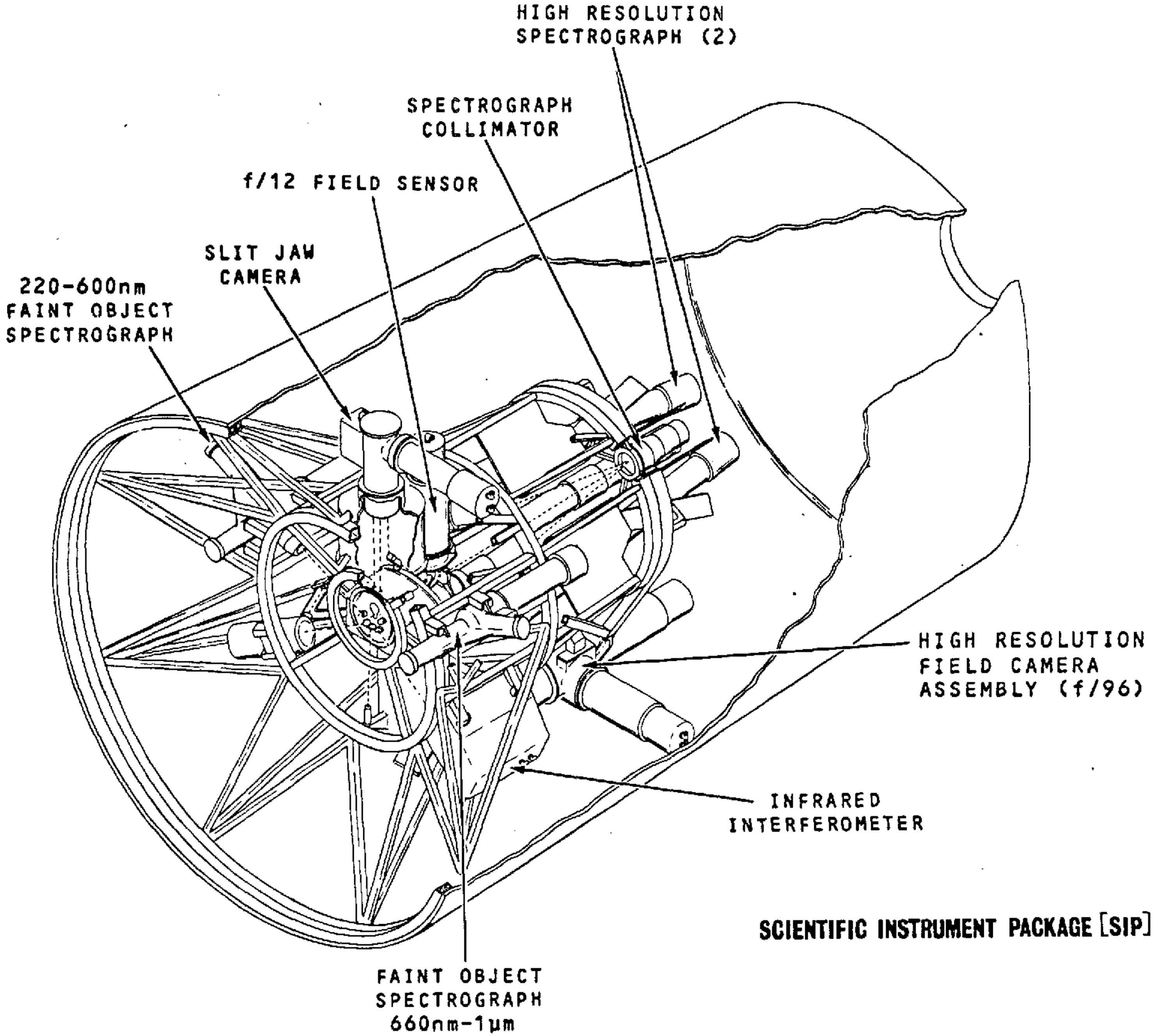


FIGURE C2.2: LST Scientific Instrument Package

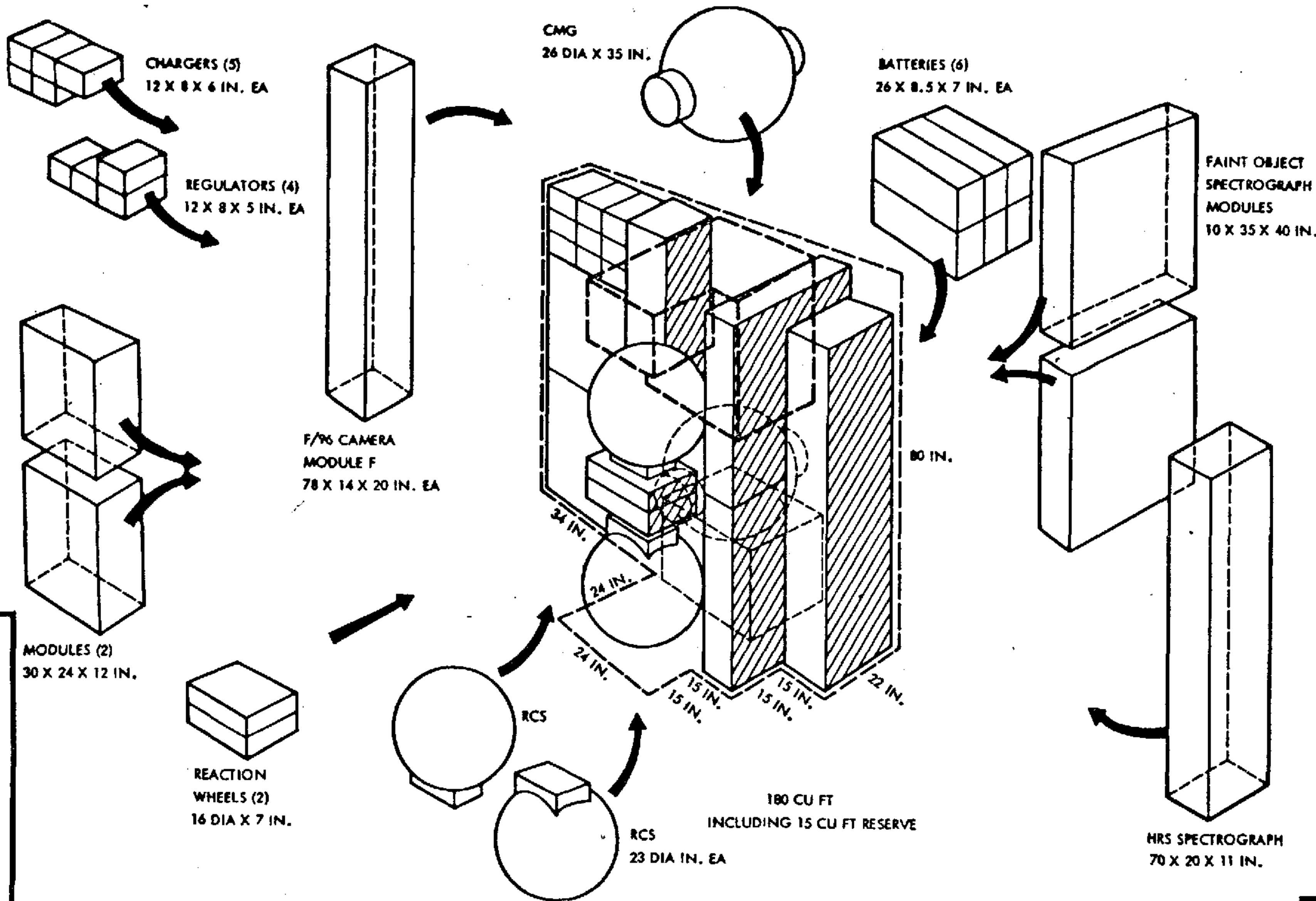


FIGURE C2.3: Stowage Concept for LST Replaceable Items (Preliminary)

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. AS-01-A

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS
• Clean class 10,000 • Sensitive to hydrocarbons and sulfides • Sensitive to humidity • Requires 2 noncontaminating, nonventing spacesuits for servicing

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU
Present design includes EVA provisions for on-orbit servicing of the payload after it has been berthed in the payload bay. Modifications for MMU servicing of free-flying payload includes: • Crew mobility aids on payload • Module temporary stowage • Crew stabilization/restraint attachment provisions

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Handholds and handrails • Temporary stowage devices • Foot restraint system • Repair kits for TPS and solar arrays • Equipment tether	Size: [Volume: 5.1 m^3 (180 ft^3) total] • F196 Camera Module: 78 x 14 x 20 in. • Faint Object Spectrograph Modules: 10 x 35 x 40 in. (2) • HRS Spectrograph: 70 x 20 x 11 in. • Regulators: 12 x 8 x 5 in. (4) • Chargers: 12 x 8 x 6 in. (5) • Batteries: 26 x 8.5 x 7 in. (6) • CMG: 26 dia. x 35 in. • RCS: 23 dia. (2) • Reaction Wheels: 16 dia. x 7 in. (2) • Modules: 30 x 24 x 12 in. (2)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN
• GN_2 pressurized tank • Solar array deployment mechanisms • High voltage

SHEET NO. 6 of 7

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. AS-01-A

WORKING GROUPS/PANEL MEMBERS CONTACTED

Harry G. Kraft, Jr., Payload Descriptions Documents, MSFC/PD-MP-T

REFERENCE DOCUMENTS AND DRAWINGS

- P/L Description Vol. I, Automated P/Ls, October 1973, MSFC (Preliminary)
- LST Brief Ins. to Industry, MSFC, NASA-TMX-64726, November 3, 1972
- Vol. I, Astronomy, Final Report of Space Shuttle Planning Working Groups, May 1973

CURRENT STATUS RELATIVE TO EVA/MMU

- EVA will be used for on-orbit servicing of payload--repair/exchange of system components and/or scientific instruments
- No MMU requirements identified to date

REMARKS/COMMENTS

Berthing the payload for servicing may prove difficult or inconvenient, especially if other payloads are in the bay. The MMU could be used to service the payload at a comfortable distance from the Orbiter with a minimum contamination impact. It may be possible to service the LST in this manner without interrupting its operation.

SHEET NO. 7 of 7

LARGE SPACE TELESCOPE SERVICING

LST Stabilization Scenario

A representative LST stabilization scenario is presented in which the MMU crewman is required to "despin" the LST from a 1 rpm rate. The MMU is required to rendezvous, attach to, and stabilize the LST to within the retrieval capability of the RMS.

LST Stabilization Timeline

The typical MMU mission outlined in this appendix involves a remote servicing of the LST although berthing the payload for standard EVA servicing is currently planned. The outline assumes a condition in which the servicing is required prior to retrieval or is more economical than a full retrieval program. Even though the tables included reflect a servicing mission, they are equally applicable to using an MMU for remote inspection, stabilization and repair operations. Table C2-1 contains a sequenced description of the task operations, equipment required, and estimated time requirements for each task.

The MMU mission is baselined as a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU, while crewman no. 2 (CM2) supports CM1 from the payload bay. The servicing tasks require crewman restraint provisions at the worksite which can either be fixed to the payload as a part of the structure, or be in the form of a portable workstation which is temporarily attached to the worksite by the EVA crewman.

MMU Requirements for LST Servicing

A typical MMU translation route is shown in Figure C2.4. Table C2-2 shows the estimated travel distance, direction changes, number of stops/starts, velocity and Δvelocity to complete the tasks.

TABLE C2-1: LST Servicing Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		2.0
Checkout MMU	X	X		15.0
Don MMU	X			15.0
Flight check MMU in bay on tether	X			15.0
Attach ancillary hardware	X		lights, experiment replacement components [illegible]k-statio[illegible]	5.0
Remove tether	X			1.0
Translate from Orbiter, visually locate LST	X			5.0
Translate to LST servicing area, attach portable workstation, temporarily restrain replacement items*	X			10.0
Perform servicing task, remove workstation**	X			20.0
Translate to MMU stowage area	X			15.0
Doff MMU, ancillary equipment and stow	X	X		10.0
Ingress airlock	X	X		5.0
End EVA	X	X		
			TOTAL TIME	120.0

*See the MMU Performance and Control Requirements sheet -- this task

**Second trip may be required for servicing--add 30 minutes

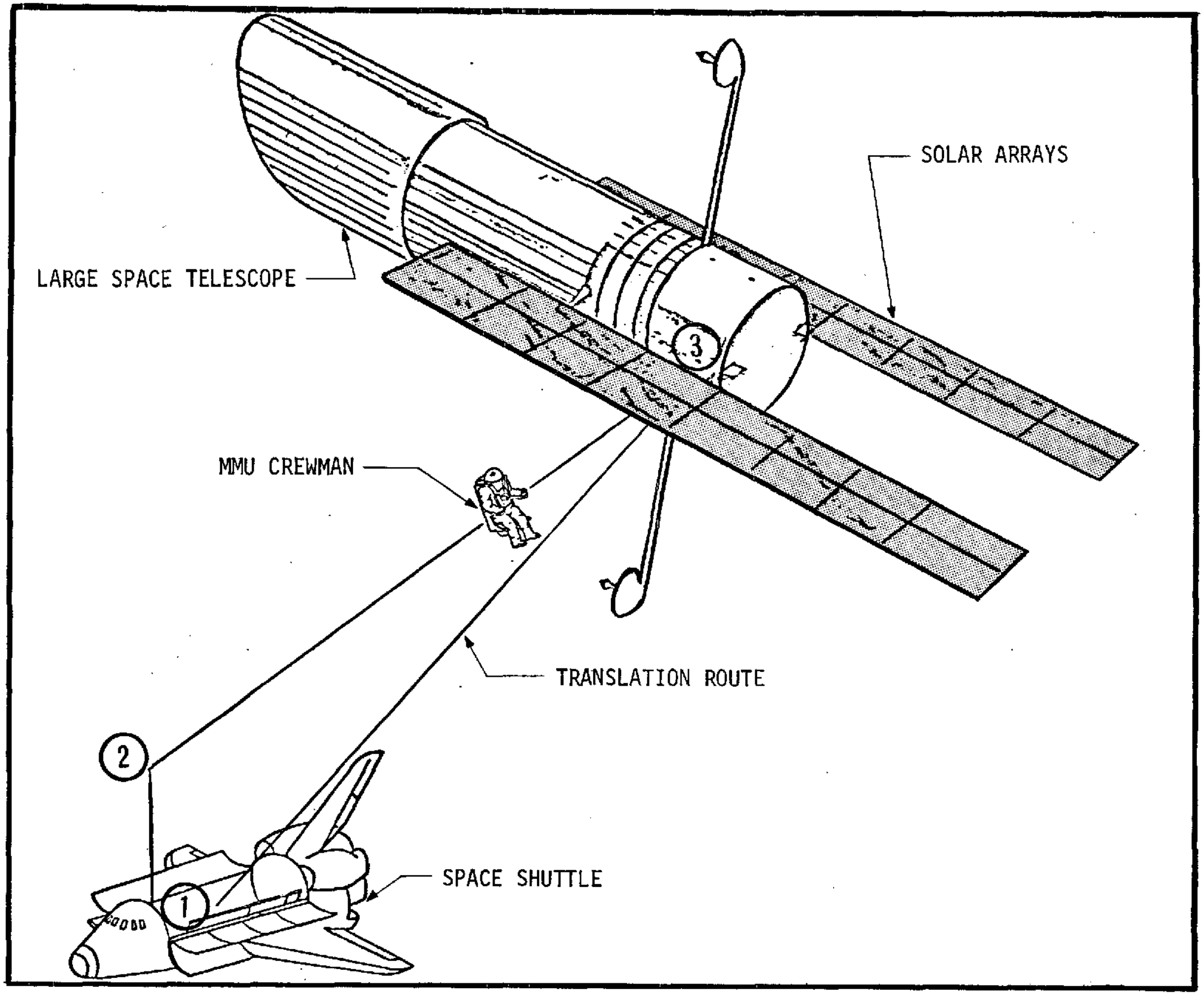


FIGURE C2.4: Translation Route for LST Servicing

TABLE C2-2: MMU Requirements for LST Servicing

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
MMU flight check	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
1 to 2-translate to vantage point	15	(50)	20	180	360	4	.12	(.4)	.48	(1.6)
2 to 3-translate to LST servicing station	153	(500)	15	30	90	5	.30	(1.0)	1.52	(5.0)
3 to 1-translate to MMU stowage area	153	(500)	15	45	90	4	.30	(1.0)	1.22	(4.0)
Retrieve components for second trip, if required, perform LST tasks and return to Orbiter	305	(1000)	30	75	180	10	.18	(.6)	1.83	(6.0)
Stow MMU and support equipment										
End EVA										
TOTAL	671	(2200)	440	690	1080	38			6.43	(21.1)
TRANSLATION ΔV + ROTATION ΔV									12.86	(42.2)

LARGE SPACE TELESCOPE (LST) STABILIZATION SCENARIO

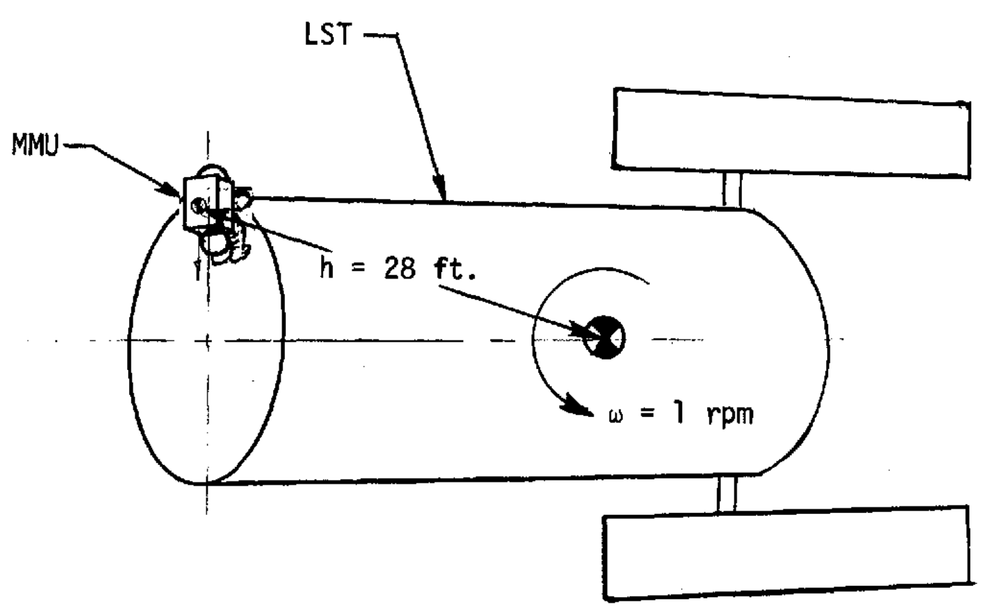
Assume the LST attitude stabilization systems have malfunctioned and the LST cannot be retrieved by the RMS. The driving condition is that the LST is unstable beyond the capture limits of the remote manipulator system--see Appendix B4. The sun shade is retracted. The LST is rotating about the cg creating a maximum moment of inertia (I_{zz}) at a rate of 1 rpm. The MMU rendezvouses with and attaches to the front of the LST 8.5 m (28 ft) from the LST cg. Assume the MMU imparts no additional disturbance to the LST during initial capture. The MMU system weighs 2380 N (535 lbs) and has a thrust capability of 4.75 lbf.

Given:

Angular velocity ω = 1 rpm = 6°/sec = .105 rad/sec

LST Moment of Inertia I_{zz} = 109,200 slug-ft^2

MMU Moment of Inertia I_M = 58.5 slug-ft^2



The velocity of the point to which the MMU must attach is

$$v = \omega r = .105\ (28) = 2.9\ \text{ft/sec.}$$

The total moment of inertia of the <u>system</u> is given by:

$$I_t = I_{zz} + I_M + m_M h^2 = 109{,}200 + 58.5 + (16.6 \times 28^2)$$

$$= 112{,}250\ \text{slug-ft}^2$$

The time required to despin the LST under the above conditions is given by

$$F = I_t \frac{\omega - \omega_0}{t} \qquad \text{where} \qquad F = (4.75)(28) = 133.0\ \text{ft-lb}$$

$$\omega_0 = 0\ \text{rad/sec}$$

$$\omega = .105\ \text{rad/sec}$$

$$t = \frac{112{,}250\ (.105)}{133.0} = 88.6\ \text{sec.}$$

Using a flow rate of .084 lb/sec for the 4.75 lbf thruster yields:

GN_2 consumed = .084 x 88.6 = 7.4 lbs.

CONCLUSION:

The MMU can sufficiently stabilize the LST while using only 7.4 lbs. of GN_2 in a time of 88.6 sec. No difficulty is anticipated in the MMU crewman rendezvous with and attaching to a point on the LST having a velocity of 2.9 ft/sec.

MMU PERFORMANCE AND CONTROL REQUIREMENTS

LST SERVICING

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	671 m.	2200 ft.
TOTAL VELOCITY CHANGE CAPABILITY	12.9 m/sec	42.2 ft/sec + 30.0 for despin*
STATION KEEPING ACCURACY ①		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±3°	--
- ATTITUDE RATE PRECISION	±3°/sec	--
ACCELERATION ②		
- TRANSLATION	$\leq$.09 m/sec^2	$\leq$.3 ft/sec^2
- ROTATION	>6°/sec	--
FORCE APPLICATIONS ②		
- LINEAR		
- TORQUE		

REMARKS

① Allows a crewman to grasp an interface point on the payload (handrail, etc.).

② Not critical to servicing task.

* Add 9.15 m/sec (30.0 ft/sec) ΔV for despin.

APPENDIX C3

LARGE HIGH ENERGY OBSERVATORY D

(HE-11-A AND REVISIT)

AUTOMATED PAYLOAD GENERAL INFORMATION

PAYLOAD NO. HE-11-A; R

PAYLOAD NAME: Large High Energy Observatory D	INITIAL LAUNCH: 1983	NO. LAUNCHED: 2	NO. RETRIEVED: 2

TOTAL NO. PAYLOADS: TBD	ORBIT: LEO	PAYLOAD LAUNCHED BY:		
		ORBITER	RMS	TUG
NO. P/L SERVICED: TBD	STABILITY: Cold gas; gyros	X	X	

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	PARAMETER \ UNITS	SI	CONV.
	DIAMETER OR WIDTH	4.58 m.	15 ft.
	LENGTH OR HEIGHT	10.22 m.	33.56 ft.
	MASS	6771 kg.	14,930 lbs.
	C.G.	5.55 m.	18.5 ft.

ORBIT CHECKOUT	X	CONTAM. COVER	X	THRUSTERS	X	LOUVERS	
REFURBISH	X	SOLAR ARRAYS	X	ANTENNA		PYROTECHNICS	
DOCKING	X	SUN SHIELD		STAR TRACKER		OTHER	

MMU/EVA REQUIREMENTS			
	PLANNED EVAs	TASK	Checkout and service payload
		NO./MISSION	3
		DURATION (hrs.)	4
	CONTINGENCY EVAs	PROBABLE TASK	Checkout, test, calibrate, repair, assist recovery of payload
		ESTIMATED DURATION (hrs)	TBD

COGNIZANT SCIENTIST OR PI--LOCATION: Dr. A. Opp	DEVELOPMENT AGENCY: NASA
	SHEET NO. 1 of 5

EVA TASK DESCRIPTION

PAYLOAD NO. HE-11-A; R

OBJECTIVE

1. Remote servicing of the payload
2. Assist in payload recovery operations

EVA/MMU TASK DESCRIPTION

1. Remote Servicing of the Payload
   - Egress airlock
   - Translate to MMU stowage area
   - Checkout MMU
   - Retrieve "trees" for temporary stowage of replacement parts
   - Load "trees" with replacement kits (2 trips may be required)
   - Retrieve portable workstation
   - Translate to payload servicing worksite
   - Attach portable workstation at worksite
   - Temporarily stow trees
   - Exchange components
   - Remove portable workstation
   - Translate to pallet
   - Stow used components, data, trees
   - Stow ancillary support hardware, lights, workstation, etc.
   - Doff MMU
   - Ingress airlock
   - End EVA
2. Assist in Payload Recovery Operations (Contingency)
   - Egress airlock
   - Translate to MMU stowage area

SHEET NO. 2 of 5

EVA TASK DESCRIPTION (continued)

PAYLOAD NO. HE-11-A; R

EVA/MMU TASK DESCRIPTION

- Don and checkout MMU
- Retrieve ancillary support hardware; cable, lights, etc.
- Translate to payload cable attach point
- Attach cable to payload
- Tow payload within reach of RMS; or position in restraints in bay if RMS is inoperative*
- Assist in retraction of antennas and arrays, as required for stowage
- Translate to MMU stowage area
- Doff and stow MMU and ancillary hardware
- Ingress airlock
- End EVA

* There may be no requirement to tow the payload; however, the MMU may be required to provide additional stabilization to the payload during capture by the RMS.

SHEET NO. 3 of 5

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. HE-11-A; R

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

Clean Class 10,000

Sensitive to hydrocarbons

Requires 2 noncontaminating, nonventing spacesuits for service

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

- Worksites include foot restraints or appropriate interface
- Handrails, handholds, or interface for on-orbit installation
- Temporary restraint provisions for cargo and ancillary equipment
- Cable attachment provisions

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Lights, cameras • Cable (for assisting payload recovery) • "Trees" for temporary stowage and handling of component replacement kits • Tools and repair kit, if required • Portable workstation	• Pointing component replacement kit • Instrument replacement kit • SSM component replacement kit, including consumables

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

- High pressure bottles

SHEET NO. 4 of 5

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. HE-11-A; R

WORKING GROUPS/PANEL MEMBERS CONTACTED

J. R. Dobbs - MSFC/PD-MP-D	High Energy Astrophysics; Payload Integration
Dr. R. L. Golden - JSC/TN2	High Energy Astrophysics Working Group

REFERENCE DOCUMENTS AND DRAWINGS

- Payloads Description Document, Vol I. Automated Payloads July 1974
- Summarized NASA Payload Descriptions Sortie and Automated Payloads, July 1974
- NASA Payload Model, October 1973
- Payload Planning Working Group Report, May 1973

CURRENT STATUS RELATIVE TO EVA/MMU

The current plan is to berth the payload for servicing by EVA. The payload also specifies a requirement for EVA contingency support in the areas of checkout, test, calibration, repair, aperture closure, solar array and antenna retraction, and rendezvous and recovery.

REMARKS/COMMENTS

Addition of an MMU to this payload would greatly enhance mission success especially in the contingency support areas, such as rendezvous and recovery of the payload. An MMU might also be valuable in normal servicing operations should a remote servicing mode be desired to reduce contamination and use of Orbiter consumables. This would also eliminate the need for a pallet-mounted tilt table and berthing attachment--1000 kg.

SHEET NO. 5 of 5

REMOTE SERVICING OF LARGE HIGH ENERGY OBSERVATORY D - HE-11-R

HE-11-R Servicing Timeline

The typical MMU mission outlined in this appendix involves a remote servicing of HE-11-A. However, the table values included are equally applicable to remote inspection/repair tasks by modifying the task times. Table C3-1 contains a sequenced description of the tasks/operations, equipment required and estimated time requirements for general tasks. Typical tasks may involve replacing modules, retracting/stowing arrays and antennae prior to RMS capture, payload stabilization and assisting retrieval operations.

The MMU mission is baselined as a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU, while crewman no. 2 (CM2) supports CM1 from the payload bay. The servicing tasks require crewman restraint provisions at the worksite which can either be integral with the payload structure, or as portable workstations which are installed at the worksite by the EVA crewman.

MMU Requirements for HE-11-R Servicing

A typical MMU translation route is shown in Figure C3.1. Table C3-2 shows the estimated travel distance, direction changes, number of starts/stops, velocity and Δvelocity.

Total ΔV Required

The translation ΔV required for this mission is approximately 3.51 m/sec (11.5 ft/sec). From M509 on-orbit experience, it was found that the ΔV required for rotation is approximately equal to that used for translation. Therefore, the total ΔV for both translation and rotation is approximately 7.02 m/sec (23.0 ft/sec).

TABLE C3-1: HE-11-R Servicing Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		2.0
Checkout MMU	X			5.0
Don MMU	X			15.0
Flight check MMU in bay on tether	X		lights, experiment replacement components, portable workstation	15.0
Remove tether	X			1.0
Translate from Orbiter, visually locate HE-11-A	X			5.0
Translate to HE-11-A servicing site	X			10.0
Attach workstation, temporarily stow replacement items	X			5.0
*Perform servicing task, remove workstation	X			20.0
Return to MMU stowage area	X			15.0
Doff and stow MMU and ancillary hardware	X	X		10.0
Ingress airlock	X	X		5.0
End EVA	X	X		
				130.0

*Multiple trips might be required to service the payload. Add 30 minutes to timeline for each.

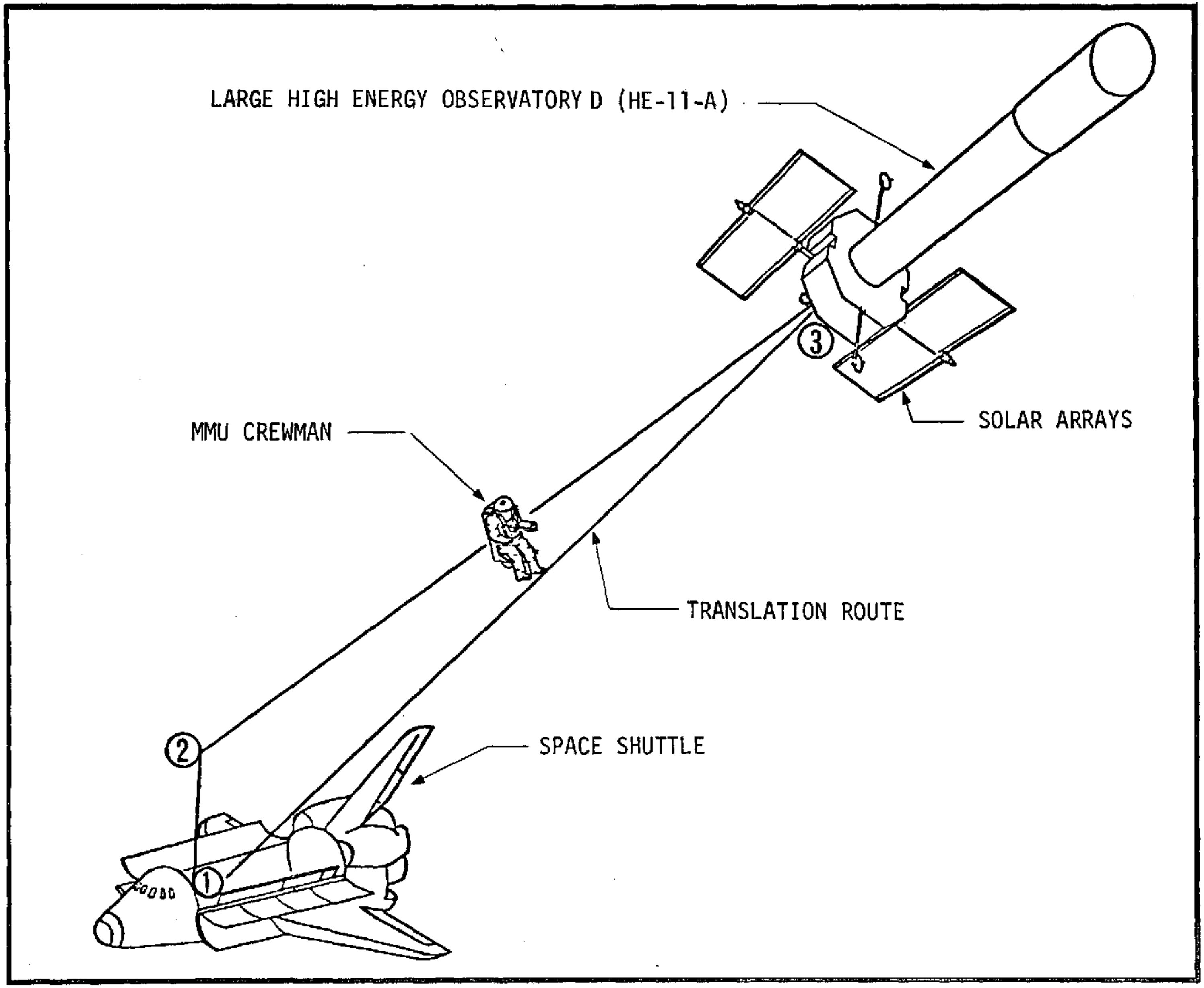


FIGURE C3.1: Translation Route for Servicing HE-11-R

TABLE C3-2: MMU Requirements For HE-11-R Servicing

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
MMU flight check	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
1 to 2 translate to vantage point	15	(50)	20	180	360	4	.12	(.4)	.48	(1.6)
2 to 3 translate to payload servicing site	137	(450)	15	30	90	3	.75	(2.5)	2.25	(7.5)
3 to 1 translate to MMU stowage area	137	(450)	15	45	90	2	.75	(2.5)	1.53	(5.0)
Stow MMU, support equipment and experiment data										
End EVA										
TOTAL	335	1100	440	690	1080	24			5.70	(18.6)
TRANSLATION ΔV + ROTATION ΔV									11.3	(37.2)
Multiple trips may be required to service this payload. Add these numbers for each additional trip	270	900	30	75	180	10	.18	(.6)	1.08	(6.0)

MMU PERFORMANCE AND CONTROL REQUIREMENTS

HE-11-R SERVICING

PARAMETER \ UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	335 m.	1100 ft.
TOTAL VELOCITY CHANGE CAPABILITY	11.3 m/sec	37.2 ft/sec
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±3°	--
- ATTITUDE RATE PRECISION	±3°/sec	--
ACCELERATION (2)		
- TRANSLATION	$\leq$.09 m/sec^2	$\leq$.3 ft/sec^2
- ROTATION	>6°	
FORCE APPLICATIONS (2)		
- LINEAR		
- TORQUE		

REMARKS

(1) Allows a crewman to grasp an interface point on the payload (handrail, etc.).

(2) Not critical to servicing task.

APPENDIX C4

LONG DURATION EXPOSURE FACILITY (LDEF)

(ST-01-A)

AUTOMATED PAYLOAD GENERAL INFORMATION

PAYLOAD NO. ST-01-A

PAYLOAD NAME: Long Duration Exposure Facility (LDEF)	INITIAL LAUNCH: 1980	NO. LAUNCHED: 6 NO. RETRIEVED:6

TOTAL NO. PAYLOADS: 1	ORBIT: LEO (500 km., 270 mi.)	PAYLOAD LAUNCHED BY:		
		ORBITER	RMS	TUG
NO. P/L SERVICED: 0	STABILITY: Gravity gradient	X	X	

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	PARAMETER / UNITS	SI	CONV.
	DIAMETER OR WIDTH	4.23 m.	14 ft.
	LENGTH OR HEIGHT	9.25 m.	30 ft.
	MASS	3860 kg.	8500 lbs.
	C.G.	4.57 m.	15 ft.

ORBIT CHECKOUT		CONTAM. COVER		THRUSTERS		LOUVERS	
REFURBISH	X	SOLAR ARRAYS		ANTENNA		PYROTECHNICS	
DOCKING	X	SUN SHIELD		STAR TRACKER		OTHER: Sample panels	X

MMU/EVA REQUIREMENTS			
	PLANNED EVAs	TASK	No planned EVAs scheduled to date
		NO./MISSION	
		DURATION (hrs.)	
	CONTINGENCY EVAs	PROBABLE TASK	Aid in deployment/retrieval of payload, inspection fly-around
		ESTIMATED DURATION (hrs)	2 - 4 hrs.

COGNIZANT SCIENTIST OR PI--LOCATION: W. H. Kinard, LaRC/SATD (703) 827-3704	DEVELOPMENT AGENCY: LaRC/OAST
	SHEET NO. 1 of 5

EVA TASK DESCRIPTION

PAYLOAD NO. ST-01-A

OBJECTIVE

Use EVA in a contingency mode to support payload deployment and retrieval.

EVA/MMU TASK DESCRIPTION

Long Duration Exposure Facility--Figure C4.1

1. Payload Deployment

- Prepare for EVA--egress airlock
- Don MMU
- Maneuver to payload RMS attach point and stabilize
- Release payload from restraints or manipulator system end effectors
- Transfer payload from immediate vicinity of Orbiter (this procedure, from a dynamic standpoint, is TBD)
- Disconnect transfer tether
- Spin payload to desired rate
- Maneuver to MMU donning station - doff MMU
- Ingress airlock

2. Payload Retrieval

- Prepare for EVA--egress airlock
- Donn MMU
- Maneuver to payload with retrieval gear
- Despin payload
- Attach tether/harness to payload
- Tow payload to Orbiter or return to payload bay and use winch system
- Position payload within reach of manipulator or in the payload bay rotation fittings--assist retrieval
- Maneuver to MMU donning station - doff MMU
- Ingress airlock

SHEET NO. 2 of 5

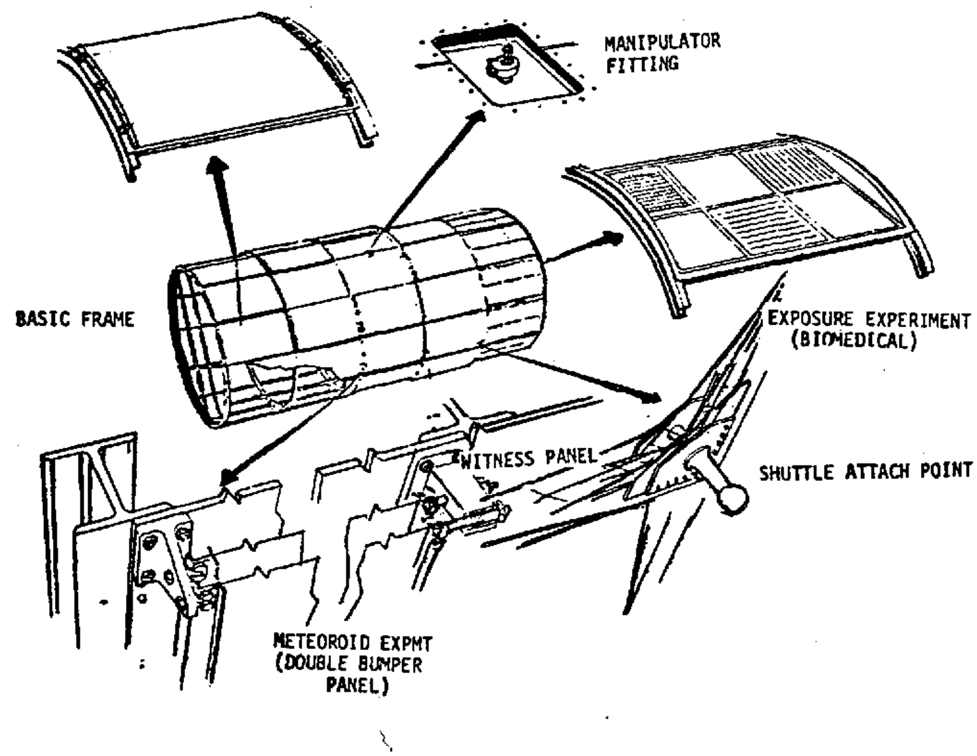


FIGURE C4.1: Long Duration Exposure Facility Panel Layout

SHEET NO. 3 of 5

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. ST-01-A

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

- No contamination constraints identified--Shuttle payload bay environment is acceptable

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

- Attach points for EVA/MMU deployment and retrieval assistance:
  - Tether/strap attach points
  - Portable workstation receptacle (if required)
  - Handholds at worksites

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Attach points for connecting payload retrieval hardware	• Present plans are to handle the payload as a unit for ground refurbishment; therefore, only crew aids, such as tethers, straps, etc. would be required: - Weight: <2.3 kg. (5 lbs.) - Size: <.007 m^3 (.25 ft^3)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

None identified to date

SHEET NO. 4 of 5

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. ST-01-A

WORKING GROUPS/PANEL MEMBERS CONTACTED

See Appendix G1

REFERENCE DOCUMENTS AND DRAWINGS

- Long Duration Exposure Facility Phase A Study - Volume II, Conceptual Design
- Payload Descriptions, Volume I, Automated Payloads, NASA/MSFC October 1973 (Preliminary)

CURRENT STATUS RELATIVE TO EVA/MMU

- EVA scheduled for contingency support during payload deployment and retrieval.

REMARKS/COMMENTS

The LDEF uses a gravity gradient system for stabilization which is highly susceptible to induced tumbles. The MMU could be used to aid in deployment and retrieval of the payload which would eliminate perturbations from the Orbiter thrusters or the manipulator.

SHEET NO. 5 of 5

RETRIEVAL OF LONG DURATION EXPOSURE FACILITY

LDEF Applications

Two representative MMU applications to the LDEF payload were developed. One scenario involves despinning the LDEF from motion about the longitudinal axis with the MMU crewman located at the axis. Another scenario involves the stabilization of the LDEF from a tumbling or flat spin condition.

LDEF Retrieval Timeline

The typical MMU mission outlined in this appendix involves a contingency retrieval of the LDEF. The contingency retrieval is considered a greater workload on the MMU than other cited applications. Table C4-1 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task. Appendix E contains data relative to MMU cargo transfer--time and propellant requirements.

The MMU mission is baselined as a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU, while crewman no. 2 (CM2) supports CM1 from the payload bay.

MMU Requirements to Retrieve LDEF

A typical translation route is shown in Figure C4.2. Table C4-2 shows the estimated travel distance, direction changes, number of starts/stops, velocity and Δ velocity.

Total ΔV Required

The translation ΔV required for the LDEF retrieval mission is approximately 5.24 m/sec (17.3 ft/sec). From M509 flight experience, it was determined that the ΔV used for rotation is approximately equal to that required for translation. Therefore, the total ΔV for both translation and rotation is approxi-

TABLE C4-1: LDEF Retrieval Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
<u>Retrieve LDEF</u>				
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		1.0
Checkout MMUs (2)	X	X		15.0
Don MMU and attach ancillary hardware	X		lights, camera, tethers, cable	15.0
MMU familiarization flight in bay	X			5.0
Remove tether	X			1.0
Egress payload bay, visually locate payload *	X			4.0
Translate toward payload (reel out cable during translation)	X			10.0
Fly around and visually inspect payload to assume no damage (check P/L attachment and restraint provisions)	X		camera, light	15.0
Note: If payload is spinning, perform the following:				
CAUTION: Do not attempt this operation if the payload is spinning at >4.0 rpm.				
Maneuver MMU to match the spin of the payload	X			10.0
Position MMU within reach of attachment point	X		tether, light	5.0
Attach to payload and counteract its motion	X			15.0
*see MMU Performance and Control Requirements sheet--this task				

TABLE C4-1: LDEF Retrieval Timeline (continued)

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Attach cable to payload attachment point	X		cable (reel type), light	5.0
Attach tether to tether attachment point	X		tether, light	5.0
Signal CM2 to slowly reel the payload toward the Orbiter	X	X		20.0
Use MMU/tether to guide payload and counteract its momentum	X			
Stop transfer of payload when within reach of RMS - assist capture of payload by RMS	X	X		15.0
Remove cable and tether from payload	X	X		5.0
Assist RMS as required in securing payload in bay	X	X	TBD	15.0
Translate to MMU stowage area	X	X		5.0
Doff MMU	X			5.0
Stow ancillary equipment	X	X	lights, cameras, tethers, cable	5.0
Secure MMU in stowage area	X			5.0
Translate to end ingress airlock	X	X		3.0
			TOTAL TIME	186.0

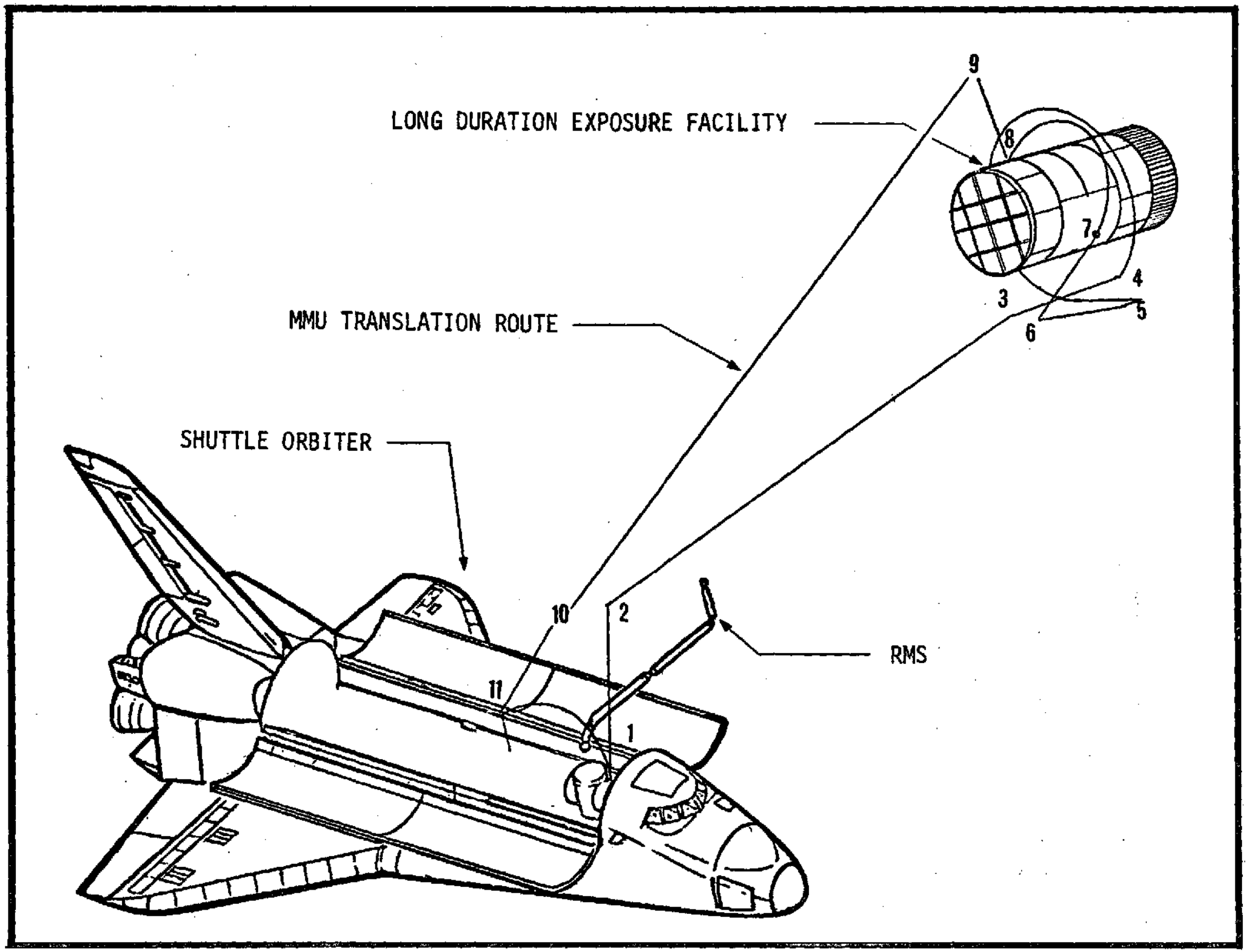


FIGURE C4.2: Translation Route for LDEF Contingency Retrieval

TABLE C4-2: MMU Requirements to Retrieve LDEF

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
Checkout	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
Retrieve LDEF										
1 to 2 translate to vantage point	15	(50)	--	30	360	2	.12	(.4)	.24	(0.8)
2 to 3 translate to LDEF	18	(60)	--	--	--	2	.18	(.6)	.36	(1.2)
3 to 4 begin inspection flyaround	5	(16.5)	--	30	45	2	.09	(.3)	.18	(0.6)
4 to 5 flyaround/inspect	30	(100)	--	360	--	2	.09	(.3)	.18	(0.6)
5 to 6 retrieve cable	5	(16.5)	--	20	90	2	.12	(.4)	.24	(0.8)
6 to 7 attach cable to payload	5	(16.5)	10	--	270	2	.12	(.4)	.24	(0.8)
7 to 8 attach tether to opposite side of P/L	10	(33)	180	180	--	2	.09	(.3)	.18	(0.6)
8 to 9 move to safe distance from P/L (attached by tether)	6	(20)	--	30	170	2	.12	(.4)	.24	(0.8)
9 to 10 guide payload and counteract momentum	18	(60)	30	90	90	5	.12	(.4)	.61	(2.0)
After RMS has control of P/L, remove cable and tether	10	(33)	190	180	270	4	.12	(.4)	.49	(1.6)
10 to 11 assist RMS in securing P/L in bay	12	(40)	90	110	110	6	.12	(.4)	.73	(2.4)
TOTAL										
TRANSLATION ΔV + ROTATION ΔV →										

TABLE C4-2: MMU Requirements to Retrieve LDEF (continued)

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec	ft/sec	m/sec	ft/sec
11 to 1 translate to MMU stowage area	9	(30)	--	30	180	2	.09	(.3)	.18	(0.6)
TOTAL	191	(625)	860	1420	1945	48			5.24	(17.3)
TRANSLATION ΔV + ROTATION ΔV →									10.48	(34.6)

mately 10.48 m/sec (34.6 ft/sec). Propellant required for despinning and stabilizing the LDEF from 1, 2 and 3 rpm are calculated (preliminary) on pages C-49 through C-52.

LONG DURATION EXPOSURE FACILITY DESPIN

Assume the LDEF was released into orbit at a spin rate about the longitudinal (x) axis of 1 rpm (malfunction of RMS upon release). The LDEF is unstable beyond the capture capability of the RMS (see Appendix B4) and the Orbiter thrusters may impose additional LDEF perturbations during approach/rendezvous.

The MMU rendezvouses with and attaches to the LDEF on one end at the longitudinal center line as shown in the sketch. The MMU is assumed not to impart additional disturbances to the LDEF during initial capture. The MMU system weighs 2380 N (535 lbs) and has a thrust capability of 4.75 lbf.

GIVEN:

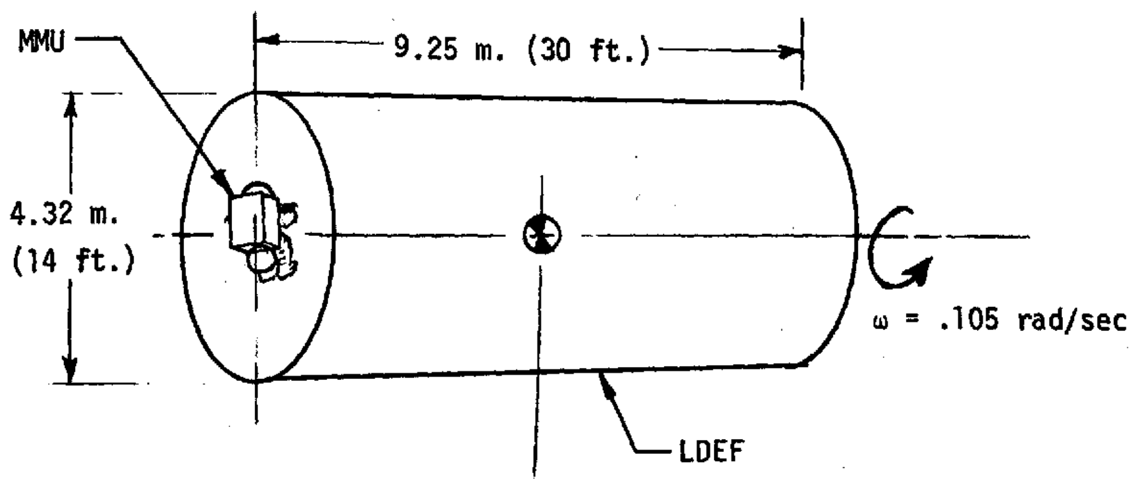
Angular velocity ω = 1 rpm = 6°/sec = .105 rad/sec

LDEF moment of inertia I_{xx} = 14,200 slug-ft^2

MMU moment of inertia:

$$I_M = \frac{1}{12} m (l^2 + b^2) = \frac{W}{12g} (l^2 + b^2) = \frac{535}{(12)\ 32.2} (6^2 + 2.5^2)$$

$$= 58.5 \text{ slug-ft}^2$$



The total moment of inertia of the system is given by:

$$I_t = I_{xx} + I_M = 14{,}200 + 58.5 \simeq 14{,}260 \text{ slug-ft}^2$$

The time required to despin the LDEF under the above conditions is:

$$F = I_t \left(\frac{\omega-\omega_0}{t}\right) \quad \text{where} \quad \begin{aligned} F &= 4.75 \text{ ft-lb} \\ \omega &= .105 \text{ rad/sec} \\ \omega_0 &= 0 \text{ rad/sec} \end{aligned}$$

$$t = \frac{I_t\,(\omega-\omega_0)}{F} = \frac{14{,}260\ (.105)}{8.0} = 187.1 \text{ sec.}$$

Using a flow rate of .084 lb/sec for the 4.75 lbf thrusters yields:

GN_2 consumed = .084 x 187.1 = 15.7 lbs. ($\simeq$64.1 ft/sec ΔV)

CONCLUSION:

The MMU can stabilize the LDEF at a 1 rpm rate with a torque capability of 8.0 ft-lbs. However, the propellant consumed appears excessive and the time at full thrust is in excess of three minutes. In order to stabilize the LDEF to within the required limits (assumed <1°/sec based on information from the EVA/RMS Payload Workshop, MSFC, October 2-3, 1974) will require instrumentation on the LDEF. Stabilization to this degree would require an MMU attitude hold precision of approximately ±.05°/sec. This MMU precision can not be justified on the LDEF isolated case. Perhaps a "looser" MMU attitude rate tolerance using a trial-and-error approach (supported by instrumentation) would accomplish the desired stabilization.

LONG DURATION EXPOSURE FACILITY STABILIZATION

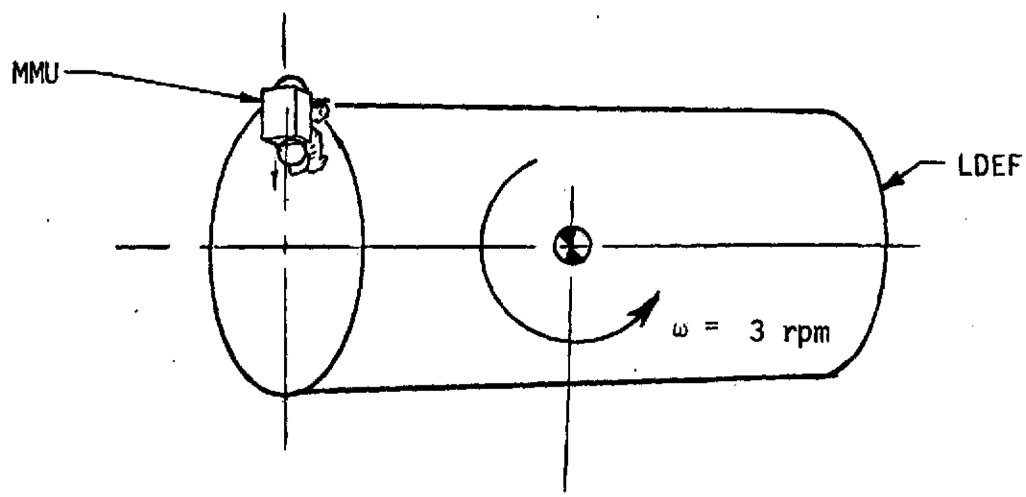
Consider an LDEF unstable situation in which the unit is tumbling or in a flat spin in one plane at a rate of 3 rpm. The Shuttle Orbiter cannot utilize the RMS for capture and stabilization at this spin rate. The MMU is required to rendezvous and stabilize the LDEF for Shuttle-RMS capture. Assume the RMS can capture the LDEF with a residual rate of .0018 rad/sec (0.1°/sec). The MMU rendezvouses with and attaches to the LDEF on one end at a radial point in which the MMU system cg is 5.3 m (17.5 ft) from the longitudinal axis (see sketch below). The MMU does not impart additional disturbances to the LDEF during initial capture. The MMU system weighs 2380 N (535 lbs) and has a thrust capability of 4.75 lbf.

GIVEN:

Angular velocity ω = 3 rpm = 18°/sec = .3141 rad/sec

LDEF moment of inertia I_{yy} = 29,000 slug-ft^2

MMU moment of inertia I_M = 58.5 slug-ft^2



The velocity of the point to which the MMU must attach is

$$v = \omega r = .315\,(17.5) = 5.51 \text{ ft/sec} \qquad (3.4 \text{ mph})$$

The total moment of inertia of the system is given by

$$I_t = I_{yy} + I_M + m_M h^2 = 29{,}000 + 58.5 + (16.6 \times 17.5^2)$$

$$= 34{,}140 \text{ slug-ft}^2$$

The time required to despin the LDEF under the above conditions is given by

$$F = I_t \frac{\omega - \omega_0}{t} \qquad \text{where} \qquad F = (4.75)(17.5) = 83.1 \text{ ft-lb}$$

$$\omega = .3141 \text{ rad/sec}$$

$$\omega_0 = .0018 \text{ rad/sec}$$

$$t = \frac{34{,}140\ (.3123)}{83.1} = 129.3 \text{ sec.}$$

Using a flow rate of .084 lb/sec for a 4.75 lbf thruster capability yields

$$GN_2 \text{ consumed} = .084 \times 129.3 = 10.9 \text{ lbs.} \qquad (\approx 44.5 \text{ ft/sec } \Delta V)$$

CONCLUSION:

The propellant consumption for one MMU to stabilize the LDEF from a 3 rpm rotation is within range of current MMU designs. One MMU could stabilize the unit from a 2 rpm rate with a fuel consumption of 7.16 lbs. GN_2 ($\approx$29.2 ft/sec ΔV) in 85.2 sec. Stabilizing the LDEF from 4 rpm can be accomplished using two MMUs.

MMU PERFORMANCE AND CONTROL REQUIREMENTS

PARAMETER / UNITS	LDEF RETRIEVAL SI	LDEF RETRIEVAL CONVENTIONAL
RANGE (TRAVEL DISTANCE)	191 m.	625 ft.
TOTAL VELOCITY CHANGE CAPABILITY	10.5 m/sec	34.6 ft/sec
STATION KEEPING ACCURACY ①		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	± 2°*	--
- ATTITUDE RATE PRECISION	± 1°/sec*	--
ACCELERATION ②		
- TRANSLATION	$\leq .09$ m/sec^2	$\leq .3$ ft/sec^2
- ROTATION	>6.0°/sec^2	--
FORCE APPLICATIONS		
- LINEAR ③	22.2 N	5 lbs.
- TORQUE ②		

REMARKS

① Stabilization requirement for capture by the RMS.

② Not critical.

③ Allows the payload to be towed to the Orbiter within a reasonable time frame with a reasonable amount of reaction time for deceleration.

* Design drivers from MMU applications analysis.

MMU PERFORMANCE AND CONTROL REQUIREMENTS

LDEF STABILIZATION

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	122 m.	400 ft.
TOTAL VELOCITY CHANGE CAPABILITY (1)	4.9 kg.	10.9 lbs. N_2* (44.5 ft/sec)
STATION KEEPING ACCURACY (2)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±.05° (est.)	--
- ATTITUDE RATE PRECISION	±.025°/sec (est.)	--
ACCELERATION (3)		
- TRANSLATION		
- ROTATION		
FORCE APPLICATIONS		
- LINEAR	22 N	4.7 lbs.
- TORQUE	10.9 N-m	8 ft-lb

REMARKS

(1) Fuel requirement for the stabilization task only.

(2) Based on payload tip-off requirements, the RMS cannot presently meet this requirement. To perform the task with the MMU would require appropriate instrumentation on the payload.

(3) Not critical for deployment task.

* Stabilize LDEF from 3 rpm flat spin.

APPENDIX C5

GENERAL INFORMATION ON AUTOMATED PAYLOAD NOS. SO-03-A AND HE-09-A

APPENDIX C5

Introduction

In considering the complexity of payloads relative to mechanical, electrical/electronic, optical, and pneumatic systems, few could be totally eliminated that would not benefit from EVA/MMU capabilities should malfunctions occur, particularly: (1) those payloads requiring aid in deployment/retrieval; (2) payloads with equipment extending beyond the payload bay door closure envelope; and (3) contamination-sensitive and other payloads with potential advantages from on-orbit servicing or refurbishment. On practically every automated payload being considered in mid-1974 for future Shuttle missions, an MMU application can be identified. The applications are based on system failures or equipment malfunctions--no MMU requirements are currently specified by the automated payloads. The author attributes the present MMU applications hesitation on: (1) the MMU is a strong contender as Shuttle program equipment but not currently baselined, (2) payload operations are not defined relative to contingency requirements, and (3) payload designers are not fully cognizant of potential MMU capabilities to design the MMU into their experiments.

Upon reviewing each payload, both automated and sortie, it became apparent that many payloads had similar (potential) applications. Each payload was reviewed and grouped relative to its application and analysis worksheets completed on selected payloads from each group or class. Analysis worksheets were not completed on each payload within each class. However, almost any payload chosen from a class would show a potential MMU application. Two examples in addition to those payloads selected for detail analysis are shown, a Solar Maximum Satellite (SO-03-A) and a Large High Energy Observatory (HE-09-A).

AUTOMATED PAYLOAD GENERAL INFORMATION

PAYLOAD NO. SO-03-A

PAYLOAD NAME: Solar Maximum Satellite (SMS)	INITIAL LAUNCH: 1977	NO. LAUNCHED: 6 NO. RETRIEVED: 6

TOTAL NO. PAYLOADS: 2	ORBIT: LEO (500 km., 270 mi.)	PAYLOAD LAUNCHED BY:		
		ORBITER	RMS	TUG
NO. P/L SERVICED: N/A	STABILITY: 3-axis stabilized Attit.Contr. GN_2	X	X	

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS			
PARAMETER \ UNITS		SI	CONV.
	DIAMETER OR WIDTH	1.62 m.	5.3 ft.
	LENGTH OR HEIGHT	3.2 m.	10.5 ft.
	MASS	760 kg.	1645 lbs.
	C.G.	1.3 m.	4.3 ft.

ORBIT CHECKOUT	X	CONTAM. COVER		THRUSTERS	X	LOUVERS	X
REFURBISH	X	SOLAR ARRAYS	X	ANTENNA		PYROTECHNICS	
DOCKING	X	SUN SHIELD		STAR TRACKER	X	OTHER Sun Tracker	X

MMU/EVA REQUIREMENTS			
	PLANNED EVAs	TASK	
		NO./MISSION	
		DURATION (hrs.)	
	CONTINGENCY EVAs	PROBABLE TASK	Payload deployment/retrieval, solar panel repair, instrument exchange
		ESTIMATED DURATION (hrs)	3+

COGNIZANT SCIENTIST OR PI--LOCATION: Dr. G. K. Oertel, Hdq/SG (202) 755-8490	DEVELOPMENT AGENCY: NASA/OSS (Phys. & Ast.)
	SHEET NO. 1 of 5

EVA TASK DESCRIPTION

PAYLOAD NO. SO-03-A

OBJECTIVE

1. Prepare recovered payload for return to earth
2. Aid in retrieval of payload (EVA/MMU)
3. Aid in deployment of payload

EVA/MMU TASK DESCRIPTION

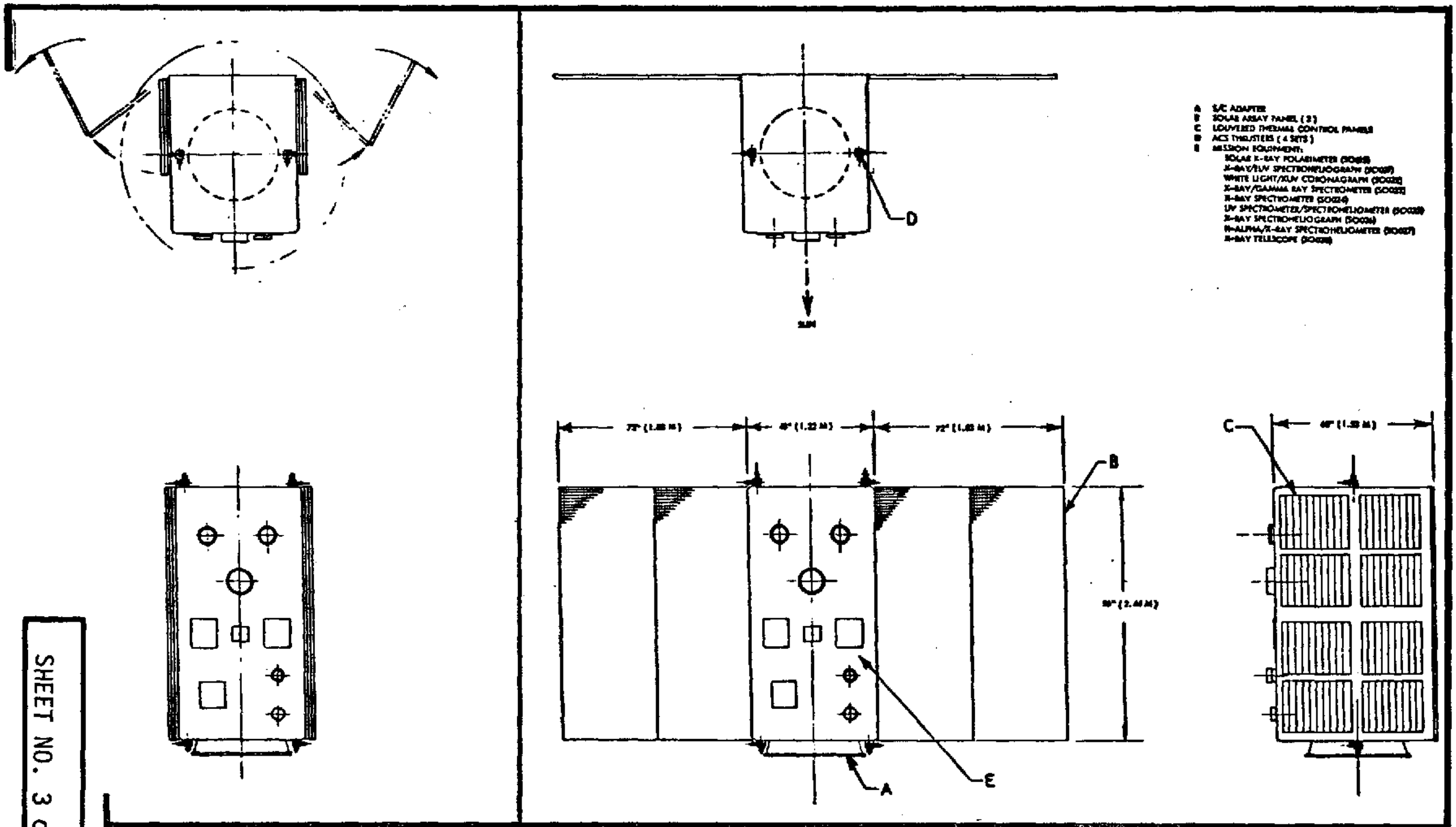
Solar Maximum Satellite (SMS)--Figure C5.1

1. Prepare recovered payload for return to earth
   - Prepare for EVA, egress airlock
   - Inspect hold down attachments and umbilical connections
   - Purge subsystems as required
   - Checkout SMS monitoring systems
   - Report status
   - Ingress airlock

2. Payload retrieval
   - Prepare for EVA, egress airlock
   - Don MMU
   - Maneuver to payload with tether system
   - Stabilize payload as required
   - Attach tether system to payload
   - Tow payload to Orbiter (from payload bay)
   - Position payload within reach of manipulator or in payload retention fittings
   - Doff MMU

3. Payload deployment (TBD)
   - This procedure will be required if there is a malfunction of the manipulator during deployment

SHEET NO. 2 of 5



Stowed Configuration

Deployed Configuration

SHEET NO. 3 of 5

FIGURE C5.1: Solar Maximum Satellite (SMS) External Envelope

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. SO-03-A

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS
• Clean class 10,000 • Acceptable humidity: Operating = 0% Non-operating = 0-50%

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU
• Crew mobility aid/stabilization provisions on payload • Interface for portable workstation and temporary module stowage • Attach points for tethers

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Portable workstation • Handholds/tethers • Video equipment • Ancillary lighting • Tool set	• No present requirement for on-orbit servicing of subsystems or components due to design--not presently designed for on-orbit servicing

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN
• Pressurized gas

SHEET NO. 4 of 5

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. SO-03-A

WORKING GROUPS/PANEL MEMBERS CONTACTED

See Appendix G

REFERENCE DOCUMENTS AND DRAWINGS

- OSO-7, OSO-1, OSO-J Experiment Summaries, NASA-OSS, 3/12/73
- Solar Physics Working Group Report, Rev. 3, GFSC, 4/12/73
- Payload Description Document, Vol. I, Automated Payloads, MSFC, October 1973, (Preliminary)

CURRENT STATUS RELATIVE TO EVA/MMU

No EVAs are currently planned for support of this payload.
EVA can be used to prepare the recovered payload for return to earth.
No on-orbit servicing is planned at this time.

REMARKS/COMMENTS

The present Orbiter has a limited capability to retrieve tumbling payloads. Should the stabilization system of this payload malfunction (causing it to tumble), it would be a candidate for retrieval by the MMU. Even under stable conditions, the MMU could be of benefit to payload retrieval by restricting: (1) contamination; (2) Orbiter thruster impingement; and (3) the use of Orbiter propellants.

SHEET NO. 5 of 5

AUTOMATED PAYLOAD GENERAL INFORMATION

PAYLOAD NO. HE-09-A

PAYLOAD NAME: Large High Energy Observatory B		INITIAL LAUNCH: 1982	NO. LAUNCHED: 1 NO. RETRIEVED: 1
TOTAL NO. PAYLOADS: 1	ORBIT: LEO (370 kg.-200 mi)		PAYLOAD LAUNCHED BY: ORBITER / RMS / TUG
NO. P/L SERVICED: 1	STABILITY: Spin stabilized Gyros w/ BU cold gas		ORBITER: X; RMS: X; TUG:

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS		
PARAMETER / UNITS	SI	CONV.
DIAMETER OR WIDTH	4.58 m.	15 ft.
LENGTH OR HEIGHT	5.5 m.	18 ft.
MASS	6255 kg.	13,600 lbs.
C.G.	3.69 m.	12 ft.

ORBIT CHECKOUT	X	CONTAM. COVER		THRUSTERS	X	LOUVERS	X
REFURBISH	X	SOLAR ARRAYS	X	ANTENNA		PYROTECHNICS	
DOCKING	X	SUN SHIELD	X	STAR TRACKER	X	OTHER	

MMU/EVA REQUIREMENTS		
PLANNED EVAs	TASK	Checkout basic functions and circuit. Activate supercon- ducting magnetic, test and calibrate instrum.
	NO./MISSION	1 per 1-3 years
	DURATION (hrs.)	3+
CONTINGENCY EVAs	PROBABLE TASK	Connect/disconnect lines, replace failed units
	ESTIMATED DURATION (hrs)	3+

COGNIZANT SCIENTIST OR PI--LOCATION: Dr. A. Opp, NASA/OSS	DEVELOPMENT AGENCY: NASA
	SHEET NO. 1 of 6

EVA TASK DESCRIPTION

PAYLOAD NO. HE-09-A

OBJECTIVE

1. On-orbit servicing
2. Inspection/repair (during in-flight checkout)
3. Aid in deployment/retrieval of payload
4. Replace liquid helium

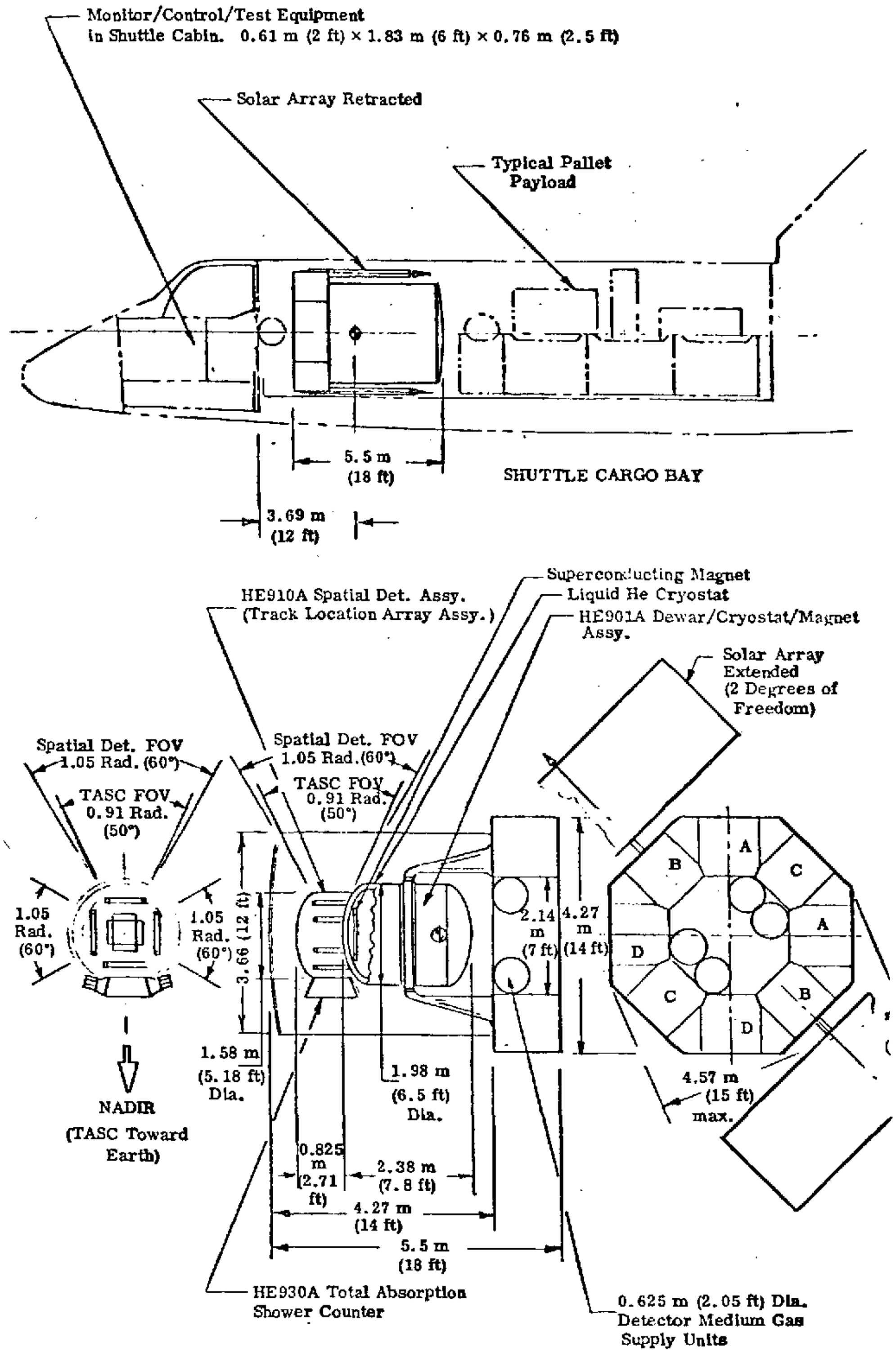
EVA/MMU TASK DESCRIPTION

Large High Energy Observatory B--Magnetic Spectrometer (Figure C5.2)

1. On-orbit servicing (nominal)
   - Prepare for EVA and egress airlock
   - Don MMU--checkout
   - Maneuver to payload with replacement components (portable workstation may be required)
   - Ingress workstation
   - Replenish LHe for super cooled magnet
   - Replace PF tubes, counter detectors and instrument gas
   - Replace failed units
   - Egress workstation
   - Maneuver to MMU donning station - doff MMU
   - Ingress airlock

2. In-flight checkout (unplanned)--payload does not properly checkout for deployment
   - Prep for EVA - egress airlock
   - Inspect accessible areas on payload (unaided EVA)
   - Replace failed units, recharge gas lines
   - If problem cannot be corrected using conventional EVA methods:
     - Don MMU
     - Fly-around--inspect payload
     - Replace failed units
     - Repair damage, if possible
     - Recharge gas lines
   - Doff MMU
   - Ingress airlock

SHEET NO. 2 of 6



A. Experiment Support (HE903A) Support Electronics (3 units).
B. Communications & Data Management System plus Solar Array Actuator.
C. Cold Gas Attitude Control & Guidance Navigation Stabilization (incl. CMGs).
D. Electrical Power System.

FIGURE C5.2: HE-09-A Large High Energy Observatory B--Payload Configuration

SHEET NO. 3 of 6

EVA TASK DESCRIPTION (continued)

PAYLOAD NO. HE-09-A

EVA/MMU TASK DESCRIPTION

3. Aid in deployment/retrieval of Payload (TBD)

   Assistance may be required because of:

   - Unstable payload
   - Malfunctioning manipulator
   - Inability or undesirability for Orbiter-controlled docking (thruster impingement, excessive contamination, excessive use of Orbiter propellants)

SHEET NO. 4 of 6

PAYLOAD NO. HE-09-A

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

- Clean class 100,000 outside instrument assembly
- Radiation 1.15 E-08 J/kgs. (4 m. rad/m.)
- Has cold gas attitude and guidance navigation stabilization
- Contamination by MMU not defined

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

- Present design consideration includes space docking capability; however, there are no provisions at this time for accommodating an EVA/MMU crewman
- Meteoroid/thermal shield and tank are sized to permit in-orbit servicing
- Provisions for manual deployment of solar arrays
- EVA/MMU stabilization/restraint attachment

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Repair kits for thermal protection system, solar arrays, etc. • Crew stabilization/restraint attachment • Temporary module stowage provisions	• LHe - Weight: 430 kg. (946 lbs.) - Size: TBD • Instrument gas: - Weight: 42 kg. (92.4 lbs.)/tank (4 tanks) - Size: TBD • Electronic Units (3) - Weight: 20.1 kg. (44.3 lbs.) - Size: .854 x .177 x .915 m. (2.8 x .58 x 3.0 ft.)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

- GN_2 pressure tank
- Solar array deployment mechanism stored energy
- Cryogenics (LHe)
- Shell pressure control and venting failure

SHEET NO. 5 of 6

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. HE-09-A

WORKING GROUPS/PANEL MEMBERS CONTACTED
Dr. R. L. Golden, Working Group - High Energy Astrophysics, JSC/TN2

REFERENCE DOCUMENTS AND DRAWINGS
• Payload Descriptions, Vol. I, Automated Payloads, MSFC, October 1973 • Payload Planning Working Group Reports, May 1973 • DCN 1-1-21-00090 (IF), Part 1, Preliminary Design and Performance Specifications for Super Conducting Magnetic Spectrometer for HEAO Mission B, 15 Feb. 1972; L. Alvarez, Univ. of Calif., Berkeley

CURRENT STATUS RELATIVE TO EVA/MMU
Planned EVA for on-orbit checkout of payloads Contingency EVA also to support payload checkout

REMARKS/COMMENTS
• MMU can aid in payload retrieval and on-orbit servicing tasks • MMU can be used to service the payload at a short distance from the Orbiter without interrupting the operation of the payload

SHEET NO. 6 of 6

APPENDIX D

SPACELAB (SORTIE) PAYLOAD ANALYSIS

APPENDIX D

TABLE OF CONTENTS

APPENDIX D INTRODUCTION

Appendix D contains informal data used in identifying and supporting the potential MMU missions selected by the contractor as representative MMU applications to the Spacelab (sortie) payloads. Initially, a review of 96 sortie payloads was conducted (see Table D-1). Three Spacelab payloads were selected for detailed applications analysis. Supporting data are provided for these representative MMU missions and include:

- Spacelab payloads analysis sheets
- Preliminary mission description and timelines
- MMU mission scenarios including delta velocity requirements
- Performance and control requirements charts

In developing the typical MMU scenarios, each mission was based on two crewmen for conducting EVAs; however, the MMU systems and supporting hardware will be designed for operation by a single suited crewman and one-man EVAs may be allowed, if necessary, for contingency situations.

APPENDIX D1

LIST OF SORTIE PAYLOADS
AND THEIR MMU APPLICATIONS

LIST OF SORTIE PAYLOADS REVIEWED

ASTRONOMY

AS-01-S — 1.5m Cryogenically-Cooled IR Telescope
AS-03-S — Deep Sky UV Survey Telescope
AS-04-S — 1m Diffraction Limited UV Optical Telescope
AS-05-S — Very Wide Field Galactic Camera
AS-06-S — Calibration of Astronomical Fluxes
AS-07-S — Cometary Simulation
AS-08-S — Multipurpose 0.5m Telescope
AS-09-S — 30m IR Interferometer
AS-10-S — Adv. XUV Telescope
AS-11-S — Polarimetric Experiments
AS-12-S — Meteoroid Simulation
AS-13-S — Solar Variation Photometer
AS-14-S — 1.0m Uncooled IR Telescope
AS-15-S — 3.0m Ambient Temperature IR Telescope
AS-18-S — 1.5 km IR Interferometer
AS-19-S — Selected Area Deep Sky Survey Telescope
AS-20-S — 2.5m Cryogenically cooled IR Telescope
AS-31-S — Combined AS-01, -03, -04, -05-S
AS-41-S — Schwartzschild Camera
AS-42-S — FAR UV Electronographic Schmidt Camera/Spectrograph
AS-43-S — UCB Black Brant Payload
AS-44-S — XUV Concentrator/Detector
AS-45-S — Proportional Counter Array
AS-46-S — Wisconsin UV Photometry Experiment
AS-47-S — Attached Far IR Spectrometer
AS-48-S — Aries/Shuttle UV Telescope
AS-49-S — First UCB Black Brant Payload
AS-50-S — Combined UV/XUV Measurements (AS-04-S, 10-S)
AS-51-S — Combined IR Payload (AS-01-S, 15-S)
AS-54-S — Combined UV Payload (AS-03-S, 04-S)
AS-61-S — Attached Far IR Photometer (Wide FOV)
AS-62-S — Cosmic Background Anisotropy

AS-01-R — LST Revisit

HIGH ENERGY ASTROPHYSICS

HE-11-S — X-ray Angular Structure
HE-12-S — High Inclination Cosmic Ray Survey
HE-13-S — X-ray/Gamma Ray Pallet

HIGH ENERGY ASTROPHYSICS, Contd

HE-14-S — Gamma Ray Pallet
HE-15-S — Magnetic Spectrometer
HE-16-S — High Energy Gamma-Ray Survey
HE-17-S — High Energy Cosmic Ray Study
HE-18-S — Gamma-ray Photometric Studies
HE-19-S — Low Energy X-ray Telescope
HE-20-S — High Resolution X-ray Telescope

HE-03-R — Extended X-ray Survey Revisit
HE-11-R — Large High Energy Observatory D Revisit

SOLAR PHYSICS

SO-01-S — Dedicated Solar Sortie Mission (DSSM)
SO-11-S — Solar Fine Pointing Payload
SO-12-S — ATM Spacelab

ATMOSPHERIC AND SPACE PHYSICS

AP-06-S — Atmospheric, Magnetospheric, and Plasmas in Space (AMPS)

EARTH OBSERVATIONS

EO-01-S — Zero-G Cloud Physics Laboratory
EO-05-S — Shuttle Imaging Microwave System (SIMS)
EO-06-S — Scanning Spectroradiometer
EO-07-S — Active Optical Scatterometer

EARTH AND OCEAN PHYSICS

OP-02-S — Multifrequency Radar Land Imagery
OP-03-S — Multifrequency Dual Polarized Microwave Radiometry
OP-04-S — Microwave Scatterometer
OP-05-S — Multispectral Scanning Imagery
OP-06-S — Combined Laser Experiment

SPACE PROCESSING APPLICATIONS

SP-01-S — SPA No. 1 - Biological (Manned) (B+C)
SP-02-S — SPA No. 2 - Furnace (Manned) (F+C)
SP-03-S — SPA No. 3 - Levitation (Manned) (L+C)
SP-04-S — SPA No. 4 - General Purpose (Manned) (G+C)
SP-05-S — SPA No. 5 - Dedicated (Manned) (B+F+L+G+C)

SPACE PROCESSING APPLICATIONS, Contd

SP-12-S — SPA No. 12 - Automated Furnace (FP+CP)
SP-13-S — SPA No. 13 - Automated Levitation (LP+CP)
SP-14-S — SPA No. 14 - Manned and Automated (B+G+C+FP+LP)
SP-15-S — SPA No. 15 - Automated Furnace/Levitation (FP+LP+CP)
SP-16-S — SPA No. 16 - Biological/General (Manned) (B+G+C)
SP-19-S — SPA No. 19 - Biological and Automated (B+C+FP+LP)
SP-21-S — SPA No. 21 - Minimum Biological (B+C)
SP-22-S — SPA No. 22 - Minimum Furnace (Manned) (F+C)
SP-23-S — SPA No. 23 - Minimum General (G+C)
SP-24-S — SPA No. 24 - Minimum Levitation (Manned) (L+C)

LIFE SCIENCES

LS-04-S — Free Flying Teleoperator
LS-09-S — Life Sciences Shuttle Laboratory
LS-10-S — Life Sciences Carry-on Laboratories

SPACE TECHNOLOGY

ST-04-S — Wall-less Chemistry + Molecular Beam (Facil. No. 1)
ST-05-S — Superfluid He + Particle/Drop Positioning (Facil. No. 2)
ST-06-S — Fluid Physics + Heat Transfer (Facil. No. 3)
ST-07-S — Neutral Beam Physics (Facil. No. 4)
ST-08-S — Integrated Real Time Contamination Monitor
ST-09-S — Controlled Contamination Release
ST-11-S — Laser Information/Data Transmission
ST-12-S — Entry Technology
ST-13-S — Wake Shield Investigation
ST-21-S — ATL P/L No. 2 (Module + Pallet)
ST-22-S — ATL P/L No. 3 (Module + Pallet)
ST-23-S — ATL P/L No. 5 (Pallet Only)

COMMUNICATIONS AND NAVIGATION

CN-04-S — Terrestrial Sources of Noise + Interference
CN-05-S — Laser Communication Experimentation
CN-06-S — Communication Relay Tests
CN-07-S — Large Reflector Deployment
CN-08-S — Open Traveling Wave Tube
CN-11-S — Stars & Pads Experimentation
CN-12-S — Interferometric Navigation & Surveillance Techniques
CN-13-S — Shuttle Navigation Via Geosynchronous Satellite

C-3

TABLE D-1: List of Sortie Payloads and Their MMU Applications

PAYLOAD NO.	INSPECT/CHECK	SUBSATELLITE DEPLOY/RETRIEVE	CONTINGENCY EQP. DATA RETRIEVAL	SYSTEMS DEPLOY/RETRACT	SYSTEMS SERVICE/REPAIR	MODULE REPLACEMENT	JETTISON				PLANNED EVA	CONTINGENCY EVA
ASTRONOMY												
AS-01-S	●				●							X
AS-03-S	●			●	●		●					X
AS-04-S	●			●	●		●					X
AS-05-S	●		●	●	●		●					X
AS-06-S	●				●							X
AS-07-S	●				●							X
AS-08-S	●				●							X
AS-09-S	●			●	●		●				X	X
AS-10-S	●				●							X
AS-11-S	●				●							X
AS-12-S												
AS-13-S												
AS-14-S	●				●							X
AS-15-S	●			●	●		●					X
AS-18-S	●				●							X
AS-19-S	●				●							X
AS-20-S	●				●							X
AS-31-S	●		●		●							X
AS-41-S	●		●		●							X
AS-42-S												
AS-43-S												
AS-44-S	●				●							X
AS-45-S												
AS-46-S	●				●							X
AS-47-S												
AS-48-S	●				●							X
AS-49-S												
AS-50-S	●		●		●							X
AS-51-S	●				●							X

●- MMU POTENTIAL APPLICATION X- EVA STATUS

PAYLOAD NO.	INSPECT/CHECK	SUBSATELLITE DEPLOY/RETRIEVE	CONTINGENCY EQP. DATA RETRIEVAL	SYSTEMS DEPLOY/RETRACT	SYSTEMS SERVICE/REPAIR	MODULE REPLACEMENT	JETTISON				PLANNED EVA	CONTINGENCY EVA
AS-54-S	●		●		●							X
AS-61-S												
AS-62-S												
AS-01-R	●		●		●	●					X	X
HIGH ENERGY ASTROPHYSICS												
HE-11-S	●				●							X
HE-12-S												
HE-13-S	●				●							X
HE-14-S	●				●							X
HE-15-S	●			●	●		●					X
HE-16-S												
HE-17-S												
HE-18-S												
HE-19-S	●				●							X
HE-20-S	●				●							X
HE-03-R	●		●		●	●					X	X
HE-11-R	●		●		●	●					X	X
SOLAR PHYSICS												
SO-01-S	●		●		●							X
SO-11-S	●		●		●							X
SO-12-S	●		●		●						X	X
ATMOSPHERIC AND SPACE PHYSICS												
AP-06-S	●	●	●	●	●		●					X
EARTH OBSERVATIONS												
EO-01-S												
EO-05-S	●			●	●		●				X	X

TABLE D-1: List of Sortie Payloads and Their MMU Applications (continued)

PAYLOAD NO.	INSPECT/CHECK	SUBSATELLITE DEPLOY/RETRIEVE	CONTINGENCY EQP. RETRIEVAL	DATA RETRIEVAL	SYSTEMS DEPLOY/ RETRACT	SYSTEMS SERVICE/ REPAIR	MODULE REPLACEMENT	JETTISON			PLANNED EVA	CONTINGENCY EVA
EO-06-S	●				●							X
EO-07-S	●				●							X
EARTH AND OCEAN PHYSICS												
OP-02-S	●				●							X
OP-03-S	●			●	●		●					X
OP-04-S	●				●							X
OP-05-S	●				●							X
OP-06-S	●				●							X
SPACE PROCESSING APPLICATIONS												
SP-01-S												
SP-02-S												
SP-03-S												
SP-04-S												
SP-05-S												
SP-12-S												
SP-13-S												
SP-14-S												
SP-15-S												
SP-16-S												
SP-19-S												
SP-21-S												
SP-22-S												
SP-23-S												
SP-24-S												
LIFE SCIENCES												
LS-04-S	●				●							X
LS-09-S	●		●		●							X

NO MMU APPLICATIONS IDENTIFIED SINCE EQUIPMENT IS LOCATED INSIDE SPACELABS AND ON PALLETS WITH NO EQUIPMENT EXTENDING BEYOND THE PAYLOAD BAY DOORS.

PAYLOAD NO.	INSPECT/CHECK	SUBSATELLITE DEPLOY/RETRIEVE	CONTINGENCY EQP. RETRIEVAL	DATA RETRIEVAL	SYSTEMS DEPLOY/ RETRACT	SYSTEMS SERVICE/ REPAIR	MODULE REPLACEMENT	JETTISON			PLANNED EVA	CONTINGENCY EVA
LS-10-S	●		●		●							X
SPACE TECHNOLOGY												
ST-04-S												
ST-05-S												
ST-06-S												
ST-07-S												
ST-08-S												
ST-09-S												
ST-11-S												
ST-12-S												
ST-13-S				●			●					
ST-21-S	●		●	●	●		●					
ST-22-S	●		●	●	●		●					
ST-23-S	●		●	●	●		●					
COMMUNICATIONS AND NAVIGATION												
CN-04-S	●				●							X
CN-05-S	●				●							X
CN-06-S	●				●							X
CN-07-S	●			●	●		●					X
CN-08-S	●			●	●		●				X	X
CN-11-S	●			●	●		●					X
CN-12-S	●			●	●		●					X
CN-13-S												

APPENDIX D2

ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE

(AP-06-S - AMPS)

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. AP-06-S

PAYLOAD NAME: Atmospheric, Magnetospheric and Plasmas in Space		INITIAL LAUNCH: 1981	FLIGHTS IN PROGRAM: 30
NO. PAYLOADS BUILT: 6	ORBIT: LEO (500 m., 270 mi.)		OMS SETS: 1

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	PARAMETER \ UNITS	SI	CONV.
	DIAMETER OR WIDTH	Various pallet and boom mounted equipment	
	LENGTH OR HEIGHT	Various pallet and boom mounted equipment	

ORBIT CHECKOUT	X	ANTENNA	X	CONTAM. COVER		STAR TRACKER	
SERVICEABLE		SUN SHIELD	X	PYROTECHNICS	X	LOUVERS	
SOLAR ARRAYS		OTHER: Subsatellites, balloons, booms					

MMU/EVA REQUIREMENTS			
	PLANNED EVAs	TASK	None defined to date
		NO./MISSION	
		DURATION (hrs.)	
	CONTINGENCY EVAs	PROBABLE TASK	Aid in deployment/retraction retrieval of subsatellites extend payload members, inspect, monitor, repair, jettison
		DURATION (hrs.)	TBD (task dependent)

COGNIZANT SCIENTIST OR PI--LOCATION: Dr. E. C. Schmerling/R. Chase, Hdq/OSS x 5-3674	DEVELOPMENT AGENCY: NASA/OSS

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EVA TASK DESCRIPTION

PAYLOAD NO. AP-06-S

OBJECTIVE

1. Deploy/retrieve subsatellites
2. Deploy extendible payload members
3. Retract extendible payload members

EVA/MMU TASK DESCRIPTION

Atmospheric and Space Plasma Physics Sortie Laboratory (Figures D2.1 - D2.7)

1. Deploy/retrieve subsatellite
   - Prepare for EVA - egress airlock
   - Don MMU - maneuver to satellite stowage location with tether system
   - Attach tether system to satellite--free satellite from stowage
   - Tow satellite to desired location (the dynamics of this task are TBD)
   - After experiment operations, tow satellite back to Orbiter
   - Maneuver satellite into its stowage locations and secure
   - Maneuver to MMU station - doff MMU
   - Ingress airlock

2. Deploy extendible payload member (condition: extendible member does not fully deploy during initial orbital checkout
   - Prepare for EVA - egress airlock
   - Don MMU - if not accessible by conventional EVA methods
   - Release automatic deployment mechanisms
   - Maneuver to end of member, deploy and lock in place
   - After experiment operations, reverse above procedure
   - If member cannot be retracted to allow payload doors to close, jettison member

3. Retract extendible payload member (condition: extendible member deploys normally, but does not fully retract following experiment operations)
   - Reference task description 2 above

SHEET NO. 2 of 11

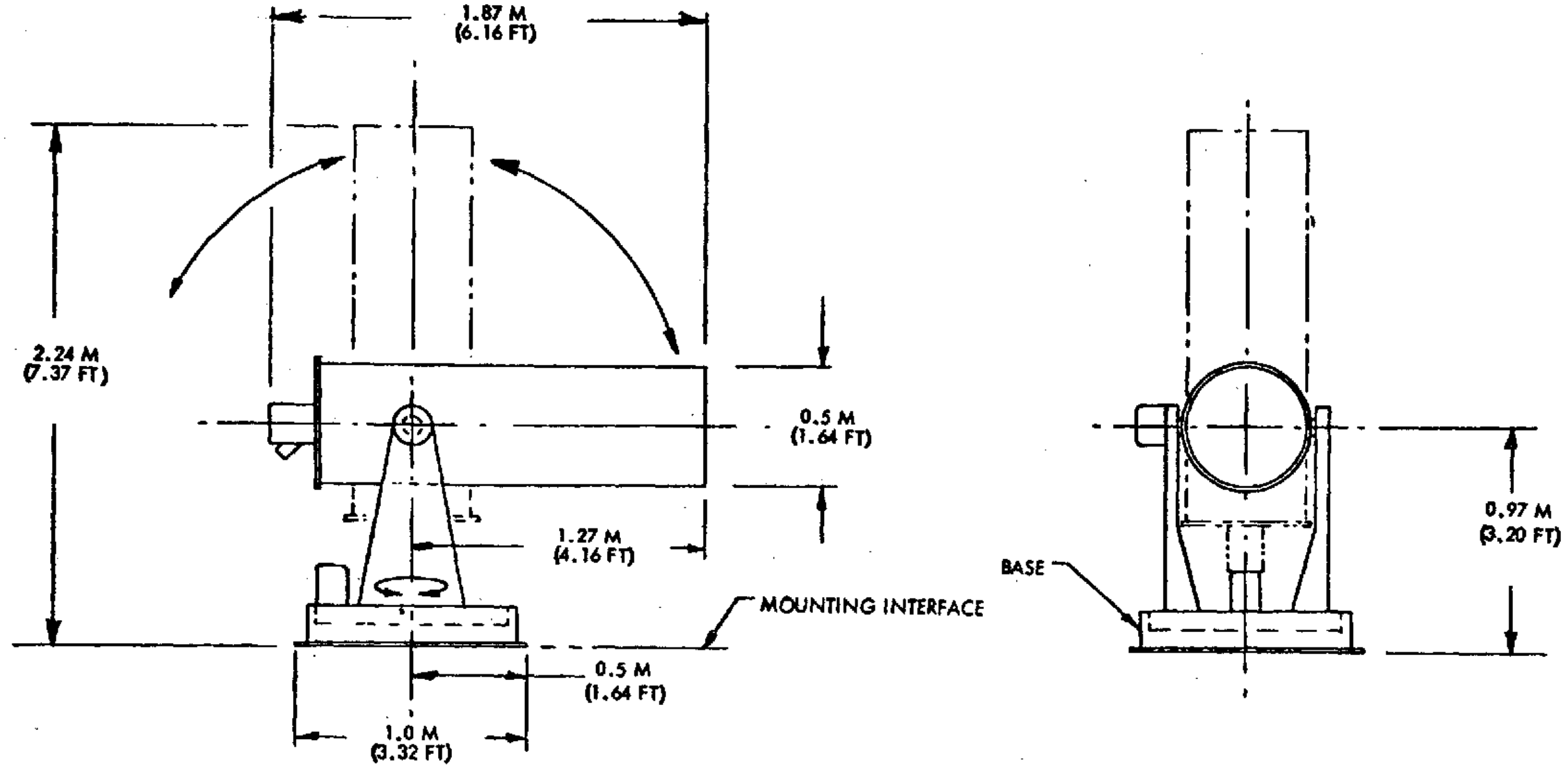


FIGURE D2.1: AP200 Laser Radar Equipment Envelope--Payload AP-06-S

AP100 REMOTE SENSING PLATFORM SYSTEM

AP101 REMOTE SENSING PLATFORM
AP102 XUV NORMAL INCIDENCE SPECTROMETER
AP103 UV-VISIBLE-NIR SCANNING SPECTROMETER
AP104 HIGH-RESOLUTION FOURIER SWIR SPECTROMETER
AP105 CRYOGENIC IR FOURIER SPECTROMETER
AP106 IR RADIOMETER
AP107 FABRY-PEROT INTERFEROMETER
AP108 FILTER PHOTOMETER
AP109 UV-VISIBLE DOCUMENTATION CAMERAS
AP110 ION MASS SPECTROMETER
AP111 NEUTRAL MASS SPECTROM
AP112 ELECTROSTATIC ANALYZER
AP113 MAGNETIC ANALYZER
AP114 KEV-MEV PARTICLE DETECTOR
AP115 TOTAL ENERGY DETECTOR
AP116 CYLINDRICAL PROBE
AP117 SEGMENTED PLANAR PROBE
AP118 RF PROBE
AP119 PLANAR PROBE

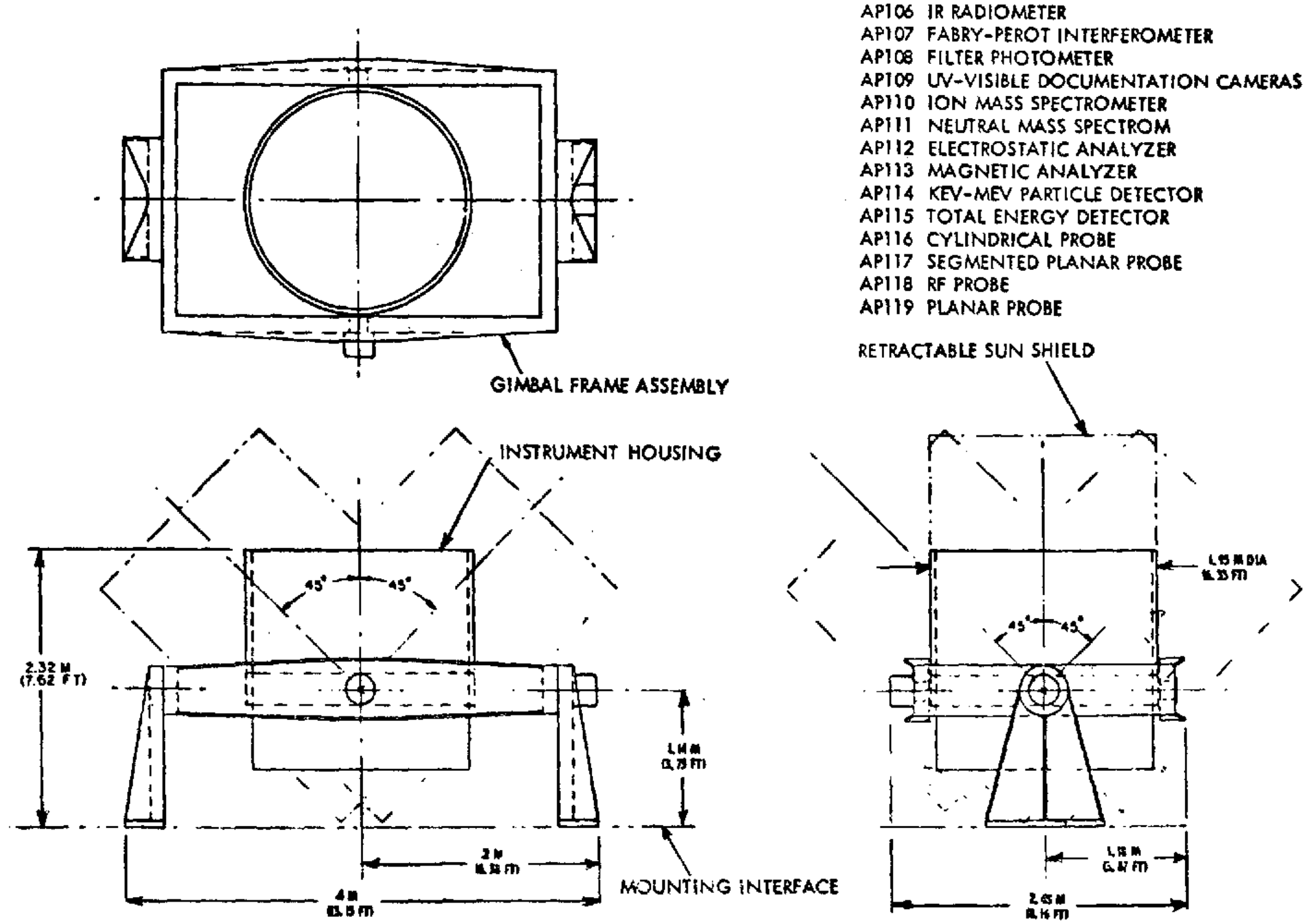


FIGURE D2.2: AP100 Remote Sensing Platform System--Payload AP-06-S

AP300 GIMBALED ACCELERATOR SYSTEM

AP301 ION ACCELERATOR Shown

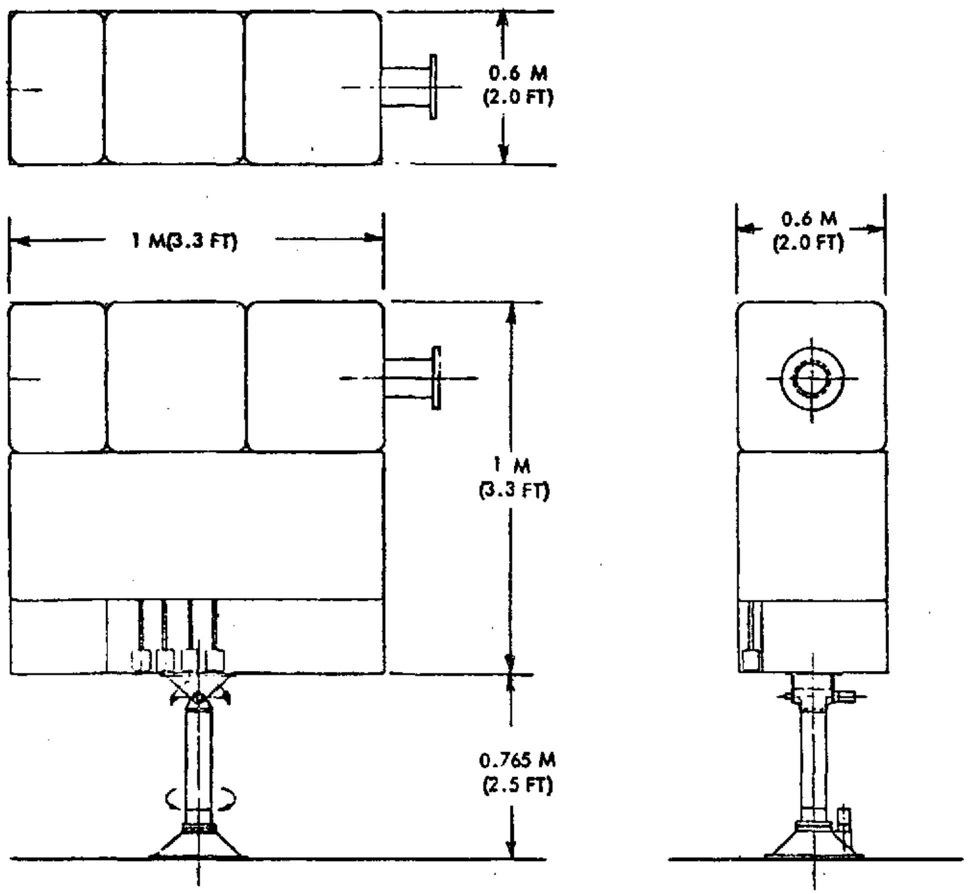


FIGURE D2.3: AP300 Gimbaled Accelerator System--Payload AP-06-S

SHEET NO. 5 of 11

AP400 TRANSMITTER/COUPLER SYSTEM

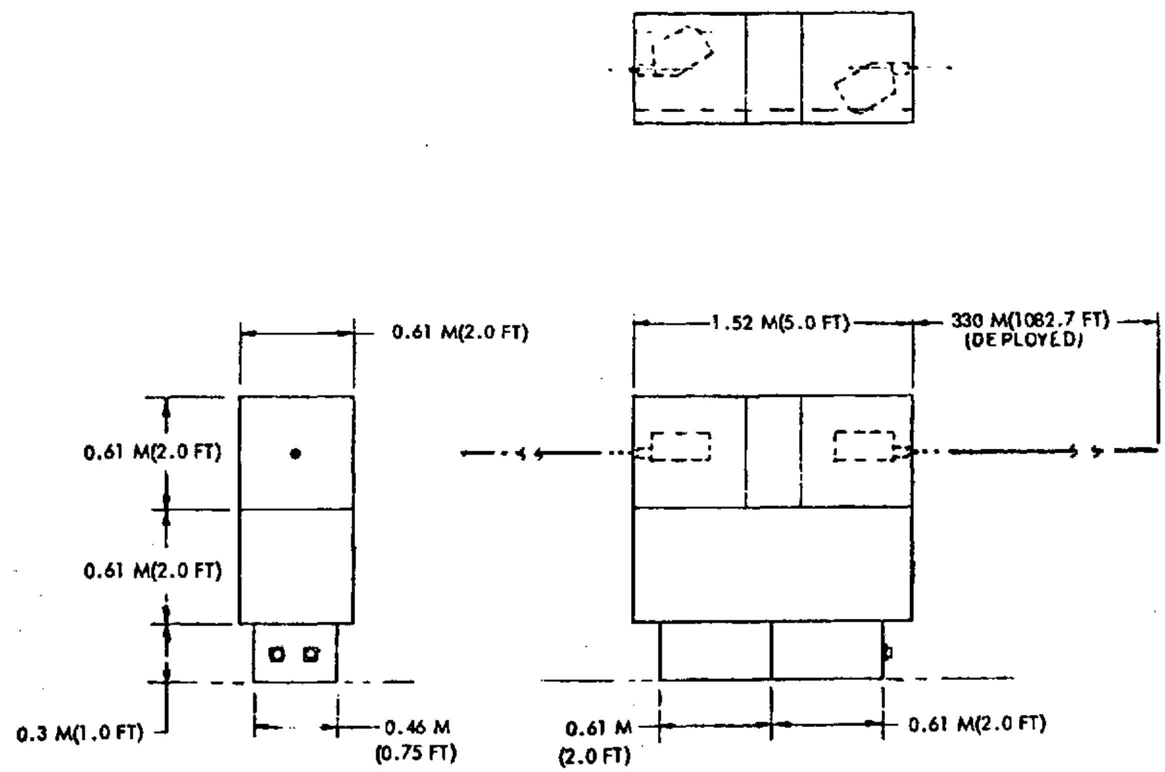
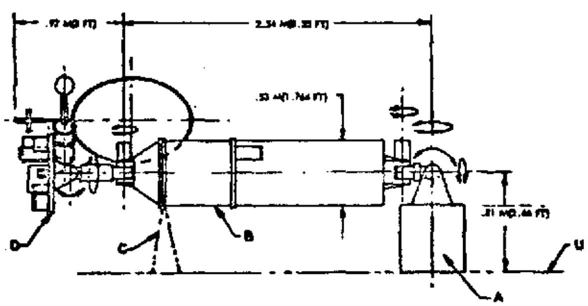


FIGURE D2.4: AP400 Transmitter/Coupler System--Payload AP-06-S

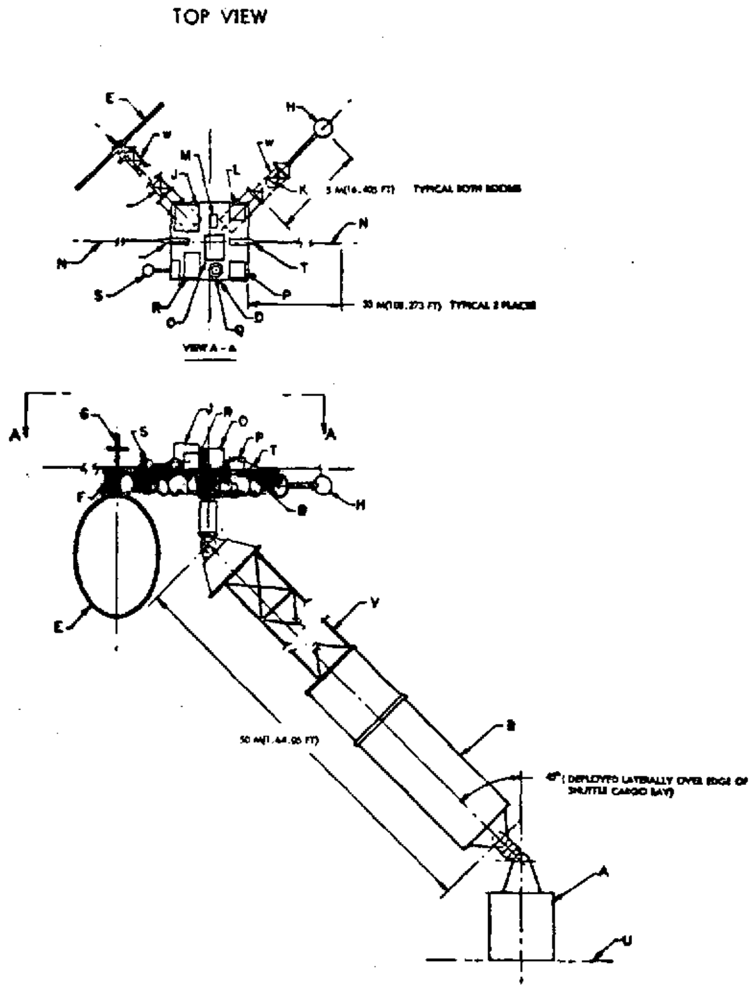
AP500 BOOM SYSTEM

AP501 50-Meter Boom A

A Mounting Base
B Mast Deployment System
C Support Strut
D Experiment Mounting Platform
E 1 Meter Loop
F Short Wavelength Electric Dipoles
G Triaxial Search Coils
H Rubidium Magnetometer
J Triaxial Hemispherical Analyzer
K Triaxial Fluxgate Magnetometer
L Planar Ion Trap or Neutral Mass Spectrometer
M Alignment TV Camera
N Long Electric Dipole for AC and DC
O Power Supply and Data System
P Planar Electron Trap
Q Cylindrical Probe
R Ion Mass Spectrometer
S Spherical Ion Probe
T Stem Actuator
U Pallet Mounting Interface
V Deployed Mast
W 5-M Booms



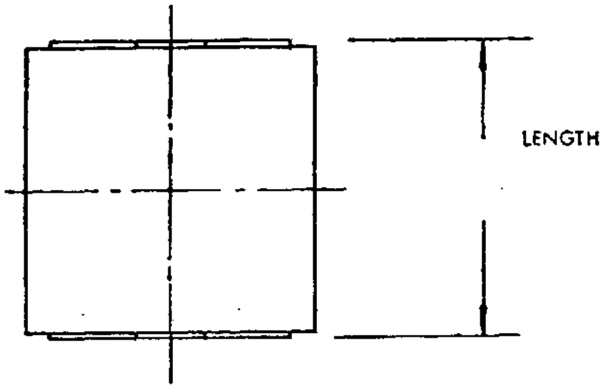
STOWED



DEPLOYED

FIGURE D2.5: AP500 Boom System (AP501 50 Meter Boom A)--Payload AP-06-S

ITEM NUMBER	EQUIPMENT NAME	DIA.	LENGTH
AP601	Barium Canister, 100 gm	0.125 (0.415)	0.125 (0.415)
AP602	Barium Canister, 1 kg	0.198 (0.66)	0.198 (0.66)
AP603	Barium Canister, 10 kg	0.3 (1.0)	0.375 (1.25)
AP610	Shaped Charge, 1 kg	0.198 (0.66)	0.61 (2.0)
AP611	Shaped Charge, 5 kg	0.350 (1.165)	1.03 (3.42)
AP612	Shaped Charge, 20 kg	0.549 (1.83)	1.63 (5.42)
AP620	Balloon - Spherical Insulated	0.198 (0.66)	0.375 (1.25)
AP621	Balloon - Spherical Conducting	0.25 (0.833)	0.498 (1.66)



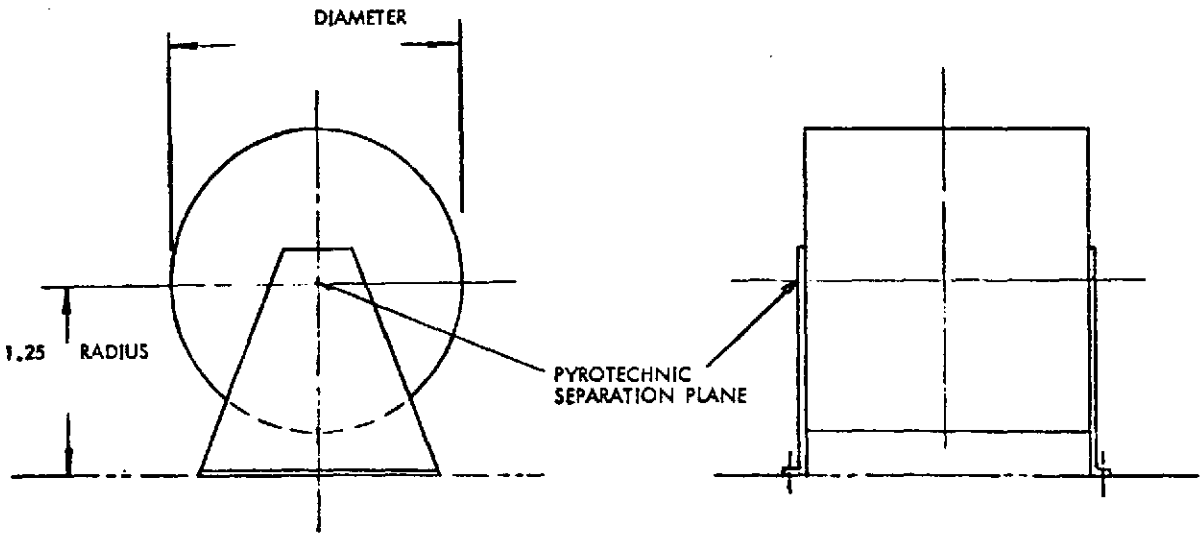
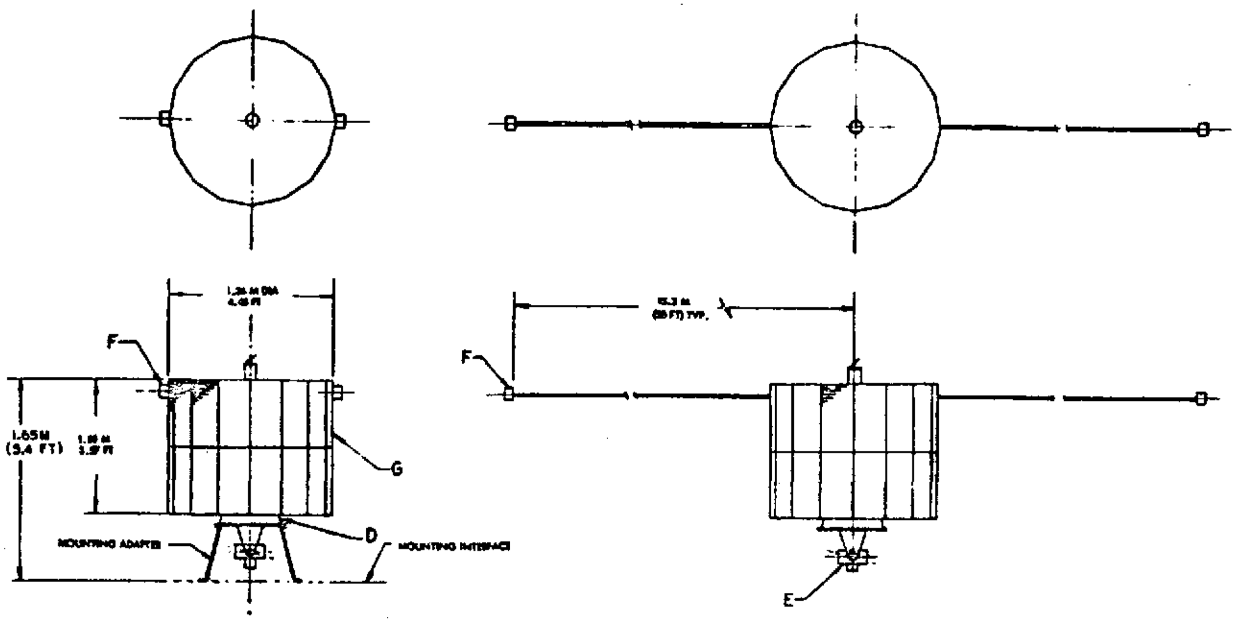


FIGURE D2.6: AP600 Deployable Units--Payload AP-06-S



STOWED

DEPLOYED

AP700 DEPLOYABLE SATELLITE SYSTEM
- AP701 SATELLITE
- AP702 TV SYSTEM
- AP703 MAG 3-AXIS FLUXGATE
- AP704 MAG SEARCH COIL
- AP705 CYL ELEC PROBE
- AP706 SEGMENTED PLANAR TRAP
- AP707 ION MASS SPECTROMETER
- AP708 TRIAXIAL HEMISPH. ANALYZER
- AP709 VLF RECEIVER
- AP710 E-FIELD METER
- AP711 SATELLITE/PALLET INTERFACE & EJECTOR MECHANISM
- AP712 TRANSPONDER, TELEMETRY & RANGING

FIGURE D2.7: AP700 Deployable Satellite System--Payload AP-06-S

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. AP-06-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

- No direct RCS impingement on optical sensors
- Clean class 300,000 (internal equipment)
- Relative humidity <60%

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

- Handrail access to pallet and payload areas
- Foot restraint provisions at worksites
- Provisions for manual operation of booms, arrays, etc.
- Tether attachment points on subsatellites

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• General tool kit • Tethers • Handrails/handholds • Portable lights • Portable foot restraints • Video/camera equipment	No on-orbit servicing is specified at this time • Subsatellites (2 required) - Volume: 3.834 m^3 (68.48 ft^3) (both satellites) - Weight: 1356.4 kg. (2994 lbs.) (both satellites) • Deployable Units - kg. (lb.) - Barium Canisters: 1.3 (2.86), 3.0 (6.6), 15.0 (33.0) - Shaped Charge: 30 (66), 150 (330), 600 (1320) - Balloons: 4.0 (8.8), 7.0 (15.4)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

- Vacuum tubes
- High voltage
- Explosive squibs (canisters)
- High pressure gas bottles

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SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. AP-06-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

see Appendix G

REFERENCE DOCUMENTS AND DRAWINGS

- Plasma Physics and Environmental Perturbation Laboratory, Performance Reviews 1 - 4, TRW Systems Group, MSFC Contract No. NAS 8-28047
- Preliminary Design Study for an Atmospheric Science Facility, R. Hutchinson, Martin Marietta, MCR 72-322, December 1972
- Payloads Description Document, Volume I, Sortie Payloads, October 1973

CURRENT STATUS RELATIVE TO EVA/MMU

- Only a contingency EVA capability is specified at this time

REMARKS/COMMENTS

The payload contains a combination of very elaborate externally mounted equipment including optical instrumentation and particle sensors, a laser radar, long booms (50 m.) for remote measurements, subsatellites, and a variety of deployable devices. It is felt that the capabilities of an EVA/MMU, if added to this payload, would greatly increase the chances for successful missions.

SHEET NO. 11 of 11

CONTINGENCY SUPPORT OF ATMOSPHERIC,
MAGNETOSPHERIC, AND PLASMAS IN SPACE
(AMPS) PAYLOADS

AMPS Experiment Hardware

The AMPS payload consists of a variety of active and passive instrumentation designed to observe and artifically perturb the space environment and upper atmosphere. Major assemblies mounted externally include a remote servicing platform, housing optical instrumentation and field and particle sensors; a laser radar (LIDAR); 50 m booms for remote measurements of the ambient environment and wake studies; transmitters and particle accelerators for simulation of the ionosphere and magnetosphere; subsatellites; and a variety of deployable devices, including those designed to release chemicals into the upper ionosphere and magnetosphere. Two mission classes are presentently defined: type A--low inclination (28.5°) and type B--high inclination (90°). The desired orbits are 435 kg. (270 mi.) circular orbit for type A and 340 kg. (210 mi.) for type B.

In addition to the 50 m. (164 ft.) deployable mast, several smaller masts and booms are contained in the AMPS equipment inventory. These include:

- Transmitter/coupler system--2 dipole elements, 330 m. (1083 ft.)
- Deployable satellite system--2 booms, 15.2 m. (50 ft.)
- One meter loop antenna--one 5 m. (16.4 ft.) mast
- Extendible electric dipole--2 m. (108 ft.)
- Rubidium magnetometer--one 5 m. (16.4 ft)
- Short VLF dipole antennas

Referencing Figure D2.8, these booms/masts are mounted on an experiment platform extended 50 m. (164 ft.) from the Orbiter payload bay. The booms/masts (listed

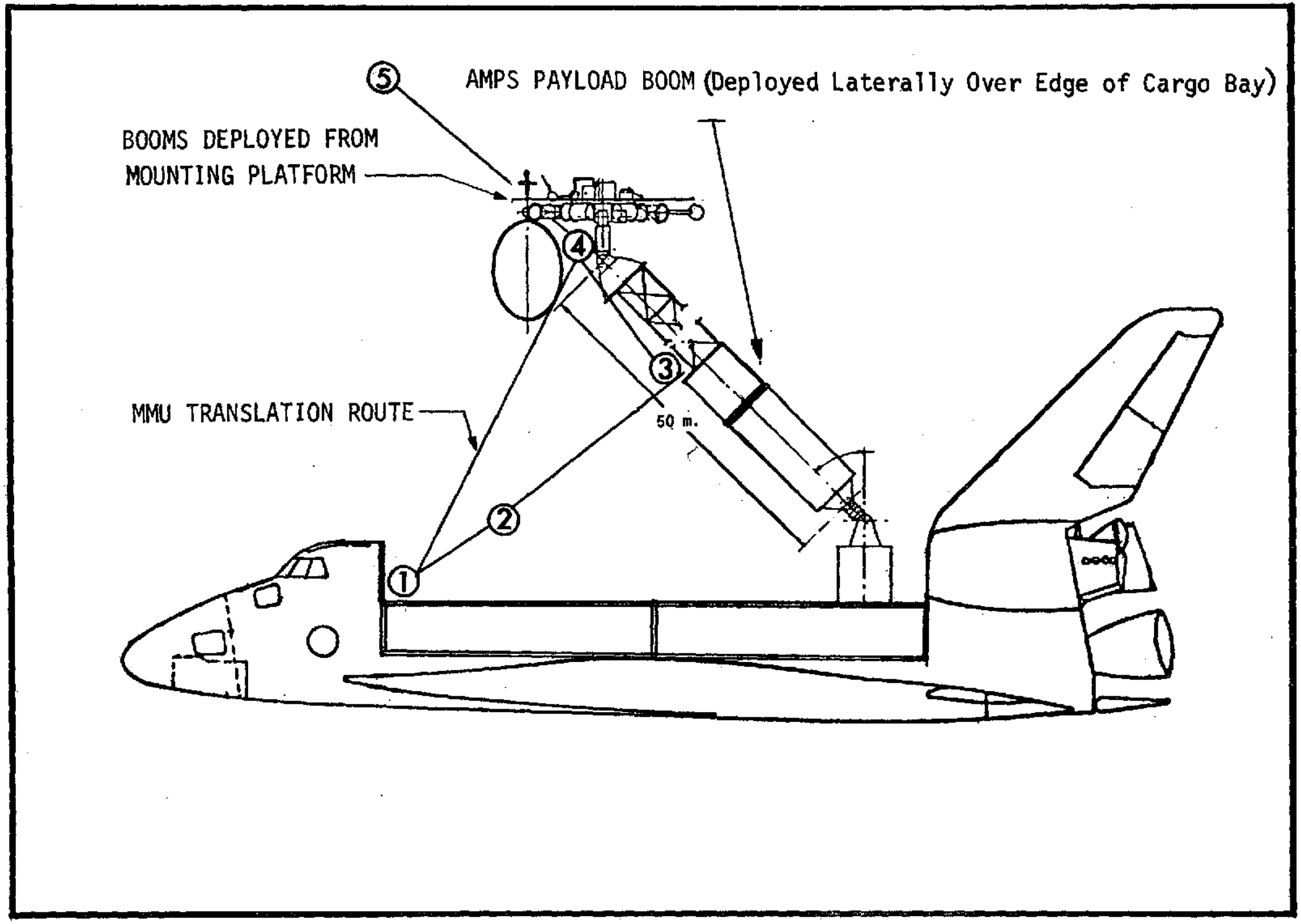


FIGURE D2.8: Translation Route for AMPS Boom Deployment above) are then extended from the experiment platform. Failure or malfunction of a boom system in an extended configuration would prohibit closing the payload bay doors and would require jettison measures. An MMU could be utilized to repair, extend, retract, or jettison failed components to avoid loss of all experiment equipment. The booms/masts were reviewed relative to use as an EVA crewman translation aid for contingency equipment servicing/repair.

State-of-the-art masts (see Table D6-6) with the capability required for the 50 m. (164 ft.) mast (mast A) on the AMPS payload appear to be:

1. Astromast articulated lattice--this beam can be made with a high stiffness to weight ratio and is at full strength at all times during deployment. However, folding is achieved by loosening one tension member (wire rope) in each bay. Although the tension members are "locked" on each bay as the truss is extended, inadvertent actuation of the wire rope tension members could cause collapse of the mast if used as an EVA crewman translation system. All mast structural members would also be required to meet EVA glove interface standards (e.g., no sharp edges, protrusions, corners) if used for translation.

2. Astromast coilable lattice--longitudinal sections are continuous coilable members. This beam is limited to low load applications, and as the load increases, the diameter of the longerons increase and quickly become too stiff to coil in a reasonable stowage area. The sides of the triangular section are buckled to initiate coiling operations. The coilable lattice mast does not appear suitable for EVA crewman translation due to the possibility of inadvertent collapse particularly if the crewman is required to apply forces during servicing.

The physical, operational and performance characteristics of the masts and booms for the AMPS payload are not fully defined; however, the units do not appear suitable for use as EVA translation systems. Additional study of the mast selected for flight will be required. Forces imparted to the mast during EV crewman activities must be studied. Also, the crewman could not access the smaller masts and booms extending from the mounting platform.

The MMU could inspect and service the AMPS equipment in the extended configuration in a free-flying mode or tethered to the mast system.

AMPS Boom Deployment Timeline

The typical MMU mission outlined in this appendix involves a contingency boom deployment operation to assist in the completion of normal mission objectives. Table D2-1 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task.

The MMU mission is baselined as a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU, while crewman no. 2 (CM2) supports CM1 from the payload bay.

MMU Requirements to Deploy AMPS Booms

A typical MMU translation route is shown in Figure D2.8. Table D2-2 shows the estimated travel distance for the mission, as well as direction changes, number of starts/stops, estimated velocity and Δvelocity requirements.

Total ΔV Required

The translation ΔV required for this MMU mission is approximately 4.61 m/sec (15.1 ft/sec). From M509 flight experience it was determined that the ΔV used for rotation is approximately equal to that required for translation. Therefore, the total ΔV for both translation and rotation is approximately 9.22 m/sec (30.2 ft/sec).

TABLE D2-1: AMPS Boom Deployment Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		2.0
Checkout MMU	X	X		15.0
Don MMU and ancillary equipment	X		tether, cable (50 m.)	15.0
Flight check MMU on tether in bay	X			15.0
Remove tether	X			1.0
Translate clear of Sortie Lab	X			1.0
Translate to boom deployment mechanism		X		3.0
Translate to boom end, attach tether	X			--
Translate along boom deployment path--reel out tether (50 m.)	X			3.0
Release boom mechanism		X		--
Tow boom to full extension*	X			5.0
Translate to boom end and release tether	X			3.0
Aid deployment of smaller booms and experiment equipment, if required*	X			10.0
Translate to MMU stowage area	X	X		5.0
Stow MMU and support equipment	X	X		15.0
Ingress airlock - End EVA	X	X		2.0
*See MMU performance and control requirements--this task				
			TOTAL TIME	97.0

TABLE D2-2: MMU Requirements to Deploy AMPS Booms

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/STOPS	m/sec	ft/sec	m/sec	ft/sec
MMU Checkout	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
<u>Deploy AMPS Boom</u>										
1 to 2 translate clear of Orbiter bulkhead	3	(10)	--	15	120	2	.09	(.3)	.18	(.6)
2 to 3 translate to boom end, attach tether	10	(33)	--	30	15	2	.12	(.4)	.24	(.8)
3 to 4 deploy tether along boom path	50	(164)	20	30	180	2	.3	(1.0)	.61	(2.0)
4 to 5 pull boom to full extension	50	(164)	10	40	90	2	.3	(1.0)	.61	(2.0)
5 to 4 translate to boom end, release tether	50	(164)	15	15	180	2	.3	(1.0)	.61	(2.0)
4 aid deployment of experiment as required	240	(785)	180	270	360	8	.09	(.3)	.73	(2.4)
4 to 1 translate to MMU stowage area	10	(33)	--	30	120	2	.12	(.4)	.24	(.8)
Doff MMU, stow, ingress airlock										
TOTAL	459	(1503)	585	790	1425	35			4.61	(15.1)
TRANSLATION ΔV + ROTATION ΔV									*9.22	(30.2)

*If boom must also be retracted total ΔV = 18.44 m/sec (60.4)ft/sec)

MMU PERFORMANCE AND CONTROL REQUIREMENTS

AMPS EXPERIMENT SUPPORT

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	460 m.	1500 ft.
TOTAL VELOCITY CHANGE CAPABILITY	9.22 m/sec	30.2 ft/sec
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.045 m.	±.15 ft.
- VELOCITY PRECISION	±.023 m/sec	±.075 ft/sec
- ATTITUDE HOLD PRECISION	±2°*	--
- ATTITUDE RATE PRECISION	±2°/sec	--
ACCELERATION (2)		
- TRANSLATION	≤.09 m/sec^2	≤.3 ft/sec^2
- ROTATION	>6°	--
FORCE APPLICATIONS (3)		
- LINEAR		
- TORQUE		

REMARKS

(1) This accuracy is required to deploy delicate experiment hardware and retrieve equipment and data from failed extendible members.

(2) Not critical for this task.

(3) The force required is failure dependent (Astromast info. not available).

* Design driver from MMU applications analysis.

APPENDIX D3

ADVANCED TECHNOLOGY LABORATORY
(ST-21-S, ST-22-S, ST-23-S)

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. ST-21-S

PAYLOAD NAME: Advanced Technology Laboratory, Payload 2				INITIAL LAUNCH: 1982		FLIGHTS IN PROGRAM: 7		
NO. PAYLOADS BUILT: TBD		ORBIT: LEO (370 km.; 200 mi.)				OMS SETS: 0		
PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	PARAMETER / UNITS		SI			CONV.		
	DIAMETER OR WIDTH		See Payload Requirements and Constraints					
	LENGTH OR HEIGHT		Four 38.1 m. booms One 15.2 m. boom One TBD m. boom			125 ft. booms 50 ft. boom TBD ft. boom		
ORBIT CHECKOUT	X	ANTENNA	X	CONTAM. COVER		STAR TRACKER		
SERVICEABLE		SUN SHIELD		PYROTECHNICS	?	LOUVERS		
SOLAR ARRAYS		OTHER: Extendible booms						
MMU/EVA REQUIREMENTS	PLANNED EVAs	TASK	No planned EVAs scheduled to date					
		NO./MISSION						
		DURATION (hrs.)						
	CONTINGENCY EVAs	PROBABLE TASK	Inspect, retrieve samples, deploy/retract/jettison, repair extension mechanism					
		DURATION (hrs.)	TBD (task dependent)					
COGNIZANT SCIENTIST OR PI--LOCATION: W. Ray Hook, LaRC/SSD (703) 827-3666					DEVELOPMENT AGENCY: LaRC/OAST			

SHEET NO. 1 of 5

EVA TASK DESCRIPTION

PAYLOAD NO. ST-21-S

OBJECTIVE

Unplanned MMU/EVA missions to:

1. XST017--Inspect and repair/jettison boom to allow door closure

EVA/MMU TASK DESCRIPTION

1. XST017 Mapping of Upper Atmospheric Neutral Gas Parameters (Figure D.3)
   - Prepare for EVA and egress Orbiter cabin
   - Inspect instrument deployment mechanism on pallet
   - Don MMU
   - Perform MMU fly-around inspection of deployment boom and instrument
   - Detach and retrieve mass spectrometer instrument
   - Remove and jettison boom (length TBD)
   - Doff/stow MMU
   - Ingress Orbiter cabin

SHEET NO. 2 of 5

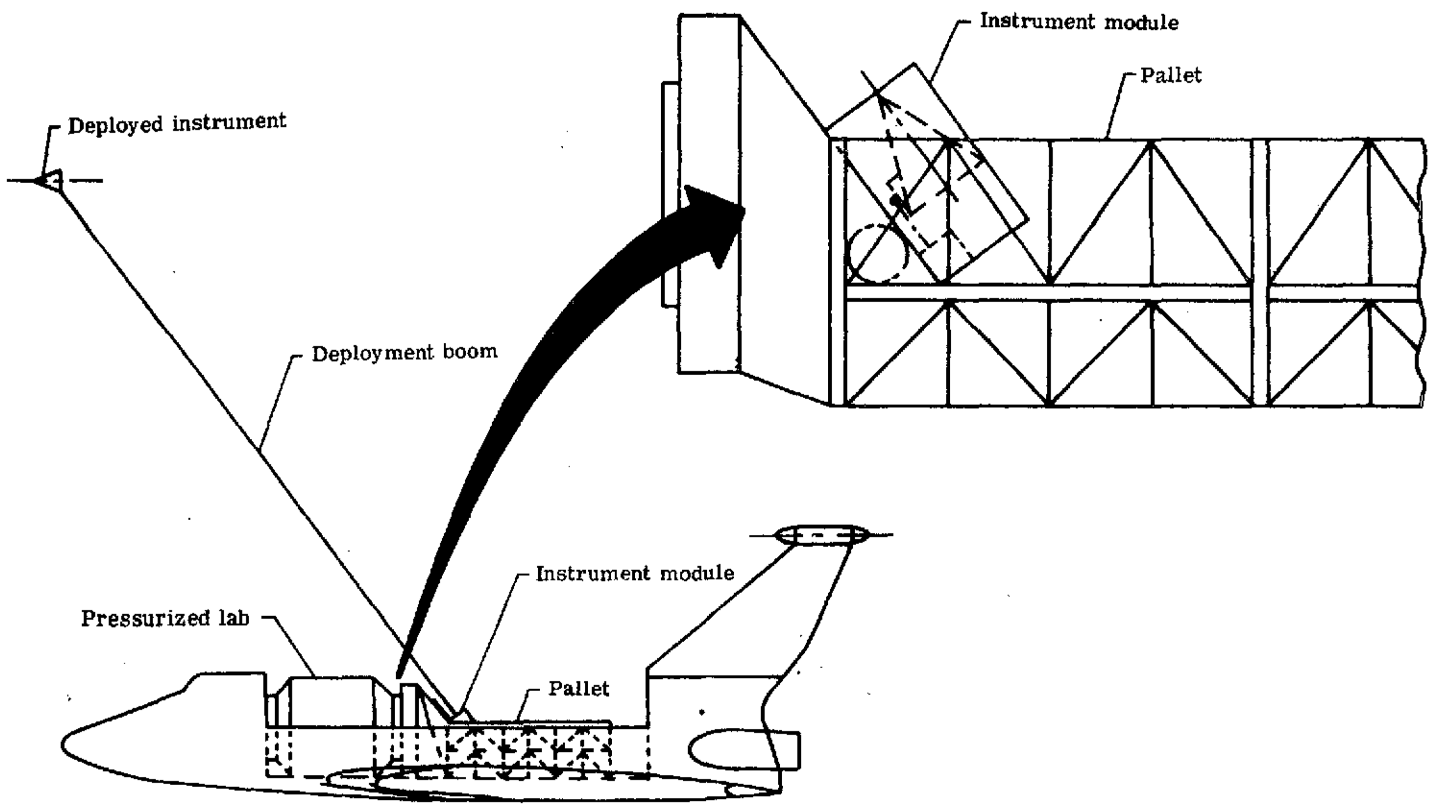


FIGURE D3.1: XST017 Mapping of Upper Atmosphere Neutral Gas Parameters--Pallet Equipment

PAYLOAD REQUIREMENTS AND CONSTRAINTS
FOR
XST017

PAYLOAD NO. ST-21-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST017:

- No contamination constraints presently defined during unplanned repair activities

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST017:

- Crewman restraint provisions at experiment mount on pallet
- Design mass spectrometer for on-orbit removal from extended boom
- Crew mobility aid on pallet

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. EVA Egress Module B. XST017 Support Equipment • Crew restraints at worksite • Portable lights • Manual backup for boom acutation • Crew access	XST017 • Mass spectrometer unit - Weight: 4.5 kg. (10 lbs.) - Size: .15 m. dia. x .3 m. (.5 ft. dia. x 1.0 ft.) - C.G.: Not critical

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST017:

- None defined

SHEET NO. 4 of 5

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. ST-21-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

- Joseph P. Loftus, Space Technology Working Group, NASA/JSC-AT
- Kenneth R. Taylor, Space Processing Applications Integration, NASA/MSFC-PD-MP-T

REFERENCE DOCUMENTS AND DRAWINGS

1. Modification and updating of the Manned Activity Scheduling System (MASS) for Shuttle and Shuttle Payload Analysis, Volume II - Space Shuttle Sortie Payload Analysis, NASA CR-112287, Contract NAS 1-11674, Convair Aerospace, San Diego, California, April 1973
2. Study of Shuttle - Compatible Advanced Technology Laboratory (ATL) NASA TMX-2813, Langley Research Center, Hampton, Va., September 1973
3. Payloads Description, Volume II, Sortie Payloads, NASA/Marshall Space Flight Center, October 1973 (Preliminary SSPD)

CURRENT STATUS RELATIVE TO EVA/MMU

Payload pallet experiments and experiments deployed from Spacelab scientific airlocks are automated systems. No planned EVA/MMU functions are presently scheduled. Unplanned or contingency EVA/MMU activities are not addressed in ATL documentation.

REMARKS/COMMENTS

The EVA/MMU practicable applications addressed are suggested for further study relative to economy, experiment salvaging, Orbiter re-entry status and safety.

SHEET NO. 5 of 5

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. ST-22-S

PAYLOAD NAME: Advanced Technology Laboratory, Payload 3				INITIAL LAUNCH: 1981		FLIGHTS IN PROGRAM: 7	
NO. PAYLOADS BUILT: TBD		ORBIT: LEO (555 km., 300 mi.)				OMS SETS: 0	
PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS		PARAMETER \ UNITS		SI		CONV.	
		DIAMETER OR WIDTH		See Payload Requirements and Constraints			
		LENGTH OR HEIGHT		One 25 x 1.98 m. antenna One 22.8 m. boom One 15.2 m. boom		82 x 6.5 ft. 75 ft. 50 ft.	
ORBIT CHECKOUT	X	ANTENNA	X	CONTAM. COVER		STAR TRACKER	
SERVICEABLE		SUN SHIELD		PYROTECHNICS	?	LOUVERS	
SOLAR ARRAYS		OTHER: Extendible booms					
MMU/EVA REQUIREMENTS		PLANNED EVAs		TASK		No planned EVAs scheduled to date	
				NO./MISSION			
				DURATION (hrs.)			
		CONTINGENCY EVAs		PROBABLE TASK		Deploy antenna, retract/jettison equipment, inspect/monitor, photograph, repair	
				DURATION (hrs.)		TBD (task dependent)	
COGNIZANT SCIENTIST OR PI--LOCATION: W. Ray Hook, LaRC/SSD (703) 827-3666						DEVELOPMENT AGENCY: LaRC/OAST	

SHEET NO. 1 of 10

EVA TASK DESCRIPTION

PAYLOAD NO. ST-22-S

OBJECTIVE

Unplanned MMU/EVA missions to:

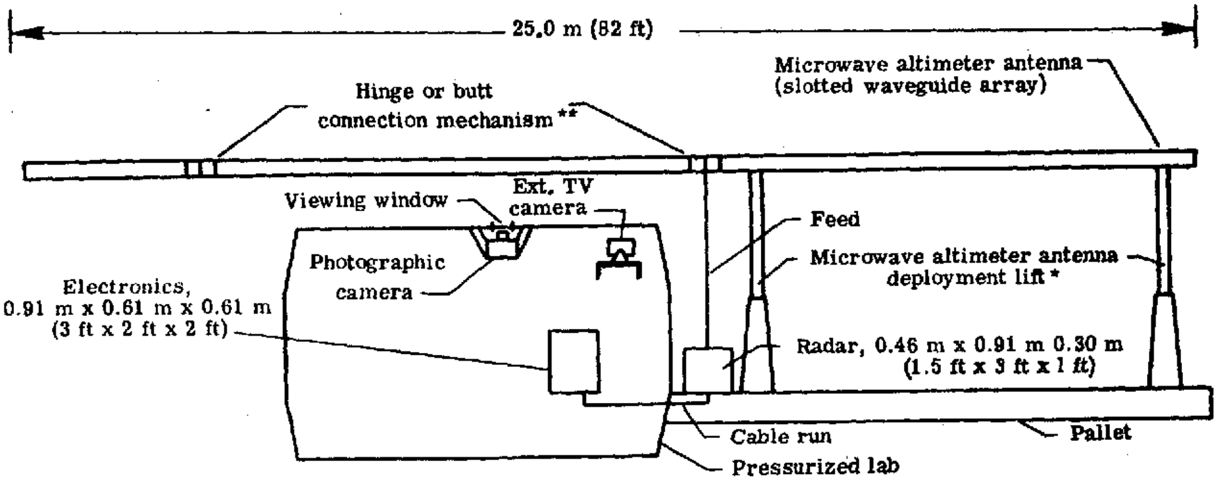
1. XST005--Inspect, repair, fold or jettison antenna system
   XST014--Inspect, retrieve hardware, repair/jettison boom
   XST029--Inspect, retrieve samples, repair/jettison boom

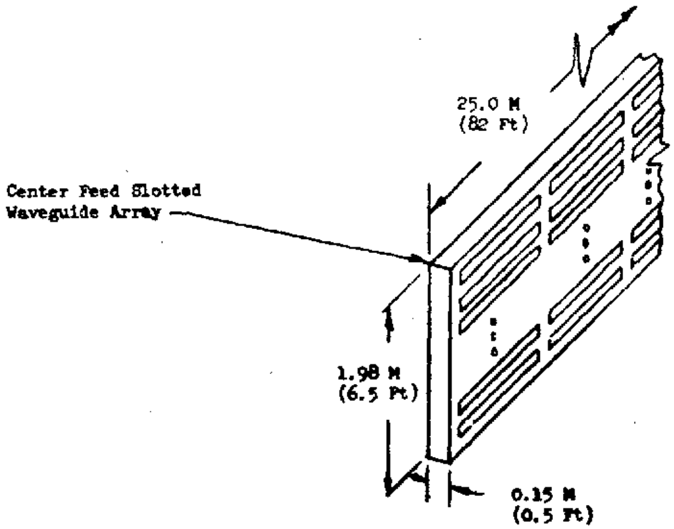
EVA/MMU TASK DESCRIPTION

1. XST005 Microwave Altimetry (Figure D3.2)
   - Inspect antenna deployment mechanism
   - Don MMU
   - Inspect microwave altimeter antenna hinge/sliding connection mechanisms
   - Perform required maintenance/repairs:
     - Release failed hinge system
     - Fold/retract antenna sections
       or
     - Remove failed antenna sections and jettison
       or
     - Remove antenna at pallet interface and jettison
   - Secure antenna systems
   - Doff/stow MMU
   - Ingress Orbiter cabin

2. XST014 Spacecraft Wake Dynamics (Figure D3.3)
   - Inspect external boom deployment system
   - Don MMU
   - Inspect diagnostic equipment on deployed boom
   - Remove and return the following equipment:
     - Retarding potential Analyzers (4)
       * Weight: 1.8 kg. (4 lbs.)
       * Size: .15 x .3 m. (.5 x 1.0 ft.)--Volume: .005m.^{3} (.19 ft.^{3})
     - Mass Spectrometers (2)
       * Weight: 4.5 kg. (10 lbs.)
       * Size: .15 x .3 m. (.5 x 1.0 ft.)--Volume: .005 m.^{3} (.19 ft.^{3})
     - Magnetometers, Flux Gate (2)
       * Weight: 9.1 kg. (20 lbs.)
       * Size: .3 x .3 m. (1.0 x 1.0 ft.)--Volume: .021 m.^{3} (.79 ft.^{3})

SHEET NO. 2 of 10





* Single point mounting may be desirable if antenna inertia can be used to maintain stability for small vehicle motion damping.

** Antenna will require folding, sliding, and/or assembly using manipulator arms to provide for stowage with shuttle bay doors closed. Specific design to be determined.

FIGURE D3.2: XST005 Microwave Altimetry--Pallet Equipment

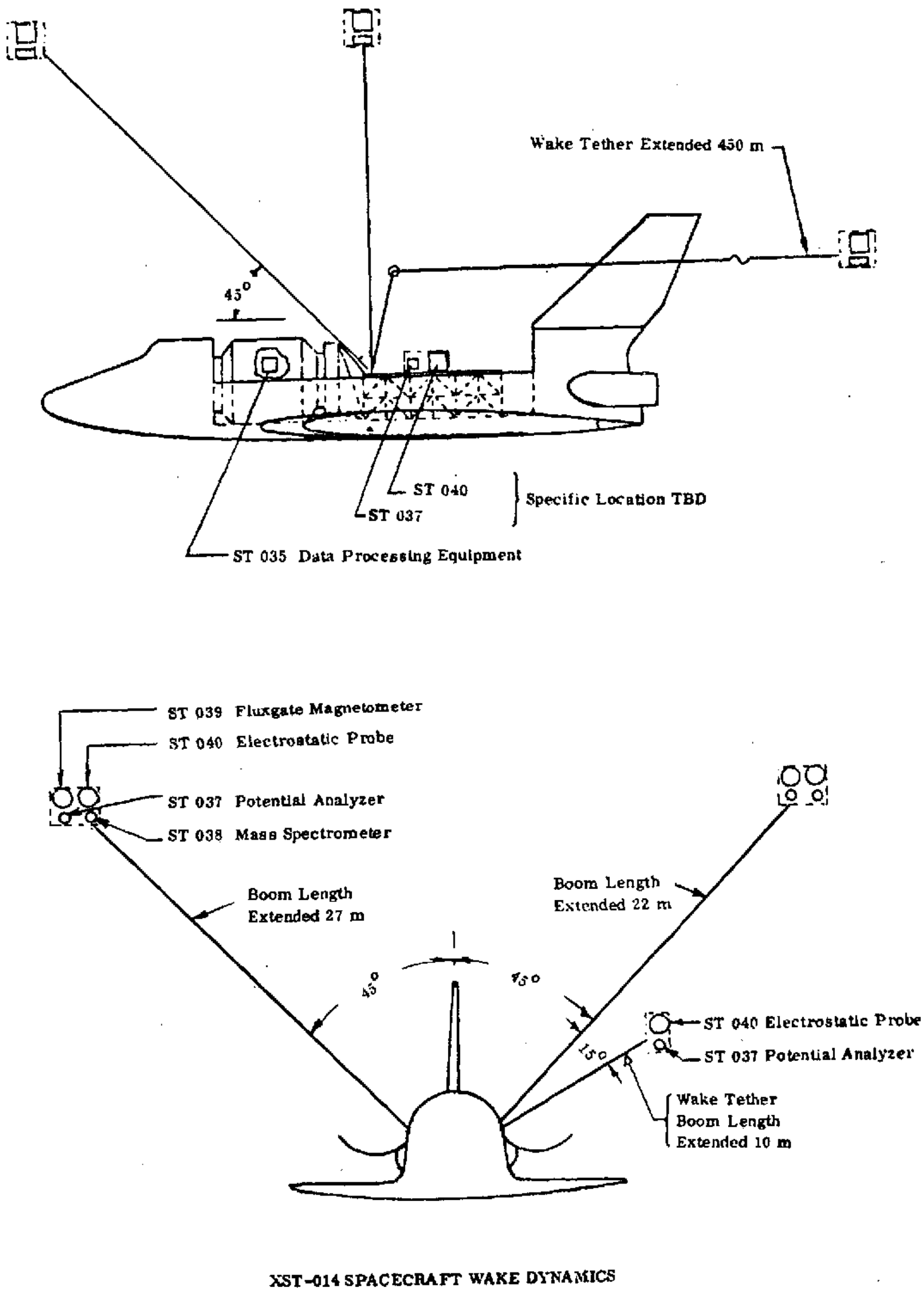


FIGURE D3.3: XST014 Spacecraft Wake Dynamics

SHEET NO. 4 of 10

PAYLOAD NO. ST-22-S

EVA/MMU TASK DESCRIPTION

2. continued

- Electrostatic Probes (4)
  * Weight: 1.8 kg. (4 lbs.)
  * Size: TBD--Volume: .029 $m.^3$ (1.02 $ft.^3$)
- Remove and jettison external boom, 22.8 m. (75 ft.)
- Doff and stow MMU
- Ingress Orbiter cabin

3. XST029 Environmental Effects on Nonmetallic Materials (Figure D3.4)

- Prepare for EVA and egress Orbiter cabin
- Inspect "STEM" deployment system on pallet
- Don MMU
- Perform MMU fly-around inspection of sample arrays
- Manually remove covers from sample containers
- Replace sample array covers and remove sample containers from boom mechanism
- Manually retract boom or jettison, 15.2 m. (50 ft.)
- Reseal sample container for vacuum stowage
- Doff/stow MMU
- Ingress Orbiter cabin

SHEET NO. 5 of 10

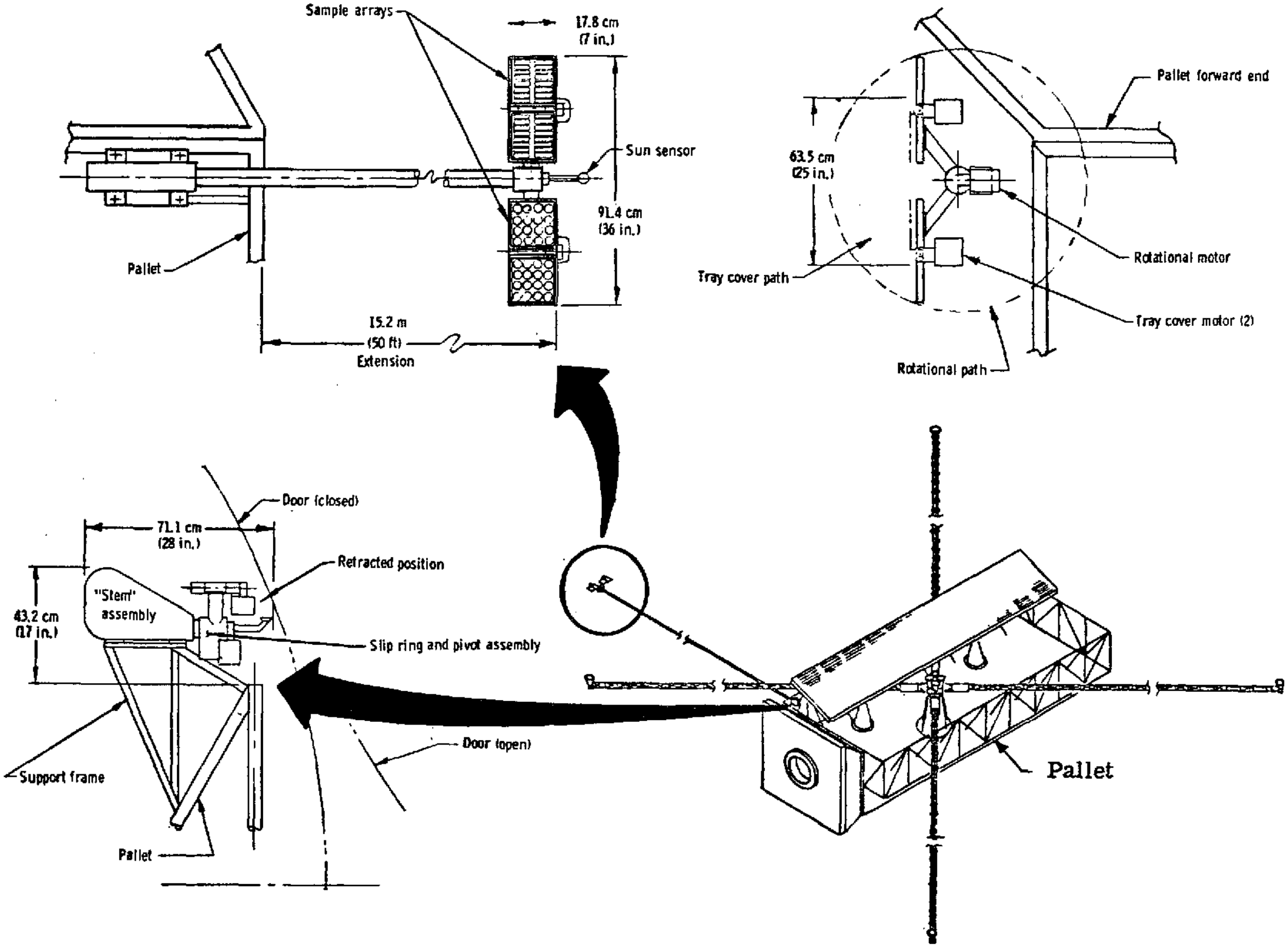


FIGURE D3.4: XST029 Environmental Effects on Nonmetallic Materials--Pallet Equipment

PAYLOAD REQUIREMENTS AND CONSTRAINTS
FOR
XST005

PAYLOAD NO. ST-22-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST005:

- No contamination constraints identified

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST005:

- Design antenna system for on-orbit EVA servicing
- Crewman restraint/stabilization provisions at worksite
- Design antenna system for contingency jettison

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. EVA Egress Module B. XST005 Support Equipment • Crew restraints at worksite • Antenna retraction tools (special) • Portable lights • Crew access	XST005 • Antenna servicing/retraction kit - Weight: <7 kg. (15 lbs.) - Size: <.03 $m.^3$ (1 $ft.^3$) - C.G.: Not critical

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST005:

- Stored energy of malfunctioned antenna retract mechanism
- Sliding antenna joints

SHEET NO.7 of 10

PAYLOAD REQUIREMENTS AND CONSTRAINTS

FOR

XST014

PAYLOAD NO. ST-22-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST014:

- Limit contamination as much as practical during unplanned/contingency experiment repair/retrieval activities

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST014:

- Design diagnostic equipment for EVA servicing/retrieval
- Crewman restraint provisions/receptacle at pallet worksite
- Crew mobility aids on pallet

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. Airlock Egress Module B. XST014 Support Equipment • Crew restraints at worksite • Crew access • Portable lights • Tools	XST014 • Diagnostic equipment - See sheets 2-5 of 10, EVA/MMU Task Description for XST014

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST014:

- None defined to date

SHEET NO. 8 of 10

PAYLOAD REQUIREMENTS AND CONSTRAINTS

FOR

XST029

PAYLOAD NO. ST-22-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST029:

- Samples may be contaminated by thrusters (not presently defined)
- No contamination constraints presently defined during unplanned retrieval/repair activities

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST029:

- Design sample containers to be operated and retrieved from extended boom by an EVA crewman
- Provide crewman restraint receptacles/interface at experiment mount on pallet
- Crew mobility aids on pallet

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. EVA Egress Module B. XST029 Support Equipment • Crew restraints at worksites • Portable lights • Manual backup (hand crank) for boom actuation • Crew Access	XST029 • Materials sample container - Weight: 2.3 kg. (5.0 lbs.) - Size: .18 x .18 x .06 m. (.6 x .6 x .2 ft.) - C.G.: Not critical

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST029:

None defined

SHEET NO. 9 of 10

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. ST-22-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

- Joseph P. Loftus, Space Technology Working Group, NASA/JSC-AT
- Kenneth R. Taylor, Space Processing Applications Integration, NASA/MSFC-PD-MP-T

REFERENCE DOCUMENTS AND DRAWINGS

1. Modification and updating of the Manned Activity Scheduling System (MASS) for Shuttle and Shuttle Payload Analysis, Volume II - Space Shuttle Sortie Payload Analysis, NASA CR-112287, Contract NAS 1-11674, Convair Aerospace, San Diego, California, April 1973
2. Study of Shuttle - Compatible Advanced Technology Laboratory (ATL) NASA TMX-2813, Langley Research Center, Hampton, Va., September 1973
3. Payloads Description, Volume II, Sortie Payloads, NASA/Marshall Space Flight Center, October 1973 (Preliminary SSPD)

CURRENT STATUS RELATIVE TO EVA/MMU

Payload pallet experiments and experiments deployed from Spacelab scientific airlocks are automated systems. No planned EVA/MMU functions are presently scheduled. Unplanned or contingency EVA/MMU activities are not addressed in ATL documentation.

REMARKS/COMMENTS

The EVA/MMU practicable applications addressed are suggested for further study relative to economy, experiment salvaging, Orbiter re-entry status and safety.

SHEET NO. 10 of 10

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. ST-23-S

PAYLOAD NAME: Advanced Technology Laboratory, Payload 5				INITIAL LAUNCH: 1982		FLIGHTS IN PROGRAM: 9	
NO. PAYLOADS BUILT: TBD		ORBIT: LEO (185 km., 100 mi.)				OMS SETS: 0	
PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	PARAMETER \ UNITS			SI		CONV.	
	DIAMETER OR WIDTH			See Payload Requirements and Constraints			
	LENGTH OR HEIGHT			One 22.8 m. boom One TBD boom One 15.2 m. boom		75 ft. TBD 50 ft.	
ORBIT CHECKOUT	X	ANTENNA	X	CONTAM. COVER		STAR TRACKER	
SERVICEABLE		SUN SHIELD		PYROTECHNICS	?	LOUVERS	
SOLAR ARRAYS		OTHER: Extendible boom					
MMU/EVA REQUIREMENTS	PLANNED EVAs	TASK		No planned EVAs scheduled to date			
		NO./MISSION					
		DURATION (hrs.)					
	CONTINGENCY EVAs	PROBABLE TASK		Retrieve experiments, deploy/retract/jettison booms, inspect, monitor			
		DURATION (hrs.)		TBD (task dependent)			
COGNIZANT SCIENTIST OR PI--LOCATION: W. Ray Hook, LaRC/SSD (703) 827-3666				DEVELOPMENT AGENCY: LaRC/OAST			

SHEET NO. 1 of 11

EVA TASK DESCRIPTION

PAYLOAD NO. ST-23-S

OBJECTIVE

Unplanned/contingency MMU/EVA missions to:

1. XST014--Inspect, retrieve hardware, repair/jettison boom
2. XST017--Inspect and repair/jettison boom to allow door closure
3. XST029--Inspect, retrieve samples, repair/jettison boom

EVA/MMU TASK DESCRIPTION

1. XST001 Microwave and Interferometer Navigation and Tracking Aid (Figures D3.5 and D3.6)

   - Prepare for EVA and egress Orbiter cabin
   - Inspect interferometer boom mount, drive mechanisms and canister on pallet
   - Don MMU
   - Perform MMU fly-around inspection of booms
   - Perform necessary repairs
     - Release restrained boom sections
     - Attach rope - pulley system and winch booms
     - Detach boom segments and jettison, 38.1 m. (125 ft.)
   - Secure interferometer boom drive and mounting system
   - Doff/stow MMU
   - Ingress Orbiter cabin

2. XST017 Mapping of Upper Atmospheric Neutral Gas Parameters (Figure D3.7)

   - Prepare for EVA and egress Orbiter cabin
   - Inspect instrument deployment mechanism on pallet
   - Don MMU
   - Perform MMU fly-around inspection of deployment boom and instrument
   - Detach and retrieve mass spectrometer instrument
   - Remove and jettison boom (length TBD)
   - Doff/stow MMU
   - Ingress Orbiter cabin

SHEET NO. 2 of 11

PAYLOAD NO. ST-23-S

EVA/MMU TASK DESCRIPTION

3. XST029 Environmental Effects on Nonmetallic Materials (Figure D3.8)

- Prepare for EVA and egress Orbiter cabin
- Inspect "STEM" deployment system on pallet
- Don MMU
- Perform MMU fly-around inspection of sample arrays
- Manually remove covers from sample containers
- Replace sample array covers and remove sample containers from boom mechanism
- Manually retract boom or jettison, 15.2 m. (50 ft.)
- Reseal sample container for vacuum stowage
- Doff/stow MMU
- Ingress Orbiter cabin

SHEET NO. 3 of 11

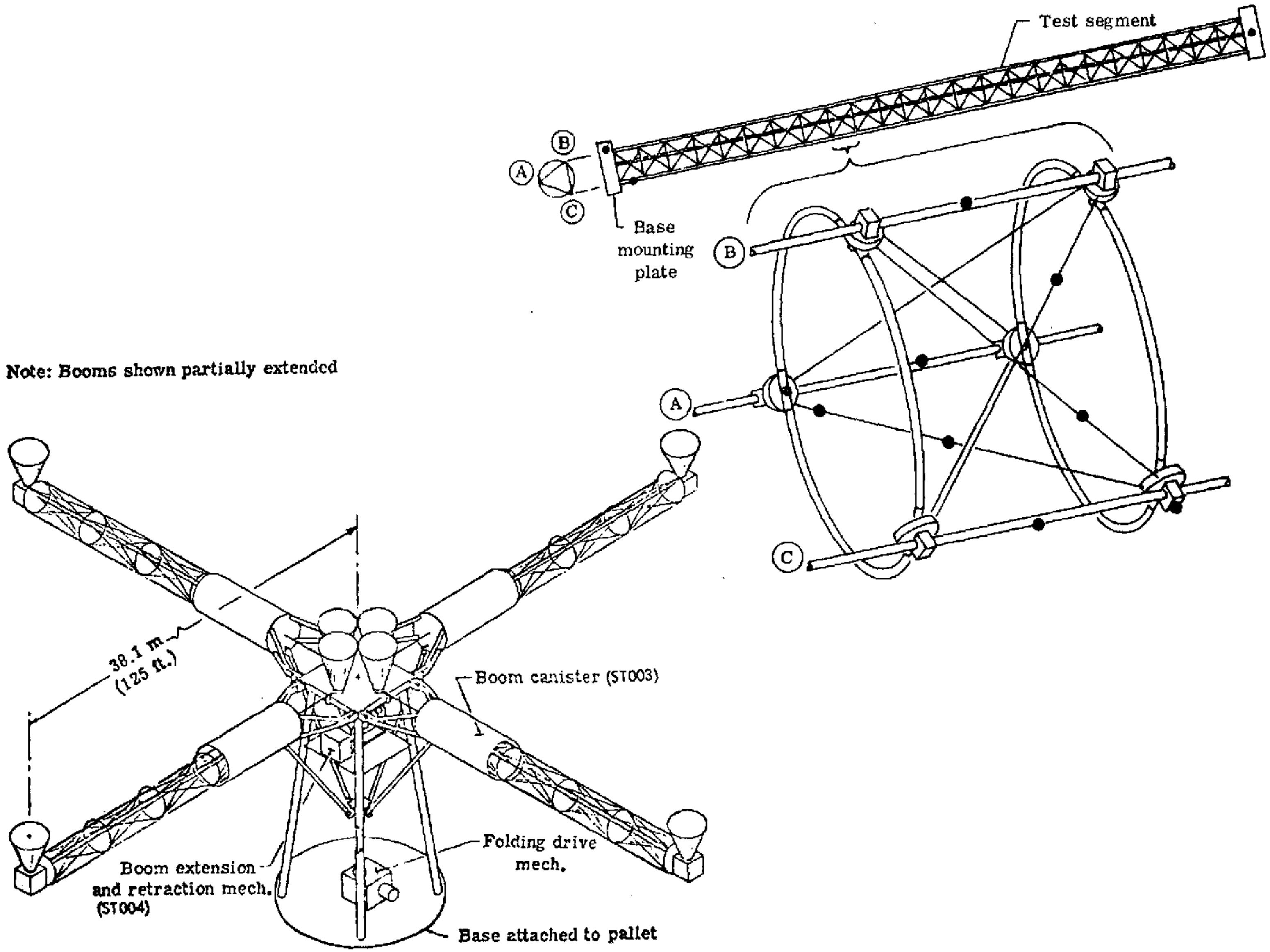


FIGURE D3.5: XST001 Microwave Interferometer Navigation and Tracking Aid--Pallet Equipment

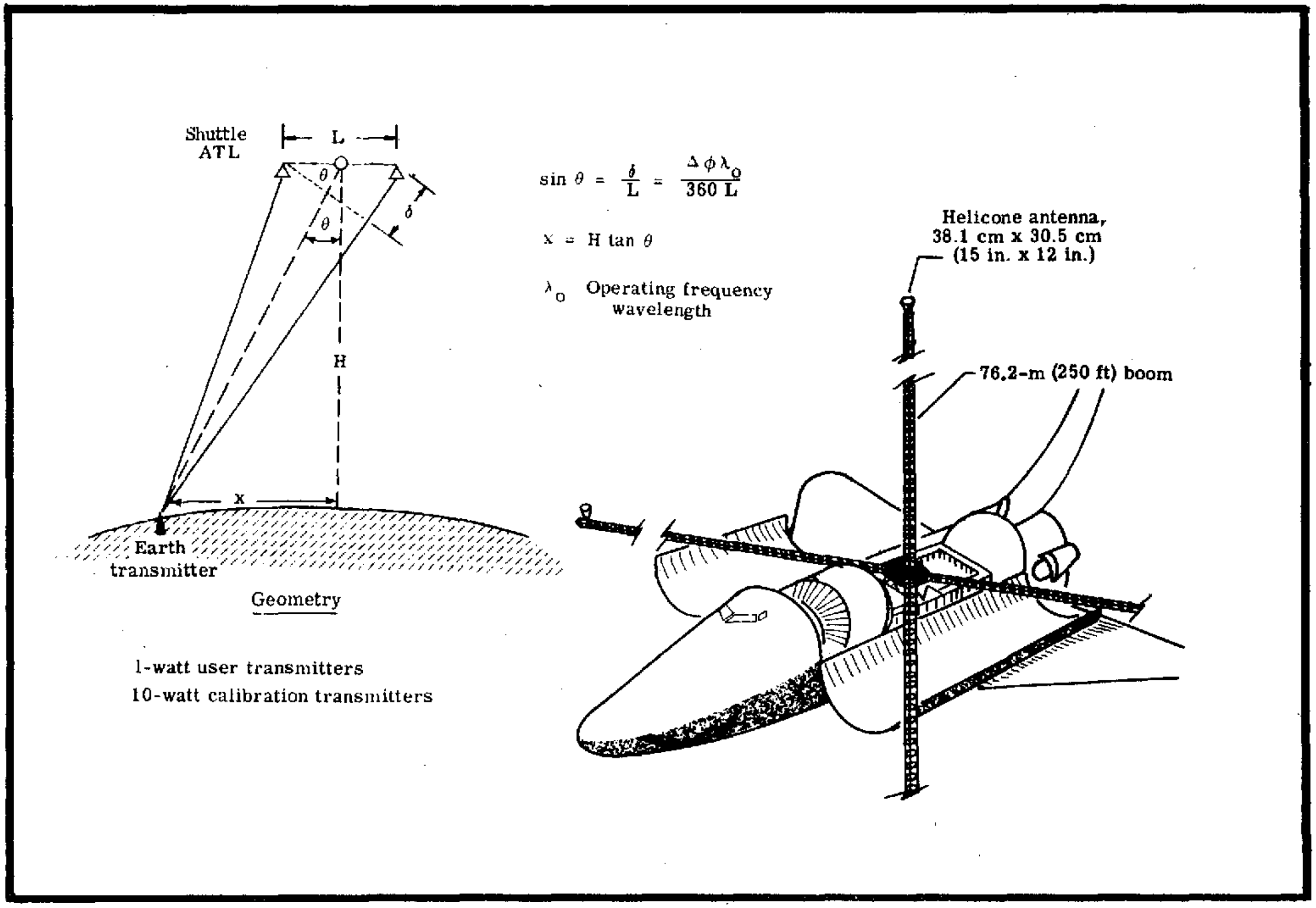


FIGURE D3.6: XST001 Microwave Interferometer Navigation and Tracking Aid--Payload Bay Arrangement

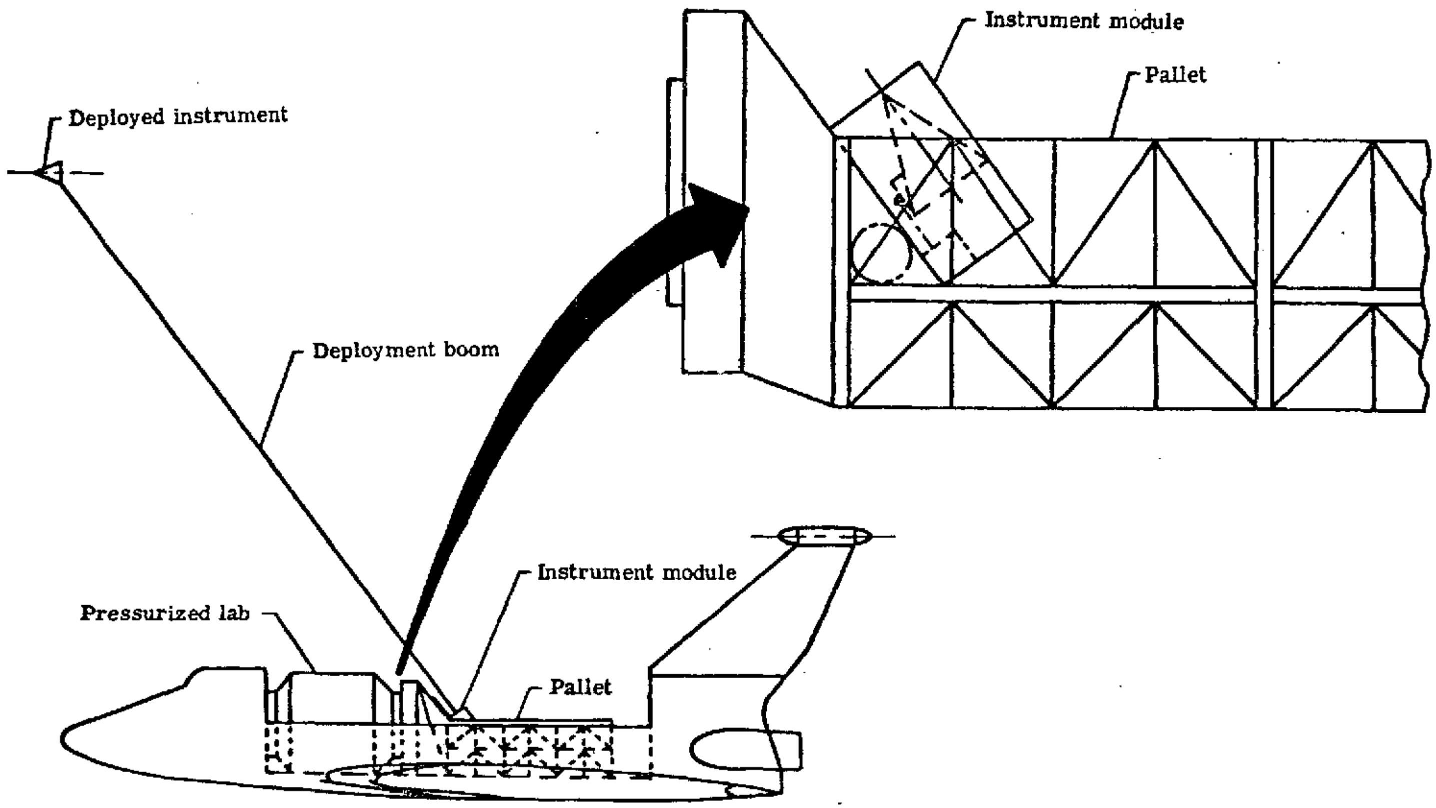


FIGURE D3.7: XST017 Mapping of Upper Atmosphere Neutral Gas Parameters--Pallet Equipment

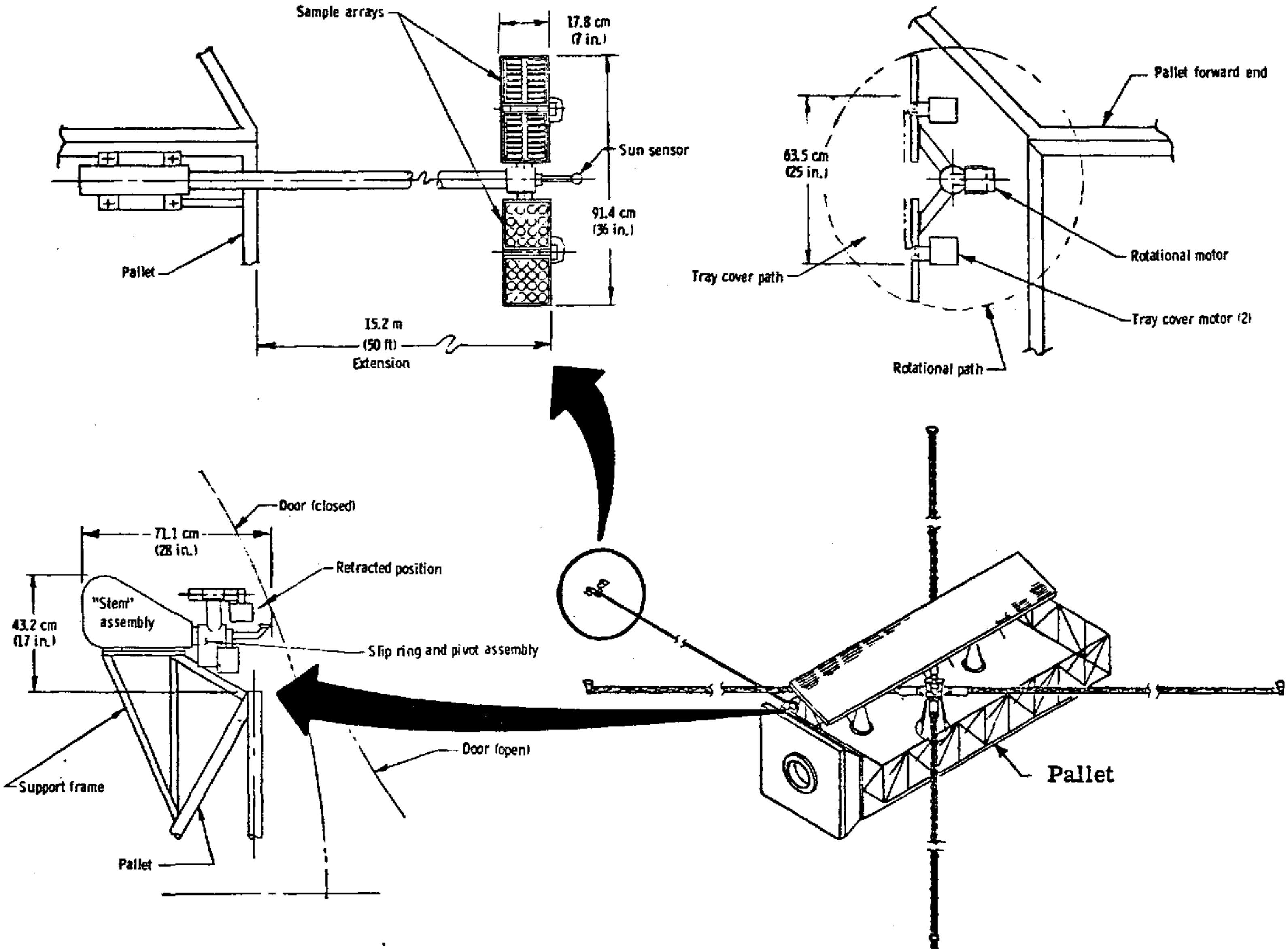


FIGURE D3.8: XST029 Environmental Effects on Nonmetallic Materials--Pallet Equipment

PAYLOAD REQUIREMENTS AND CONSTRAINTS

FOR

XST001

PAYLOAD NO. ST-23-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST001:

- No contamination constraints presently defined during unplanned repair activities

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST001 Booms:

- Attach points for manually retracting booms on experiment and Orbiter
- Crewman restraint provisions at pallet--experiment interface
- Crew mobility aid on pallet

ANCILLARY EQUIPMENT REQUIRED

A. EVA Egress Module

B. XST001 Support Equipment
- "D" ring, swivel eye
- Rope-pulley system
- Crew restraints at worksite
- Portable lights
- Manual backup (hand crank) for boom actuation

CARGO TRANSFER (Item, Size, Mass and C.G.)

XST001

- Boom retrieval rope-pulley system
  - Weight: <1.4 kg. (3 lbs.)
  - Size: <.01 $m.^3$ (.5 $ft.^3$)
  - C.G.: Not critical

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST001:

- Stored energy of booms if restrained due to mechanical interference and deployment system is activated

SHEET NO. 8 of 11

PAYLOAD REQUIREMENTS AND CONSTRAINTS
FOR
XST017

PAYLOAD NO. ST-23-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS	
XST017: • No contamination constraints presently defined during unplanned repair activities	

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU	
XST017: • Crewman restraint provisions at experiment mount on pallet • Design mass spectrometer for on-orbit removal from extended boom • Crew mobility aid on pallet	

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. EVA Egress Module B. XST017 Support Equipment • Crew restraints at worksite • Portable lights • Manual backup for boom acutation • Crew access	XST017 • Mass spectrometer unit - Weight: .45 kg. (10 lbs.) - Size: .15 m. dia. x .3 m. (.5 ft. dia. x 1.0 ft.) - C.G.: Not critical

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN	
XST017: • None defined	

SHEET NO. 9 of 11

PAYLOAD REQUIREMENTS AND CONSTRAINTS

FOR

XST029

PAYLOAD NO. ST-23-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST029:

- Samples may be contaminated by thrusters (not presently defined)
- No contamination constraints presently defined during unplanned retrieval/repair activities

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST029:

- Design sample containers to be operated and retrieved from extended boom by an EVA crewman
- Provide crewman restraint receptacles/interface at experiment mount on pallet
- Crew mobility aids on pallet

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. EVA Egress Module B. XST029 Support Equipment • Crew restraints at worksites • Portable lights • Manual backup (hand crank) for boom actuation • Crew Access	XST029 • Materials sample container - Weight: 2.3 kg. (5.0 lbs.) - Size: .18 x .18 x .06 m. (.6 x .6 x .2 ft.) - C.G.: Not critical

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST029:

None defined

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SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. ST-23-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

- Joseph P. Loftus, Space Technology Working Group, NASA/JSC-AT
- Kenneth R. Taylor, Space Processing Applications Integration, NASA/MSFC-PD-MP-T

REFERENCE DOCUMENTS AND DRAWINGS

1. Modification and updating of the Manned Activity Scheduling System (MASS) for Shuttle and Shuttle Payload Analysis, Volume II - Space Shuttle Sortie Payload Analysis, NASA CR-112287, Contract NAS 1-11674, Convair Aerospace, San Diego, California, April 1973
2. Study of Shuttle - Compatible Advanced Technology Laboratory (ATL) NASA TMX-2813, Langley Research Center, Hampton, Va., September 1973
3. Payloads Description, Volume II, Sortie Payloads, NASA/Marshall Space Flight Center, October 1973 (Preliminary SSPD)

CURRENT STATUS RELATIVE TO EVA/MMU

Payload pallet experiments and experiments deployed from Spacelab scientific airlocks are automated systems. No planned EVA/MMU functions are presently scheduled. Unplanned or contingency EVA/MMU activities are not addressed in ATL documentation.

REMARKS/COMMENTS

The EVA/MMU practicable applications addressed are suggested for further study relative to economy, experiment salvaging, Orbiter re-entry status and safety.

SHEET NO. 11 of 11

CONTINGENCY SUPPORT OF ADVANCED

TECHNOLOGY LABORATORY PAYLOAD (ATL)

ATL Experiment Hardware

The ATL payloads are dedicated sortie modules for the NASA Langley Research Center, Space Research Programs. They are multi-disciplinary payloads which include navigation, earth observations, physics and chemistry, microbiology, components and systems test, and environmental effects disciplines. As in the AMPS payloads, the experiments hardware contains numerous extendible systems that protrude beyond the payload bay. In the payloads ST-21-S, ST-22-S and ST-23-S, the extendible equipment includes:

- Molecular beam subdivider--22 m. (72.2 ft.) booms
- Spacecraft wake dynamics:
  - 27 m. (78.5 ft.) boom
  - 22 m. (72.2 ft.) boom
  - 10 m. (32.8 ft.) boom
  - 450 m. (1476 ft.) tether
- Environmental effects on non-metallic materials--15.2 m. (50 ft.) boom
- Microwave interferometer--four 38.1 (125 ft.) masts

The booms/masts position experiment equipment and sample arrays for data collection. Should the booms malfunction, the system may have to be jettisoned if the means of servicing the malfunctioned equipment is not available. Servicing by an MMU appears to be a highly economical alternative to discarding the experiment equipment into space. The arrangement of equipment (Figure D3.9) on several of the ATL payloads may require jettison of hardware not involved in a failure to allow clear access for jettisoning the malfunctioning components. The MMUs capability to access all deployed equipment may preclude equipment loss.

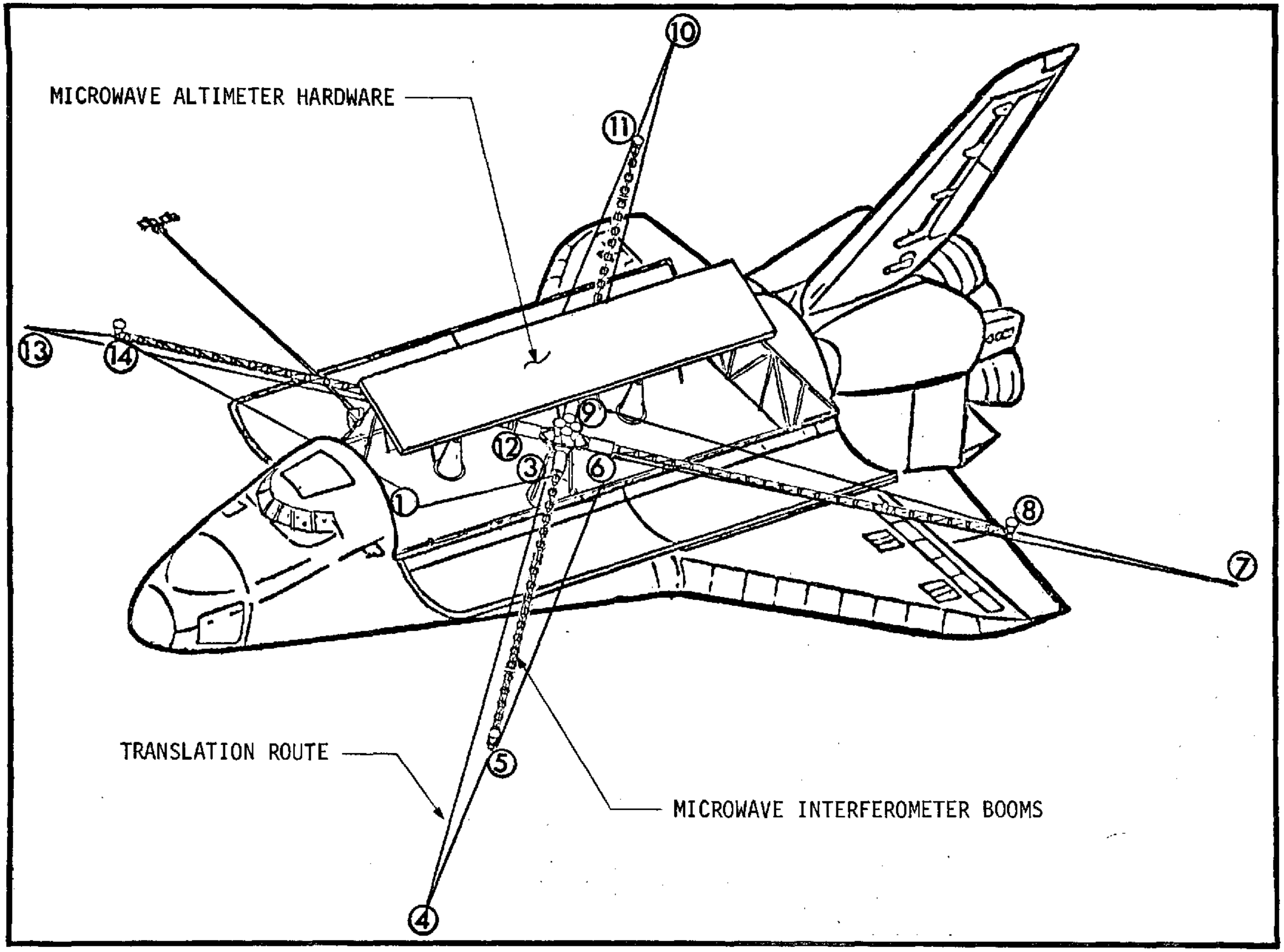


FIGURE D3.9: Translation Route for ATL Boom Deployment

The typical MMU mission outlined in this appendix involves a contingency boom deployment or retraction operation to assist in the completion of normal mission objectives and disposition of experiment equipment to permit payload door closure. Table D3-1 contains a sequenced description of the tasks/operations, equipment required, and estimated time requirements for each task.

The MMU mission is baselined as a two-EVA crewman operation with crewman No. 1 (CM1) performing the tasks from the MMU, while crewman No. 2 (CM2) supports CM1 from the payload bay.

A typical MMU translation route is shown in Figure D3.9. Table 3-2 shows the estimated travel distance for the mission, as well as direction changes, number of starts/stops, estimated velocity and Δvelocity requirements.

Total ΔV Required

The translation ΔV required for this MMU mission is approximately 6.17 m/sec (20.18 ft/sec). From M509 flight experience it was determined that the ΔV required for rotation is approximately equal to that used for translation. Therefore, the total ΔV for both translation and rotation is approximately 12.34 m/sec (40.36 ft/sec).

TABLE D3-1: ATL Boom Deployment Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Deploy Booms (Failure of Automatic Deployment Mechanisms)				
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		1.0
Checkout MMUs	X	X		15.0
Don MMU and attach ancillary hardware	X	X	tether, cable	15.0
Flight check MMU in bay	X			15.0
Remove tether	X			2.0
Translate clear of Sortie Lab	X			1.0
Translate to boom housing		X		
Translate to end of first boom	X			3.0
Attach tether to first boom end *	X			2.0
Translate along boom target path reeling out tether (76.2 m.)	X			5.0
Release boom 1		X		1.0
Pull boom 1 to complete extension*	X			5.0
Lock boom in place		X		
Repeat procedure for other failed booms	X	X		48.0
Return to MMU station, doff and stow MMU and support equipment	X	X		15.0
End EVA				
*see MMU Performance and Control Requirements--this task				
			TOTAL TIME	130.0

TABLE D3-2: MMU Requirements for ATL Boom Deployment

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec^2	ft/sec^2	m/sec	ft/sec
MMU checkout	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
Deploy ATL booms										
1 to 2 translate clear of lab	3	(10)	--	--	120	2	.09	(.3)	.18	(.6)
2 to 3 translate to first boom end, attach tether	10	(33)	--	30	--	2	.12	(.4)	.24	(.8)
3 to 5 deploy tether along boom path	38	(125)	20	30	180	2	.12	(.4)	.24	(.8)
5 to 4 pull boom to full extension	38	(125)	10	40	90	2	.15	(.5)	.30	(1.0)
4 to 5 translate to boom end, release tether	38	(125)	15	15	180	2	.12	(.4)	.24	(.8)
5 to 6 translate to boom 2 housing, attach tether	41	(135)	10	10	30	2	.12	(.4)	.24	(.8)
Repeat deployment procedure for all booms (3)	467	(1530)	165	285	1240	24	.13	(.42)	3.12	(10.08)
Translate to MMU station	10		--	30	--	2	.12	(.4)	.24	(.8)
Doff MMU and support equipment, egress airlock, end EVA										
TOTAL	691	(2233)	580	800	2200	53			6.17	(20.18)
TRANSLATION ΔV + ROTATION ΔV →									12.34	(40.36)

MMU PERFORMANCE AND CONTROL REQUIREMENTS

ATL MAST DEPLOY

PARAMETER \ UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	690 m.*	2250 ft.*
TOTAL VELOCITY CHANGE CAPABILITY	12.3 m.sec	40.4 ft/sec
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±3°	--
- ATTITUDE RATE PRECISION	±3°/sec	--
ACCELERATION (2)		
- TRANSLATION	$\leq .09$ m/sec^2	$\leq .3$ ft/sec^2
- ROTATION	>6°	--
FORCE APPLICATIONS (3)		
- LINEAR		
- TORQUE		

REMARKS

(1) Based on requirement for a crewman to fasten a cable to an attach point on the experiment hardware.

(2) Not critical.

(3) Force is failure dependent.

* Design driver from MMU applications analysis

APPENDIX D4

SHUTTLE IMAGING MICROWAVE SYSTEM

(EO-5-S - SIMS)

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. EO-05-S

PAYLOAD NAME: Shuttle Imaging Microwave System	INITIAL LAUNCH: 1980	FLIGHTS IN PROGRAM: 18
NO. PAYLOADS BUILT: TBD	ORBIT: (435 m., 235 mi.)	OMS SETS: 0

PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	PARAMETER \ UNITS	SI	CONV.
	DIAMETER OR WIDTH	SIMS B: 18 m. width	SIMS B: 60 ft.
	LENGTH OR HEIGHT	SIMS B: 18 m. length	SIMS B: 60 ft.

ORBIT CHECKOUT	X	ANTENNA	X	CONTAM. COVER		STAR TRACKER	
SERVICEABLE		SUN SHIELD		PYROTECHNICS	?	LOUVERS	
SOLAR ARRAYS		OTHER: TV camera (portable)					

IVA/EVA REQUIREMENTS			
	PLANNED EVAs	TASK	• Deploy and stow antennas • Set up cameras
		NO./MISSION	2 per 7 days
		DURATION (hrs.)	4 - 7 hrs.
	CONTINGENCY EVAs	PROBABLE TASK	• Aid antenna deployment • Antenna repair • Antenna jettison
		DURATION (hrs.)	TBD

COGNIZANT SCIENTIST OR PI--LOCATION: L. L. Liccini, Hdq/ERF (202) 755-8603	DEVELOPMENT AGENCY: NASA/Earth Obs.
	SHEET NO. 1 of 5

EVA TASK DESCRIPTION

PAYLOAD NO. EO-05-S

OBJECTIVE

- Determine the feasibility of assembly and deployment of large antenna systems in space

EVA/MMU TASK DESCRIPTION

Shuttle Imaging Microwave System--Figure D4.1

1. Assembly and deploy antennas:
   - Prepare for EVA
   - Prepare SIMS antenna for deployment (18 m. x 18 m. deployed)
   - Set up TV and photo equipment
   - Assemble SIMS antenna
   - Stow SIMS B

2. Addition of an MMU to this payload would greatly enhance mission success by adding the following capabilities:
   - EVA/MMU would provide a backup to the automatic deployment of SIMS B
   - EVA/MMU could provide a repair capability to the SIMS B
   - EVA/MMU could assist in the safe jettison of SIMS B
   - EVA/MMU could provide better TV coverage of antenna deployment

SHEET NO. 2 of 5

SHEET NO. 3 of 5

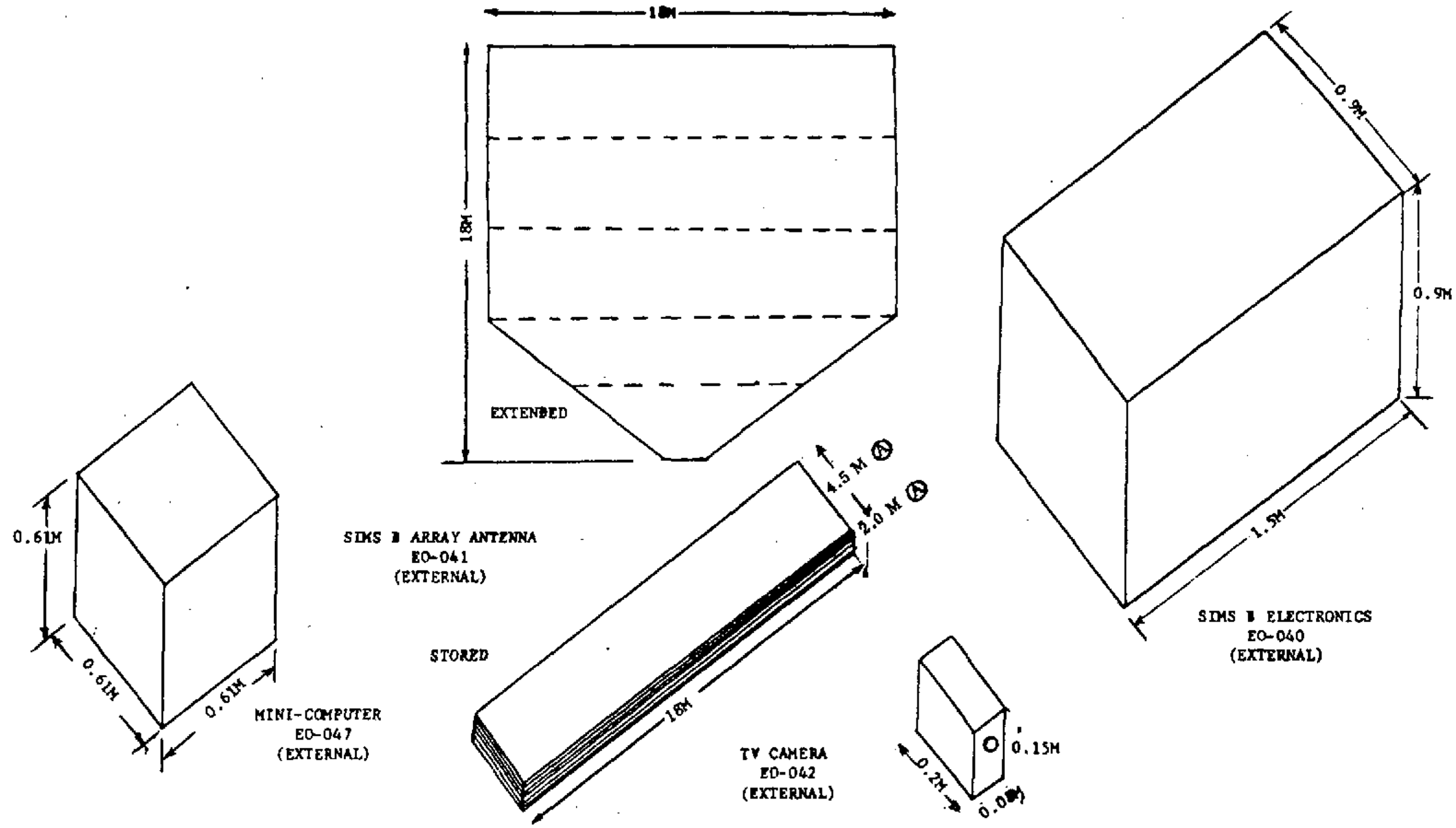


FIGURE D4.1: SIMS B Antenna

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. EO-05-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

- Humidity - 70% (max.)
- Clean class - 100,000
- Radiation - 8.3E-06 J/kg-s
- No contamination constraints identified during EVA/MMU activities

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

- Mobility and stabilization aids for access to work areas
- Design payloads for EVA/MMU access, erection and servicing

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Repair kit for inflatable antenna • Portable lighting • Portable handholds • Portable foot restraints • Video equipment	• TV equipment: - Weight: 2.3 kg. (5 lbs.) • SIMS Antenna 18 x 18 m. (60 x 60 ft.) Mass: 6680 kg. (14,700 lb.)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

High voltage

SHEET NO. 4 of 5

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. EO-05-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

see Appendix G

REFERENCE DOCUMENTS AND DRAWINGS

- Summarized NASA/ESRO Payload Descriptions, Sortie Payloads, MSFC, October 1973 (Preliminary)
- Preliminary Level II Data from JPL (Based on Design Handbook: Imaging Microwave Radiometer Systems for Space Applications, 4/15/73)

CURRENT STATUS RELATIVE TO EVA/MMU

- EVA is planned for the deployment/stowage of SIMS B and camera setup
- The MMU could aid in deployment, repair and ejection of SIMS B
- The MMU could offer a better vantage point for TV coverage of antenna deployment

REMARKS/COMMENTS

One of the major objectives of EO-05-S is to determine the feasibility of assembly and deployment of large antenna systems in space. The addition of an MMU would greatly enhance mission success.

SHEET NO. 5 of 5

DEPLOYMENT OF THE

SHUTTLE IMAGING MICROWAVE SYSTEM (SIMS) ANTENNA

SIMS Experiment/Hardware

The Shuttle Imagine Microwave System (SIMS) is a high resolution multifrequency-multiwave system to be used in application-oriented and scientific studies of earth and its near environment. The major objectives are:

- Determine the feasibility of assembly and deployment of large antenna systems in space
- Perform passive microwave earth observations of the solid earth, ocean and atmosphere
- Determine proper frequency band to use for each application

The equipment consists of a deployable SIMS B array antenna 18 x 18 m. (59 x 59 ft.) and supporting systems. The antenna is deployed and retracted from the payload bay.

Typical MMU applications would include:

- Assist in deployment/retraction operations should malfunctions occur
- Jettison the antenna if only partially deployed and possibility exists of entanglement with aft Orbiter equipment if integral jettison system is used
- Deploy antenna using MMU to obtain data on the feasibility utilizing manned maneuvering units for assembly and maintenance of large structures in space
- Video coverage of automatic antenna erection and retraction operations.

Contingency Deployment of SIMS Antenna Timeline

The typical MMU mission outlined in this appendix involves a contingency deployment of the SIMS antenna. Table D4-1 contains a sequenced description of the tasks/operations, equipment required and estimated time requirements for each task.

This MMU mission is baselined as a two-EVA crewman operation with crewman no. 1 (CM1) performing the tasks from the MMU while crewman no. 2 (CM2) supports CM1 from the payload bay.

MMU Requirements for SIMS Antenna Deployment

A typical MMU translation route is shown in Figure D4.2. Table D4-2 shows the estimated travel distance for the mission, as well as direction changes, number of starts/stops, estimated velocity and delta velocity requirements.

Total ΔV Required

The translation ΔV required for this MMU mission is approximately 3.94 m/sec (13 ft/sec). From M509 flight experience it was determined that the ΔV required for rotation is approximately equal to that used for translation. Therefore, the total ΔV for both translation and rotation is approximately 7.88 m/sec (26 ft/sec).

TABLE D4-1: Contingency Deployment of SIMS Antenna Timeline

TASK/OPERATION	CM1	CM2	EQUIPMENT REQUIRED	EST. TIME (MIN.)
Egress airlock	X	X		2.0
Translate to MMU stowage area	X	X		2.0
Checkout MMU	X			15.0
Don MMU	X			15.0
Flight check MMU in bay on tether	X			15.0
Attach ancillary hardware	X	X	tools, lights, camera, cable	5.0
Remove MMU tether	X			1.0
Translate to antenna stowage area, fasten cable to antenna*	X	X		3.0
Release antenna deployment mechanism	X	X		15.0
Deploy antenna	X			30.0
Translate to MMU stowage area	X			3.0
Doff and stow MMU and ancillary equipment	X	X		5.0
Ingress airlock	X			2.0
End EVA	X			
				113.0
Reverse procedure for retraction of antenna	X	X		83.0
*see MMU Performance and Control Requirements--this task				
			TOTAL TIME	196.0

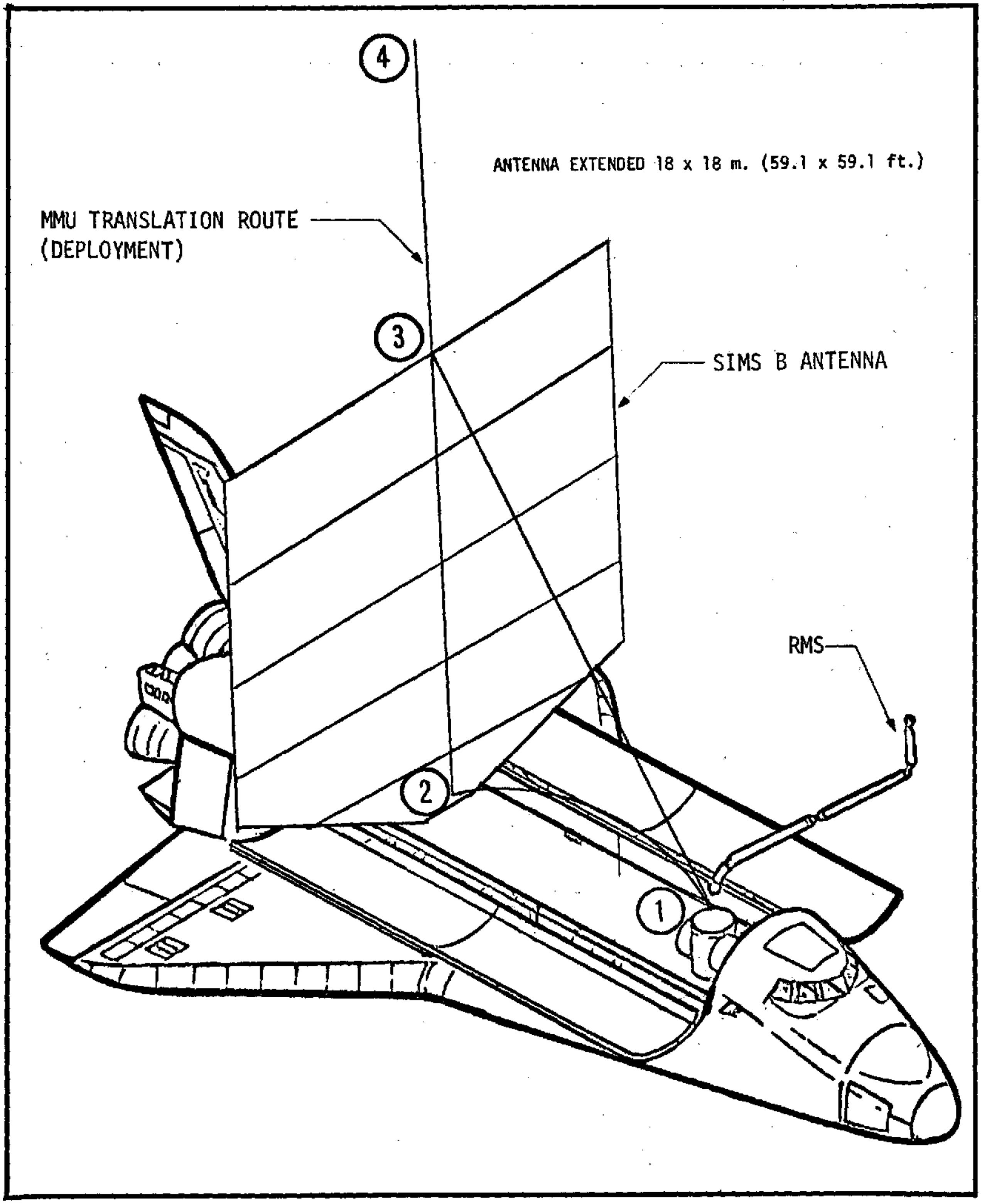


FIGURE D4.2: Translation Route for SIMS Antenna Deployment

TABLE D4-2: MMU Requirements for SIMS Antenna Deployment

TRAVEL DISTANCE			DIRECTION CHANGE			LINEAR CHANGE	VELOCITY		ΔV TRANSLATION	
	m.	ft.	ROLL	PITCH	YAW	STARTS/ STOPS	m/sec^2	ft/sec^2	m/sec	ft/sec
MMU flight check	46	(150)	360	360	360	15	.09	(.3)	1.37	(4.5)
1 to 2 translate to antenna stowage area	14	(45)	15	30	90	3	.09	(.3)	.27	(.9)
2 to 3 fasten a cable to the antenna and deploy the cable along antenna deployment path	20	(65)	--	90	110	2	.09	(.3)	.18	(.6)
3 to 4 pull antenna to full extension	20	(65)	30	30	180	2	.15	(.5)	.30	(1.0)
4 to 3 translate to cable attach point and release cable	20	(65)	30	30	180	2	.12	(.4)	.24	(.8)
3 to 1 return to MMU stowage area	18	(60)	15	90	75	2	.12	(.4)	.24	(.8)
Reverse procedure for antenna retraction	92	(300)	90	270	635	11	.12	(.4)	1.34	(4.4)
TOTAL	230	(750)	540	900	1630	37			3.94	(13.0)
TRANSLATION ΔV + ROTATION ΔV →									7.88	(26.0)

MMU PERFORMANCE AND CONTROL REQUIREMENTS

SIMS ANTENNA DEPLOY

PARAMETER / UNITS	SI	CONVENTIONAL
RANGE (TRAVEL DISTANCE)	230 m.	750 ft.
TOTAL VELOCITY CHANGE CAPABILITY	7.9 m/sec	26 ft/sec
STATION KEEPING ACCURACY (1)		
- TRANSLATION HOLD PRECISION	±.06 m.	±.2 ft.
- VELOCITY PRECISION	±.03 m/sec	±.1 ft/sec
- ATTITUDE HOLD PRECISION	±4°	--
- ATTITUDE RATE PRECISION	±2°/sec	--
ACCELERATION (2)		
- TRANSLATION	$\leq$.09 m/sec^2	$\leq$.3 ft/sec^2
- ROTATION	>6°	--
FORCE APPLICATIONS (3)		
- LINEAR		
- TORQUE		

REMARKS

(1) Based on the requirement to attach a cable to an interface point on the antenna.

(2) Not critical--should be near values shown.

(3) Force required is dependent on the design of the antenna which is not available at this time.

APPENDIX D5

GENERAL INFORMATION ON SORTIE PAYLOADS NOS. AS-09-S AND ST-04-S

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. AS-09-S

<table>
<tr><td colspan="4">PAYLOAD NAME: 30 m IR Interferometer</td><td colspan="2">INITIAL LAUNCH: 1985</td><td colspan="2">FLIGHTS IN PROGRAM: 1</td></tr>
<tr><td colspan="3">NO. PAYLOADS BUILT: 1</td><td colspan="3">ORBIT: LEO (740 m., 400 mi.)</td><td colspan="2">OMS SETS: 1</td></tr>
<tr><td colspan="2" rowspan="3">PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS</td><td colspan="2">UNITS / PARAMETER</td><td colspan="2">SI</td><td colspan="2">CONV.</td></tr>
<tr><td colspan="2">DIAMETER OR WIDTH</td><td colspan="2">Optical bench: 0.3 m.</td><td colspan="2">0.985 ft.</td></tr>
<tr><td colspan="2">LENGTH OR HEIGHT</td><td colspan="2">15.2 m.</td><td colspan="2">50 ft.</td></tr>
<tr><td>ORBIT CHECKOUT</td><td>X</td><td>ANTENNA</td><td>X</td><td>CONTAM. COVER</td><td></td><td>STAR TRACKER</td><td>X</td></tr>
<tr><td>SERVICEABLE</td><td>X</td><td>SUN SHIELD</td><td></td><td>PYROTECHNICS</td><td>?</td><td>LOUVERS</td><td></td></tr>
<tr><td>SOLAR ARRAYS</td><td></td><td colspan="6">OTHER: Extendible booms</td></tr>
<tr><td colspan="2" rowspan="5">MMU/EVA REQUIREMENTS</td><td rowspan="3">PLANNED EVAs</td><td colspan="2">TASK</td><td colspan="3">• Aid in deployment/retraction of interferometer booms</td></tr>
<tr><td colspan="2">NO./MISSION</td><td colspan="3">1</td></tr>
<tr><td colspan="2">DURATION (hrs.)</td><td colspan="3">2+</td></tr>
<tr><td rowspan="2">CONTINGENCY EVAs</td><td colspan="2">PROBABLE TASK</td><td colspan="3">• EVA/MMU beam retraction, inspection, monitor, repair</td></tr>
<tr><td colspan="2">DURATION (hrs.)</td><td colspan="3">3+</td></tr>
<tr><td colspan="5">COGNIZANT SCIENTIST OR PI--LOCATION:
Dr. N. G. Roman, Hdq/SG (202) 755-3649</td><td colspan="3">DEVELOPMENT AGENCY:
NASA/OSS Astronomy</td></tr>
</table>

SHEET NO. 1 of 6

EVA TASK DESCRIPTION

PAYLOAD NO. AS-09-S

OBJECTIVE

1. Aid in deployment/retraction of 30 m IR Interferometer (conventional EVA)
2. Use MMU to aid retraction of beams (contingency)
3. Inspect/monitor experiment and service (contingency)

EVA/MMU TASK DESCRIPTION

30 m IR Interferometer--Figures D5.1 and D5.2

1. Deploy/retract Interferometer
   - Prepare for EVA, egress airlock
   - Free beam ends (2) from auxiliary support structure
   - Translate to aft payload worksite
   - Deploy Interferometer booms (2)
   - After experiment operations - retract beams
   - Translate to auxiliary support structure (forward payload bay)
   - Secure beam ends (2)
   - Ingress airlock

2. Retract beams (EVA/MMU). This procedure assumes beams will not retract using conventional methods and that a crewman is already in an EVA mode
   - Disengage beam linkages at mount (2)
   - Translate to MMU donning station, don MMU
   - Maneuver to extreme end of boom
   - Attach tether and return with other end of tether to payload bay
   - Pull beam to its stowed location
   - Secure beam end to the auxiliary support structure
   - Repeat procedure for the remaining beam
   - Maneuver to MMU donning station - doff MMU
   - Ingress airlock

SHEET NO. 2 of 6

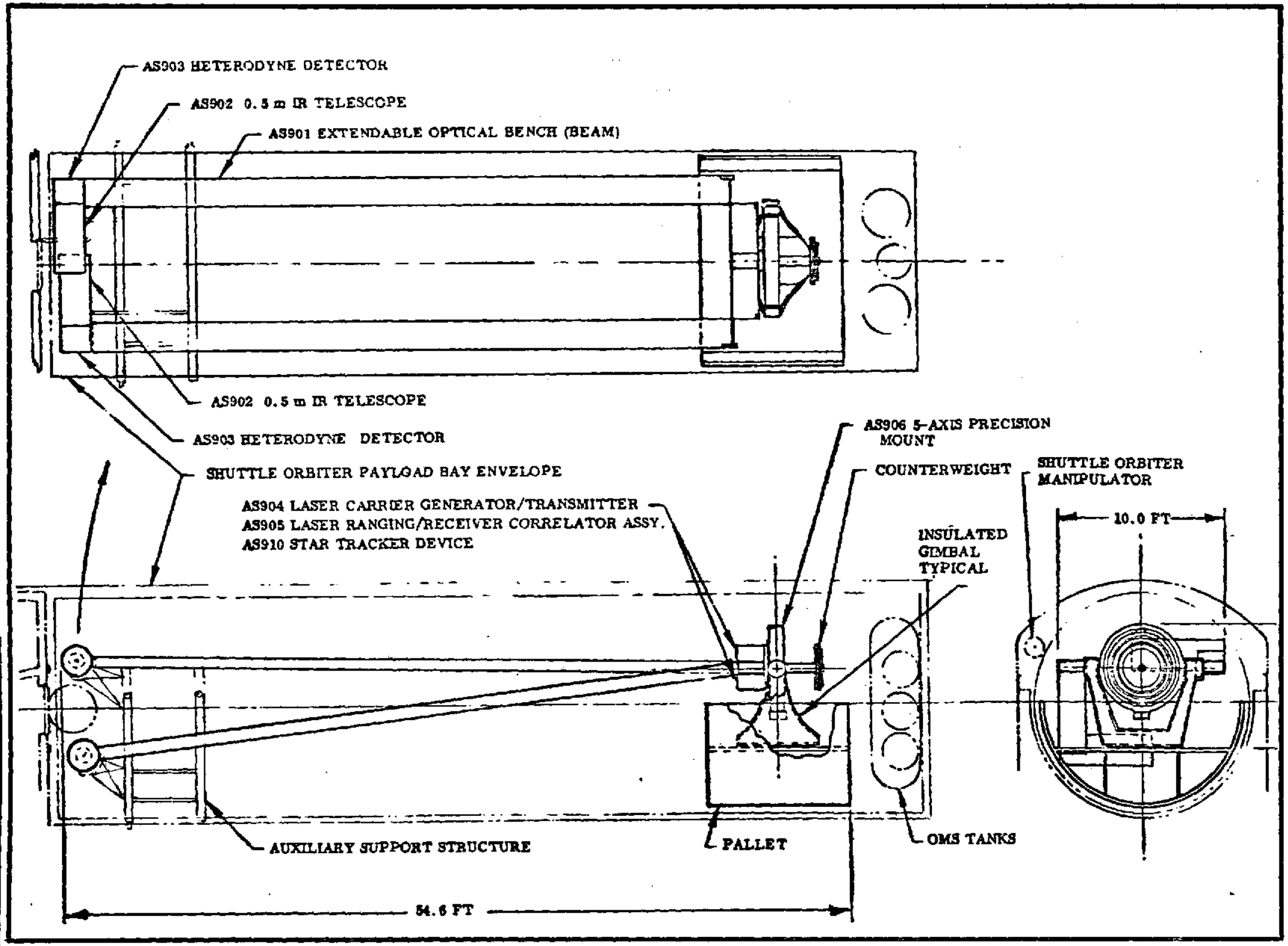


FIGURE D5.1: 30 m IR Interferometer--Stowed Configuration

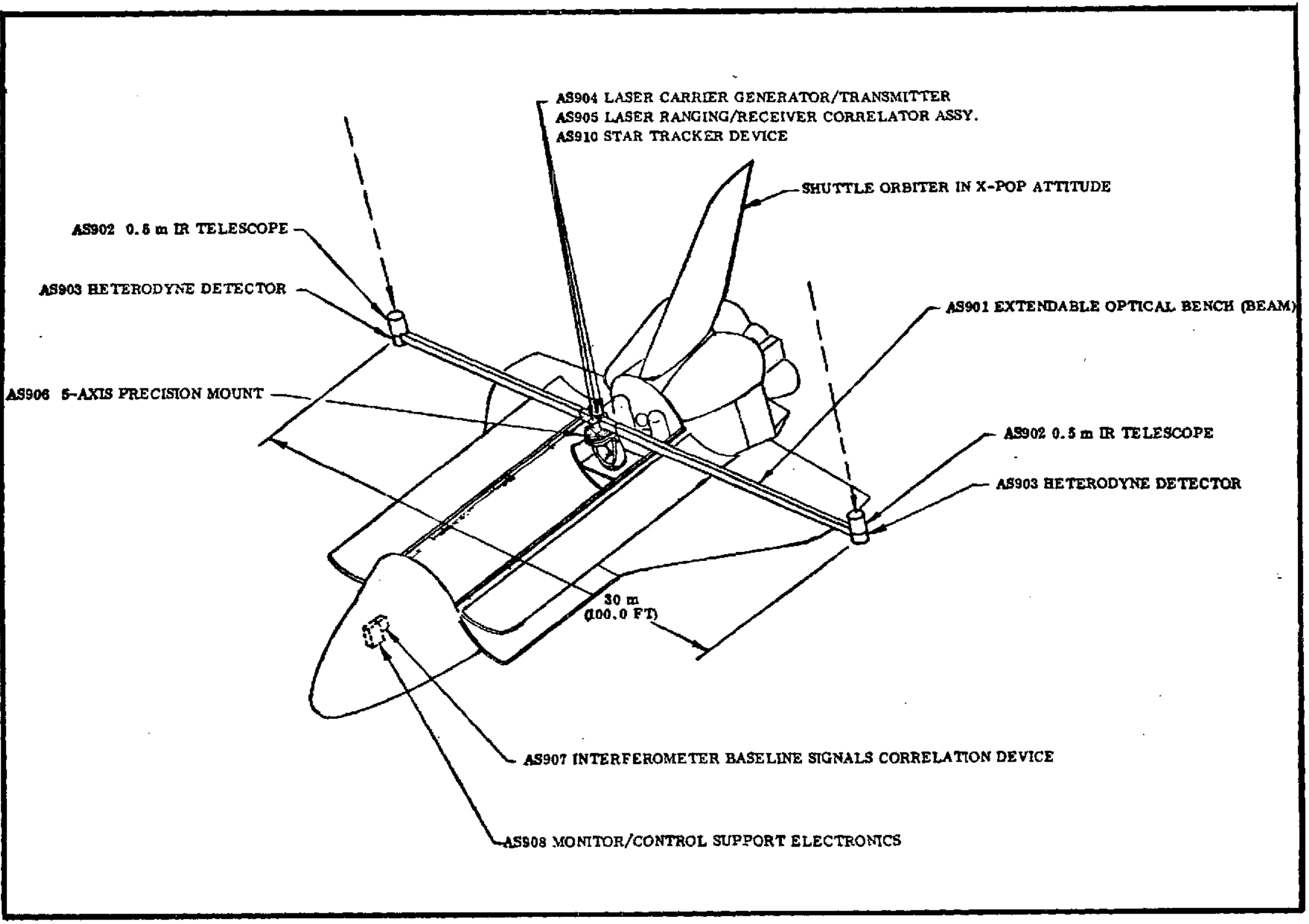


FIGURE D5.2: 30 m IR Interferometer--Deployed Configuration

PAYLOAD REQUIREMENTS AND CONSTRAINTS

PAYLOAD NO. AS-09-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS
No environmental constraints identified

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU
• Mobility/stabilization aid interfaces/equipment • Crewman/MMU restraints at worksite • Booms should be designed for EVA/MMU servicing (Example: Pull a pin to disengage mechanical linkages so beams are free to be maneuvered into stowed position in the payload bay)

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
• Tether system • Portable foot restraints • Handholds/handrails • Portable lighting • Video equipment	• Tether system - Length: ≈18.3 m. (60 ft.) - Weight: <2.3 kg. (5 lbs.) - Volume: <.007 m^3 (.25 ft^3) • Portable handhold - Length: TBD - Weight: TBD - Volume: TBD

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN
No hazardous conditions identified

SHEET NO. 5 of 6

SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. AS-09-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

see Appendix G

REFERENCE DOCUMENTS AND DRAWINGS

- Woods Hole Summer Study, July 1973
- Final Report of the Space Shuttle Planning Working Groups, Vol. I, Astronomy, May 1, 1973
- Payloads Description, Vol. I, Sortie Payloads, MSFC, October 1973, (Preliminary)

CURRENT STATUS RELATIVE TO EVA/MMU

EVA is planned to aid in the deployment and retraction of the Interferometer.

REMARKS/COMMENTS

The two main beams of the Interferometer extend outward from the payload bay approximately 30 meters each. An MMU would be valuable to an EVA crewman to assure that the beams are properly deployed and retracted, and to aid in correcting malfunctions that might occur during these sequences.

SHEET NO. 6 of 6

SPACELAB/SORTIE PAYLOAD GENERAL INFORMATION

PAYLOAD NO. ST-04-S

PAYLOAD NAME: Physics and Chemistry Sortie Laboratory Facility 1		INITIAL LAUNCH: 1980	FLIGHTS IN PROGRAM: 23
NO. PAYLOADS BUILT: 1	ORBIT: LEO (500 km., 270 mi.)		OMS SETS: 0

	PARAMETER \ UNITS	SI	CONV.
PAYLOAD PHYSICAL AND OPERATIONAL CHARACTERISTICS	DIAMETER OR WIDTH	See Payload Requirements and Constraints	
	LENGTH OR HEIGHT	One TBD m. truss Two 22.9 m. trusses	TBD 75 ft.

ORBIT CHECKOUT	X	ANTENNA		CONTAM. COVER		STAR TRACKER	
SERVICEABLE		SUN SHIELD		PYROTECHNICS	?	LOUVERS	
SOLAR ARRAYS		OTHER: Extendible booms					

MMU/EVA REQUIREMENTS	PLANNED EVAs	TASK	No planned EVAs scheduled to date
		NO./MISSION	
		DURATION (hrs.)	
	CONTINGENCY EVAs	PROBABLE TASK	Inspect, retrieve experiments, deploy/retract/jettison trusses, secure for re-entry
		DURATION (hrs.)	TBD (task dependent)

COGNIZANT SCIENTIST OR PI--LOCATION: John P. Mugler, Jr., LaRC/SATD (703) 827-3704	DEVELOPMENT AGENCY: LaRC/OAST
	SHEET NO. 1 of 10

EVA TASK DESCRIPTION

PAYLOAD NO. ST-04-S

OBJECTIVE

Unplanned/contingency EVA/MMU missions to:

1. XST031--Retrieve experiment hardware, repair/retract/jettison boom
2. XST032--Retrieve hardware, repair/retract/jettison boom, close hatch
3. XST034--Inspect, retrieve hardware, repair/jettison boom to allow door closure

EVA/MMU TASK DESCRIPTION

1. XST031 Gas Chemistry Experiment in Space (Figure D5.3)

- Prepare for EVA, egress airlock and don MMU
- Inspect scientific airlock and fly-around experiment
- Remove and return the following equipment units

Unit One

* EUV Photometer
* Electron Probe
* EUV Spectrometer
* Visible - IR Spectrometer
* Gas Bottles

- WEIGHT: ≈42.3 kg. (94.5 lbs.)
- VOLUME: ≈.06 $m.^3$ (2.1 $ft.^3$)

Unit Two

* Mass Spectrometer
* Electron Probe
* Electrometer
* Temperature Probe
* Telemetry Package

- WEIGHT: ≈16.7 kg. (37 lbs.)
- VOLUME: ≈.052 $m.^3$ (1.9 $ft.^3$)

- Remove extendible truss to allow scientific airlock hatch closure and jettison truss segment
- Doff and stow MMU
- Ingress Orbiter cabin

2. XST032 Mass and Energy Analysis of Neutral Species (Figure D5.4)

- Prepare for EVA, egress airlock and don MMU
- Inspect truss/most deployment systems
- Remove and return mass/energy analyzer and power supply
- Remove and jettison deployable truss (22.9 m., 75 ft.) to allow scientific airlock hatch closure
- Doff and stow MMU
- Ingress Orbiter cabin

SHEET NO. 2 of 10

PAYLOAD NO. ST-04-S

EVA/MMU TASK DESCRIPTION

3. XST034 Ion Beam Experiments (Figure D5.5)

- Egress EVA airlock and inspect deployable mechanisms
- Don MMU and translate to deployed experiment
- Remove and return ion detector to pallet
- Remove and jettison truss (22.9 m., 75 ft. max.)
- Retract/secure rail deployment system
- Close experiment airlock hatch (if possible)
- Doff and stow MMU
- Ingress Orbiter cabin

SHEET NO. 3 of 10

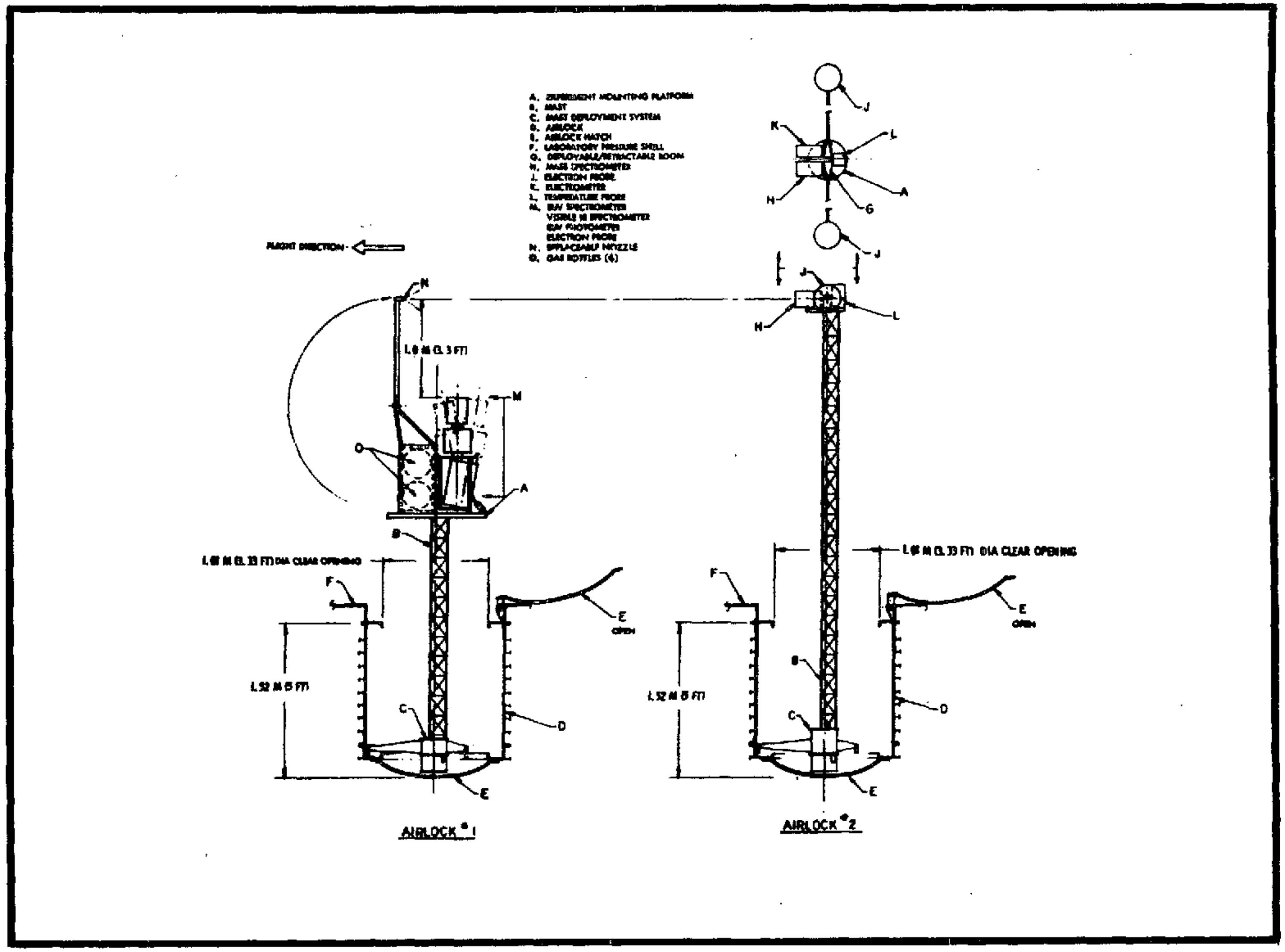


FIGURE D5.3: XST031 Gas Chemistry Experiments--External Equipment

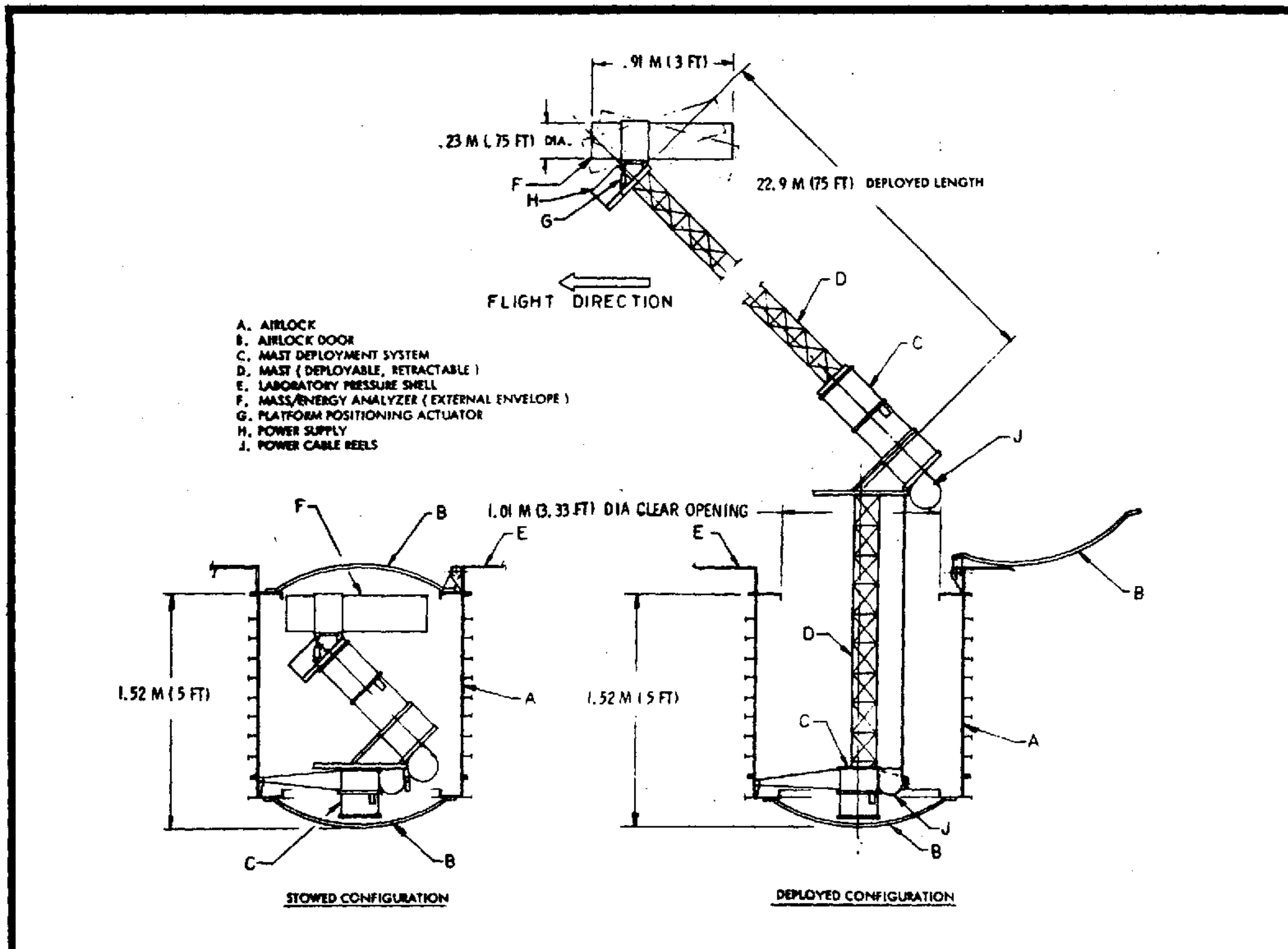
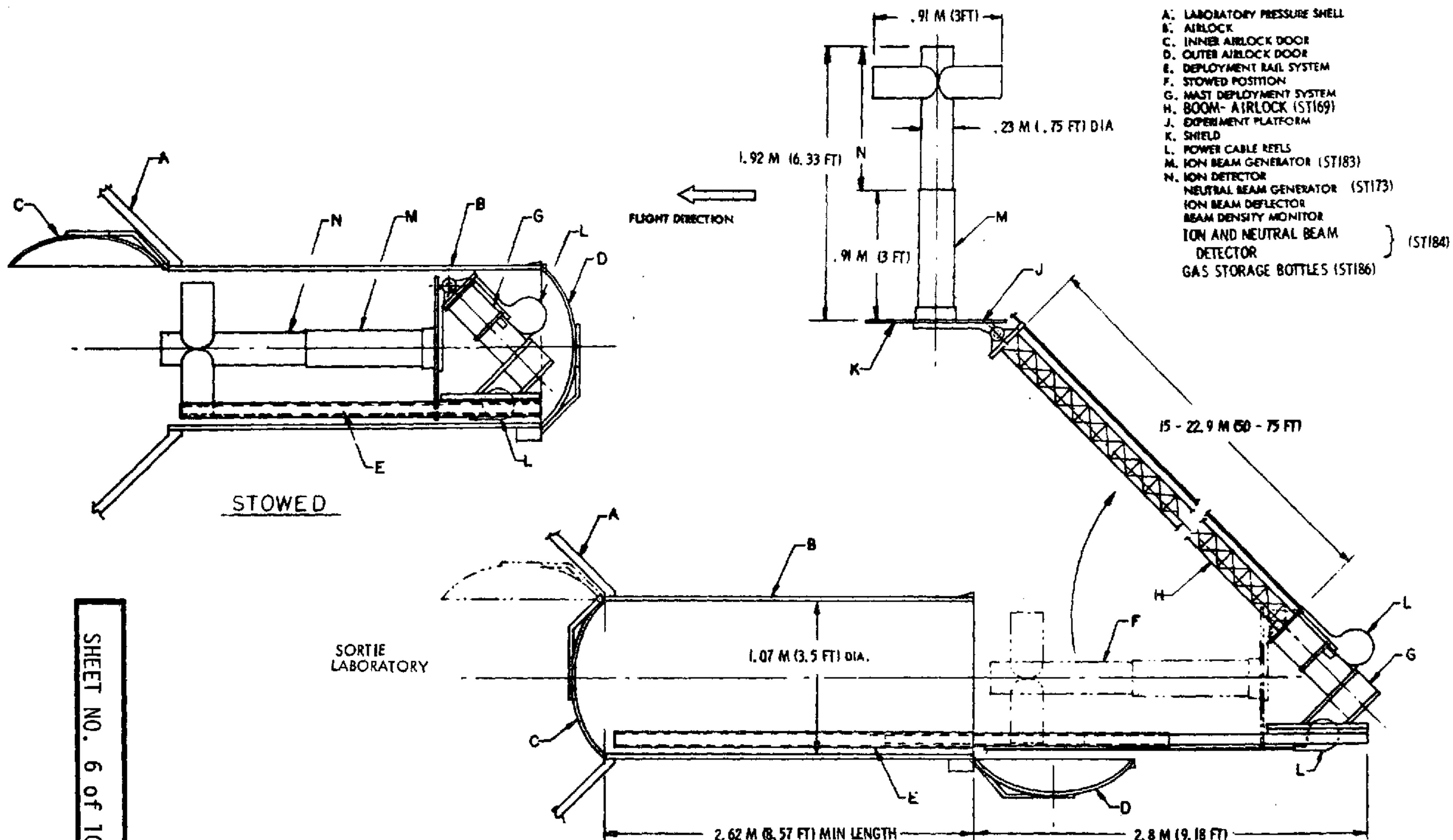


FIGURE D5.4: XST032 Mass and Energy Analysis of Neutral Species--External Equipment



SHEET NO. 6 of 10

FIGURE D5.5: XST034 Ion Beam Experiment--External Equipment

PAYLOAD REQUIREMENTS AND CONSTRAINTS
FOR
XST031

PAYLOAD NO. ST-04-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST031:

- No contamination constraints identified

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST031:

- Design experiment hardware for on-orbit EVA servicing
- Crew/MMU stabilization at worksite
- Design deployable truss for contingency jettison

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. Airlock Egress Module B. XST031 Support Equipment • Crew restraints at worksite • Tools • Portable lights • Temporary stowage at worksite	XST031 • Experiment Units One and Two See Sheets 2-3 of 11, EVA/MMU Task Description for XST031

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST031:

- No danger from experiment when deactivated
- Stored energy of truss retraction mechanisms

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PAYLOAD REQUIREMENTS AND CONSTRAINTS

FOR

XST032

PAYLOAD NO. ST-04-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS

XST032:

- No contamination constraints identified

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU

XST032:

- Design experiment hardware for on-orbit EVA servicing
- Design deployable trusses for contingency jettison
- Crew stabilization provisions at worksite

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. Airlock Egress Module B. XST032 Support Equipment • Crew stabilization at worksite • Tools • Temporary stowage at worksite • Portable lights	XST032 • Analyzer - mass and energy - Weight: 18 kg. (40 lbs.) - Size: .23 x .91 m. (.75 x 3.0 ft.) • Power Supply - Weight: 13.5 kg. (30 lbs.) - Size: .20 x .30 m. (.67 x 1.0 ft.)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN

XST032:

- No hazardous conditions from experiment when deactivated
- Stored energy of truss retraction mechanism

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PAYLOAD REQUIREMENTS AND CONSTRAINTS

FOR

XST034

PAYLOAD NO. ST-04-S

ENVIRONMENTAL/CONTAMINATION CONSTRAINTS
XST034: • No contamination constraints identified

PAYLOAD STRUCTURAL MODIFICATIONS TO ACCOMMODATE EVA/MMU
XST034: • Design deployable systems for on-orbit servicing • Design extendible trusses for contingency jettison • Crew/MMU stabilization/restraint at worksites

ANCILLARY EQUIPMENT REQUIRED	CARGO TRANSFER (Item, Size, Mass and C.G.)
A. Airlock Egress Module B. XST034 Support Equipment • Crew restraints at rail system • Crew stabilization at truss worksite • Tools • Temporary stowage • Portable lights	XST034: • Ion Detector - Weight: 18.0 kg. (40 lbs.) - Size: .3 x .3 x .61 m. (1 x 1 x 2 ft.) • Ion Beam Generator - Weight: 18.0 kg. (40 lbs.) - Size: .3 x .3 x .61 m. (1 x 1 x 2 ft.) Total Unit Size: 1.92 x .91 m. (6.33 x 3 ft.)

UNIQUE TASKS OR CONDITIONS HAZARDOUS TO EVA CREWMAN
XST034 • No hazards from deactivated experiment • Stored energy of malfunctioned rail system or truss deployment mechanisms

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SUPPLEMENTARY PAYLOAD INFORMATION

PAYLOAD NO. ST-04-S

WORKING GROUPS/PANEL MEMBERS CONTACTED

- Kenneth R. Taylor, Space Processing Applications Integration, NASA/MSFC-PD-MP-T

REFERENCE DOCUMENTS AND DRAWINGS

1. Research and Applications Module (RAM) Phase B Study, General Dynamics Contract NAS 8-27539, May 1972
2. Payloads Descriptions, Volume II, Sortie Payloads, MASA/Marshall Space Flight Center, October 1973 (Preliminary SSPD)

CURRENT STATUS RELATIVE TO EVA/MMU

Payload pallet experiments and experiments deployed from Spacelab scientific airlocks are automated systems. No planned EVA/MMU functions are presently scheduled. Unplanned or contingency EVA/MMU activities are not addressed in documentation.

REMARKS/COMMENTS

The EVA/MMU practicable applications addressed are suggested for further study relative to economy, experiment salvaging, Orbiter reentry status and safety.

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APPENDIX D6

EXTENDIBLE MEMBERS FOR SPACE APPLICATION

(EXCERPTED FROM "DESIGN DATA HANDBOOK FOR FLEXIBLE SOLAR ARRAY SYSTEMS; NAS 9-11039 MSC-07161; LMSC D159618; MARCH 1973)"

DEPLOYMENT/RETRACTION STRUCTURES

This appendix summarizes the evaluation of current extensible structures technology and is presented in a fashion to facilitate trade-off and systems selections. Eight Tables have been prepared for this purpose:

Table D6-1	Basic Beam Cross-Section Forms
Table D6-2	Beam and Beam Member Cross Section Variations
Table D6-3	Truss Configuration Variations
Table D6-4	Basic Stowage Methods and Variations
Table D6-5	Extension/Retraction Methods
Table D6-6	Deployable Structures Survey
Table D6-7	Characteristics of Spar Aerospace Stem-type Booms
Table D6-8	Characteristics of Astro Research Astromasts

These should provide sufficient information to perform a preliminary analysis of the applicability of a deployment/retraction structure to specific mission requirements. To facilitate this analysis, the tables have been functionally grouped and are presented in the pages that follow.

Basic Structure Forms

Table D6-1, Basic Beam Cross Section Forms, shows the common forms of beam members. Each member has advantages, as indicated, and the selection of one over the other should involve trade-offs of weight, strength, cost, availability, and manufacturability. Table D6-2, Beam and Beam Member Cross-section Variations, presents some of the possible variations in beam form. It should be noted that these variations are generally the result of functional considerations and not purely structural ones, i.e., the tubular variations result from the requirement that the member be flattened for stowage and/or extension and/or retraction, and the solid variations result from efficiency considerations. The structural characteristics of the members vary considerably from those of their basic form. The last table to be presented in this section is Table D6-3, Truss Configuration Variations. Trusses are defined as a combination of members so arranged and joined as to form a rigid framework. They

TABLE D6-1

BASIC BEAM CROSS SECTION FORMS

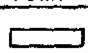
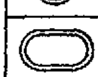
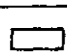
STRUCTURE	FORM	STRUCTURAL CHARACTERISTICS	COMMENTS
SOLID		GOOD TENSION MEMBER, MOMENT OF INERTIA CHANGES IN ORTHOGONAL DIRECTIONS	ECONOMICAL MATERIAL SECTION, FLAT SURFACES FACILITATE FABRICATION OF TRUSS STRUCTURES
		FAT SECTION SUITABLE FOR HIGH SHEAR LOADS	PRIMARILY USED IN MECHANISMS; HOWEVER USEFUL FOR SHORT BEAMS OR STRUTS
		FAT SECTION SUITABLE FOR HIGH SHEAR LOADS, CONSTANT MOMENT OF INERTIA	ECONOMICAL MAT'L SECTION, BEAM END FITINGS FABRICATED WITH SIMPLE DRILLED HOLES
		MOMENT OF INERTIA CHANGES IN ORTHOGONAL DIRECTIONS	USUALLY A FORGED SHAPE;USED EXTENSIVELY AS A SIMPLE BEAM
TUBES		TORSIONALLY GOOD, PROVIDES DIFFERENT MOMENT OF INERTIA IN ORTHOGONAL AXIS	WIDELY USED IN ANTENNA STRUCTURES WHEREIN WAVEGUIDE SERVES ITS NORMAL MICROWAVE FUNCTION AS WELL AS STRUCTURAL SUPPORT
		TORSIONALLY GOOD, PROVIDES EQUAL MOMENT OF INERTIA IN ORTHOGONAL AXIS	USED IN STRUCTURES WHERE FLAT SURFACES FOR MOUNTING OR FABRICATION ARE DESIRED
		TORSIONALLY STIFFEST TO WEIGHT FORM AVAILABLE,CONSTANT MOMENT OF INERTIA	ECONOMICAL, WIDELY USED FORM COMMERCIALLY AVAILABE IN A BROAD SELECTION OF MATERIALS AND ALLOYS
		TORSIONALLY GOOD, PROVIDES DIFFERENT MOMENT OF INERTIA IN ORTHOGONAL AXIS	USUALLY PRODUCED IN FABRICATION SHOP BY FLATTENING A ROUND TUBE
TRUSS BEAMS		TORSIONALLY GOOD, PROVIDES DIFFERENT MOMENT OF INERTIA IN ORTHOGONAL AXIS	COMMONLY USED IN BRIDGE TRUSSES OR ANY TRUSS WITH UNSYMMETRICAL LOADING
		TORSIONALLY GOOD, PROVIDES EQUAL MOMENT OF INERTIA IN ORTHOGONAL AXIS	COMMONLY USED WHERE LOADS ARE SYMMETRICAL SUCH AS RADIO TOWERS
		TORSIONALLY GOOD, MOMENT OF INERTIA MAY BE VARIED IN ANY OF THREE DIRECTIONS	GENERALLY USED FOR SYMMETRICAL LOADS, HOWEVER CAN BE MADE ASYMMETRICAL FOR SPECIAL CONDITIONS

TABLE D6-2
BEAM AND BEAM MEMBER CROSS SECTION VARIATIONS

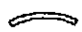
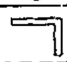
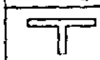
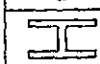
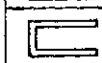
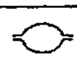
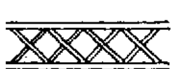
BEAM FORM	VARIATION	COMMENTS
OPEN SECTIONS		LOW OUT OF PLANE STIFFNESS LIMIT THIS TO LOW BENDING AND TORSIONAL LOAD APPLICATIONS.
		LOW TORSIONAL STIFFNESS, HIGH DYNAMIC DAMPING. EVEN WHEN MADE TO OVER-LAP. WIDELY USED AS SMALL DIAMETER, LONG MEMBERS FOR ELECTROMAGNETIC ANTENNA. SEVERE THERMAL BENDING PROBLEMS.
		BROAD RANGE OF SIZES AND MATERIALS AVAILABLE. SUITABLE FOR STIFFENERS OR COMPONENT PARTS OF A BUILT-UP BEAM OR COLUMN.
		SIMILAR TO ABOVE WITH SLIGHTLY IMPROVED BENDING STRENGTH.
		WIDELY USED AS STRUCTURAL BEAMS. IDEAL FOR HIGH BENDING LOADS ABOUT THE MAJOR PRINCIPAL AXIS
		AS ABOVE EXCEPT HIGHER FLANGE BUCKLING HAZARD. SHEAR CENTER NOT COINCIDENT WITH C.G.
 ROUND TUBE	 	APPROACHES THE STRUCTURAL CHARACTERISTICS OF A THIN WALLED TUBE. EXACT MECHANICAL PROPERTIES DEPEND UPON INDIVIDUAL DESIGN. USUALLY <6 IN DIA AND WITH APPROX 250:1 DIAMETER TO THICKNESS RATIO. CRITICAL REVIEW OR APPLICATIONS ARE REQUIRED TO MINIMIZE THERMAL BENDING PROBLEMS.
 FLATTENED TUBE	 	USUALLY IN THIN WALLED SECTIONS. BENDING LOAD CAPACITY VARIES WITH LATERAL CURVATURES. TEST DATA LIMITED, ANALYSIS METHOD NOT DEVELOP FOR BEAM WITH SEALED EDGES. CENTER PIECE HELPS STABILIZE SHAPE, HENCE INCREASES STRENGTH AND STIFFNESS. HOWEVER INCREASED DRUM WEIGHT SHOULD BE STUDIED IN A TRADE-OFF.
 TUBULAR DELTA		USUALLY IN THIN WALLED SECTIONS AND LIMITED IN SIZE TO 6 INCHES PER SIDE.

TABLE D6-3
TRUSS CONFIGURATION VARIATIONS

CONFIGURATION	COMMENTS
1 	DIAGONALS AND BATTENS BOTH SUBJECTED TO COMPRESION AND TENSION LOADS.
2 	SAME AS ABOVE
3 	DIAGONAL MEMBERS SUBJECTED TO BOTH COMPRESSION AND TENSION. CONSEQUENTLY MEMBERS MUST BE HEAVY ENOUGH TO RESIST COLUMN BUCKLING.
4 	REDUNDANT DIAGONALS SUBJECTED TO BOTH COMPRESSION AND TENSION. OFTEN USED WHEN TRUSS IS TO BE FOLDED.
5 	LIGHTWEIGHT DESIGN, SHORT BATTENS SUBJECTED TO COMPRESSION LOADS LONG DIAGONALS SUBJECTED TO TENSION LOADS.

FIGURES 1,2, AND 3 HAVE APPROXIMATELY THE SAME STRENGTH AND WEIGHT. THE COMBINATION OF FIGURES 4 AND 5 TRUSS FORMS MAKES A FEASIBLE STRUCTURE.

are the most efficient structures in terms of stiffness, weight, and material economy. Trusses also have the geometry required to allow the beam to be folded, and yet be strong, stiff and lightweight when extended.

Basic Structures Stowage and Deployment Methods

The three basic methods of stowing beams--folding, rolling, and telescoping--are presented in Table D6-4. Folding is mechanically the simplest and most versatile stowage method and, as a result, is the method most frequently used for general extensible structure applications. Rolling beams on or in drums is a possible low volume solution to some stowage problems and is a method that can be used for stowing beams of a variety of cross-sectional shapes. The thickness and therefore strength of the beams, however, is limited by the coiling stresses. Telescoping of beams, the last method, is a relatively common method of stowage and has been used for a variety of applications. Although the stowage efficiency ratio of stowed-to-extended height is low, it may be increased by either increasing the number of telescoping sections or combining the telescoping method with the folding method. Both alternatives are at the expense of weight and/or beam stiffness.

In Table D6-5 are presented several basic methods of extending or retracting the above beams. The prime movers can be changed in accordance with design constraints. For example, it is conceivable that pneumatic or hydraulic motors could be interchanged with electric motors to produce rotary motion but they cannot be reversed. Whatever the case, the most effective or available energy source and the motion required determine the method or energy/motion transducer used.

TABLE D6-4
BASIC STOWAGE METHODS AND VARIATIONS

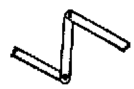
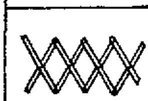
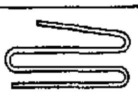
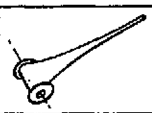
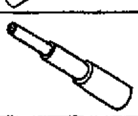
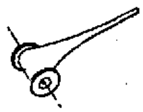
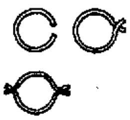
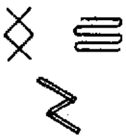
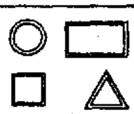
METHOD	VARIATIONS	CHARACTERISTICS	COMMENTS
FOLDED		STOWS BY DISPLACEMENT ONLY, STOW VOLUME IS APPROX. EQUAL TO EXTENDED VOLUME.	SIMPLE, EFFECTIVE, AND WIDELY USED, LIGHT WEIGHT FOR MORE HEAVILY LOADED SYSTEMS.
		STOWS VERY COMPACT, REQUIRES LATCHES TO DEVELOP RIGIDITY. EXCELLENT DEPLOYMENT DEVICE	MULTIPLE HINGE JOINTS REQUIRE PRUDENT DESIGN TO MINIMIZE LOOSENESS. USUALLY SPRING LOADED AGAINST A DAMPER MECHANISM.
		STOWAGE CAPABILITY DEPENDS UPON THE MATERIAL ALLOWABLE STRESS AND THICKNESS. INFLATIBLES USING METAL FOILS STOW VERY COMPACTLY	NO JOINTS OR LATCHES REQUIRED TO PROVIDE A RIGID STRUCTURE. COLUMN STRENGTH IS LIMITED BY MATERIAL THICKNESS, STOWED CONFIGURATION, AND ALLOWABLE STRESS. NO REMOTE RETRACTION.
ROLLED		BEAM IS WRAPPED AROUND A REEL AND ITSELF. REQUIRES A SECTION OF THE BEAM REMAIN EXTENDED BUT STOWS COMPACTLY. CAN BE SELF EXTENDING BUT USUALLY MOTOR DRIVEN	USUALLY CAPABLE OF MANY EXTENSIONS AND RETRACTIONS WITHOUT DEGRADING PERFORMANCE, DEVELOPS FULL STRENGTH AT PARTIAL EXTENSION. COLUMN STRENGTH IS LIMITED BY MAT'L THICKNESS STOW CONFIG. & STRESS
		USUALLY SELF EXTENDING BY STORED-SPRING ENERGY, ALTHOUGH SOME MOTOR DRIVEN MODELS HAVE BEEN USED	CAPABLE OF MANY EXTENSIONS OR RETRACTIONS WITHOUT DEGRADING PERFORMANCE. COLUMN STRENGTH IS VERY LIMITED.
TELESCOPED		STOWED VOLUME FROM 20 TO 50 PERCENT OF EXTENDED VOLUME. DESIGNS READILY ADAPT TO DEVELOP ALL USABLE STRENGTH OR INDIVIDUAL MEMBERS	SIMPLE, FEW PARTS, MAKE DESIGN VERY RELIABLE. MAY BE TRUSSES, TUBES OR COMBINATIONS OF THE TWO

TABLE D6-5

EXTENSION/RETRACTION METHODS

PRIME MOVER	STOWAGE METHOD	BEAM SECTION FORM	CHARACTERISTICS
ELECTRIC MOTOR	 REEL STORED		REMOTE ACTUATION, CAPABLE OF MULTIPLE EXTENSIONS AND RETRACTIONS. SOME MODELS INCORPORATE TWO STORAGE REELS THAT ARE INTERCONNECTED AND DRIVEN BY A COMMON MOTOR.
			REMOTE ACTUATION, CAPABLE OF MULTIPLE EXTENSIONS AND RETRACTIONS. USES THREE STORAGE REELS INTERCONNECTED AND DRIVEN BY A COMMON MOTOR.
			REMOTE ACTUATION, CAPABLE OF MULTIPLE EXTENSIONS AND RETRACTIONS. A SINGLE STORAGE REEL IS DRIVEN BY THE MOTOR.
			WIRE TRUSS IS FOLDED AND ROLLED UP ON A SINGLE, MOTOR DRIVEN REEL.
	 TELESCOPING		REMOTE EXTENSION MAY BE ACCOMPLISHED BY MOTOR DRIVEN WINCH ACTION OR A MOTOR DRIVEN HYDRAULIC SYSTEM. BEAM SECTIONS MAY BE SOLID OR TRUSS.
	 FOLDING	VARIOUS	REMOTE EXTENSION MAY BE ACCOMPLISHED BY MOTOR DRIVEN WINCH ACTION OR BY A MOTOR DRIVEN SCREW JACK (USUALLY IN CONJUCTION WITH MECHANICAL SPRINGS).
MECHANICAL SPRINGS	 REEL STORED	SAME BEAM SECTION USED AS ELECT. MOTOR CONFIG.	SPRING MOTOR POWERS EXTENSION ONLY, MANUAL RETRACTION REWINDS MOTOR.
	 TELESCOPING		SPRINGS OR SPRING MOTOR POWERS EXTENSION ONLY, REQUIRES MANUAL RETRACTION. GENERALLY USED WITH A DAMPER TO CONTROL EXTENSION DYNAMICS.
	 FOLDING	VARIOUS	SPRINGS AT EACH JOINT EXTEND STRUCTURE, MANUAL RETRACTION REQD. MAY BE USED IN CONJUNCTION WITH AN ELECTRICAL MOTOR THAT WILL ASSIST IN EXTENSION AND CONTROL EXTENSION DYNAMICS.
PNEUMATIC (STORED GAS)	 TELESCOPING		SLIDING SEALS MAKE TELESCOPIC MAST GAS TIGHT, GAS PRESSURE EXTENDS CYLINDERS. MANUAL RETRACTION REQD.
	 FOLDING	 VARIOUS	SEALED TUBES INFLATED WITH GAS PRESSURE, MANUAL RETRACTION REQD PNEUMATIC ACTUATORS MAY BE EMPLOYED TO ERECT HINGED JOINTS, AGAIN MUST BE RETRACTED MANUALLY.

Deployment/Retraction Structures Reviewed

The purpose of this section is to inform the designer of the state of the art in extension/ retraction structures so that efficient utilization of design time can be obtained by drawing on the experience of other designers. The survey presented in Table D6-6 considers twenty unique extensible structures, most of which are available from several sources. The structures are separated in the chart by stowage method (telescoping, folding, or rolling). Further, they are separated by structural differences, i.e., truss vs solid, interlocking vs overlapping, etc. The chart displays general characteristics, uses and experiences, and known fabricators. It will be noted that many of the designs have fundamental similarities; each system has features that exhibit dominance of one or more primary considerations such as stiffness, strength, weight, economy, stowage, deployment, or retraction. Additional information as well as photographs of each structure can be obtained from Reference 1.

Deployment/Retraction Structures for Flexible Arrays

The total field of current extendible structure technology that was reviewed in References 1 and 2 indicated that all deployment booms used on flexible solar arrays could be grouped into two categories: the extendible stored reel and the articulated lattice. Of the two, the extendible stored reel has received by far the most usage. It must be stated, though, that the boom strength relative to the length requirements have been very minimal for nearly all of these applications. However, in low load applications, the stored reel is the ideal choice of deployment/retraction device. Table D6-7 exemplifies the many possible parametric variations of this type of boom. Although it was prepared by Spar Aerospace, it should be remembered that other companies also fabricate this type of boom (see References 1 and 2). The relative characteristics of each must be traded off to match the application. Table D6-8 presents parametric characteristics of existing Astro Research Astromasts. This articulated lattice type of boom has the best potential when strength or stiffness governs a design. In any case, because either of these two basic boom types can be used for most applications, the applicable vendor must be consulted for the most recent and applicable design information so that a decision for a specific mission has a firm qualitative and quantitative basis.

REFERENCES

(Section D6)

1. First Topical Report, Evaluation of Space Station Solar Array Technology, Report No. LMSC-A981486, December 1970.

2. First Topical Report Update, Evaluation of Space Station Solar Array Technology, Report No. LMSC D159124, July 1972.

3. Second Topical Report, Design and Analysis, Space Station Solar Array Technology Evaluation Program, Report No. LMSC-A995719, November 1971.

TABLE D6-6
DEPLOYABLE STRUCTURES SURVEY
(Sheet 1 of 2)

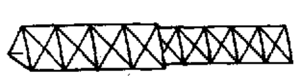
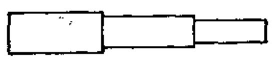
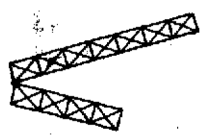
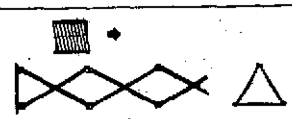
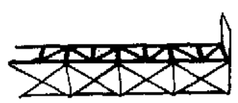
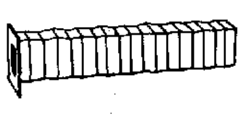
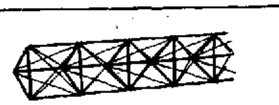
NO. & NAME OF EXTENDIBLE STRUCTURE	ILLUSTRATION	DESCRIPTION & OPERATION OF STRUCTURE & MECHANISM (RETRACTION CAPABILITIES)	FLIGHT EXPERIENCE	SOURCE	DEVELOPMENT WORK	GENERAL DESIGN COMMENTS	PRODUCIBILITY	TESTING & HANDLING: GROUND DEPLOYMENT DEMO, ENVIRONMENTAL TESTING, STATIC LOAD TEST	TESTING & HANDLING: INSTALLATION ON SPACECRAFT
1 TELESCOPING TRIANGULAR TRUSS		CONCENTRIC TRIANGULAR TRUSS SECTIONS SUPPORTED BY ROLLERS. SECTIONS ARE EXTENDED AND LATCH IN THE FULL EXTENDED POSITION. CAN BE UNLATCHED AND RETRACTED	FLIGHT EXPERIENCE: NONE	TRI-EX TOWER CORP., VISALIA, CALIFORNIA	USED EXTENSIVELY IN EARTH APPLICATIONS SUCH AS PORTABLE ANTENNA TOWERS. SIMPLE CONSTRUCTION IS QUITE ADAPTABLE TO SPACE USAGE	TRIANGULAR SHAPE PROVIDES EXCELLENT STIFFNESS-TO-WEIGHT CHARACTERISTICS. MEMBERS MAY BE SIZED-UP ACCORDING TO LOAD REQUIREMENTS AND PACKAGING ENVELOPE. VERY SIMPLE DESIGN ANALYSIS. AN EXTREMELY EFFICIENT BEAM IF THREE OR LESS TELESCOPIC SECTIONS ARE USED. LOOSENESS IN THE JOINTS WILL YIELD A NON-LINEAR SYSTEM AND MUST BE AVOIDED OR MINIMIZED. AN IDEAL BEAM FOR THERMAL BENDING WHEN USED WITH A CONSTANT SUN ANGLE, AS EXPOSURE TO SUNLIGHT CAN BE NEARLY EQUAL ON ALL LONGITUDIONAL MEMBERS. UNEVEN SIDE HEATING COULD PRODUCE DEFORMATION AND RESULT IN RETRACTION PROBLEMS.	SIMPLE PARTS SECURED BY CONVENTIONAL METHODS REQUIRES MINIMAL SPECIAL JIGS AND TOOLING. DESIGN WOULD ADAPT WELL TO USE COMPOSITE MATERIALS	RUGGED CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTIONS WITHOUT PERFORMANCE DEGRADATION. MINIMAL FIXTURES REQUIRED FOR ENVIRONMENT AND LOAD TESTING	USES LONG NARROW STOWAGE SPACE. NO SPECIAL HANDLING REQUIRED.
2 TELESCOPING CYLINDERS		CONCENTRIC SOLID TUBES IN GRADUATED DIAMETERS. SECTIONS ARE EXTENDED AND LATCH IN THE FULL EXTENDED POSITION. CAN BE UNLATCHED AND RETRACTED	FLIGHT EXPERIENCE: UNKNOWN FLIGHT EXPERIENCE UNKNOWN FLIGHT EXPERIENCE: NONE	SANDERS ASSOC. INC., NASHAU, N.H. ROYAL AIRCRAFT ESTABLISHMENT, FARNSBOROUGH, U.K. TRI-EX TOWER CORP., VISALIA, CALIFORNIA	TELESCOPING MAST WITH INCREMENTAL EXTENSION; LATCHING AND RETRACTION UNLATCHING. TWO MODELS, 21 FEET AND 30 FEET, HAVE BEEN BUILT AND TESTED. VERY INTERESTING ACTUATOR/LATCH MECHANISM. TWO MODELS OF PNEUMATIC OPERATED 17-FT LONG TELESCOPING MAST USED EXTENSIVELY IN GROUND APPLICATIONS UP TO 100 FT, "SKY NEEDLE TOWERS". USES MOTORIZED WINCH AND CABLES SYSTEM FOR EXTENSION	COLUMN LOADED THIN WALL TUBES ARE BEST USED FOR INTERMEDIATE LENGTH BEAMS (LESS THAN 50 FT.). INCREASES IN LENGTH REQUIRE AN INCREASE IN TUBE DIAMETER TO MAINTAIN A MINIMUM SLENDERNESS RATIO. SIMULTANEOUSLY THE TUBE WALL THICKNESS MUST BE INCREASED TO MAINTAIN A LOW R/T RATIO TO AVOID LOCAL BUCKLING. CONSIDERABLE OVERLAP IS REQUIRED TO AVOID ROTATIONAL LOOSENESS. NONUNIFORM TEMPERATURES WILL CAUSE BENDING. CROSS-SECTION WILL NOT REMAIN CIRCULAR AND MUST BE ANALYZED FOR BINDING DURING RETRACTION. THERMAL CONTROL SURFACE MUST WITHSTAND SLIDING ABRASION DURING EXTENSION AND RETRACTION.	SIMPLE PARTS, PRUDENT DESIGN WILL PRECLUDE THE NEED FOR EXTENSIVE TOOLING. STRUCTURAL SHAPES COULD BE ADAPTED TO USE COMPOSITE MATERIAL	SAME AS NO. 1 (ABOVE)	SAME AS NO. 1 (ABOVE)
3 FOLDING BEAM		SECTIONS MAY BE TRUSS, TUBULAR, OR SOLID; HINGES ON EITHER END AND LATCHES AT FULL EXTENSION. USUALLY DEPLOYED BY A TENSION CABLE SYSTEM WITH PULLEYS AT EACH JOINT. CAN BE UNLATCHED AND RETRACTED.	USED FREQUENTLY IN SPACE FLIGHTS, USUALLY AS RELATIVELY SHORT MEMBERS. (LESS THAN 30 FT.)	BOEING CO., SEATTLE, WASHINGTON FAIRCHILD HILLER CORP., GERMANTOWN, MD. MOBILE AERIAL TOWERS INC., FT. WAYNE, IND.	BOEING DID DEVELOPMENT WORK ON A 63-FT LONG SOLAR ARRAY THAT DEPLOYED IN THIS MANNER. FAIRCHILD HILLER BUILT A WORKING MODEL 36-FT LONG MANUFACTURE FOR GROUND USE A LINE OF MOBILE AERIAL TOWERS TO ELEVATE MEN AND EQUIPMENT AS HIGH AS 130 FT. SIMPLE CONSTRUCTION IS QUITE ADAPTABLE TO SPACE USAGES.	CHARACTERISTICS ARE THOSE OF THE BASIC SECTION SELECTED; MAY BE VERY EFFICIENT, DEPENDING UPON THE DETAIL DESIGN. LOOSENESS IN THE JOINTS WILL RESULT IN A DYNAMICALLY NON-LINEAR SYSTEM AND MUST BE MINIMIZED. THERMAL BINDING IS UNLIKELY. ALL OTHER THINGS EQUAL, THIS BEAM GENERALLY REQUIRES MORE STORAGE SPACE THAN A TELESCOPING BEAM.	SIMPLE PARTS SECURED BY CONVENTIONAL METHODS REQUIRES MINIMAL SPECIAL JIGS AND FIXTURES FOR FABRICATION (SEE TESTING). PARTS OF THE STRUCTURE WILL BE ADAPTABLE TO COMPOSITE MATERIALS.	RUGGED CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTIONS WITHOUT PERFORMANCE DEGRADATION. ZIG-ZAG DEPLOYMENT MAY REQUIRE EXTENSIVE FIXTURES FOR GROUND DEPLOYMENT	NO SPECIAL HANDLING REQUIRED; HOWEVER, DOES NOT STOW EFFICIENTLY. STOWAGE SHAPE MAY BE TAILORED SOMEWHAT BY CHANGING THE SECTION LENGTHS.
4 LAZY TONG		STRUCTURAL PANELS HINGED TOGETHER AND STABILIZED ATTACHMENT TO HINGED BEAMS AT THE EDGES. THE HINGED BEAMS ARE SOMEWHAT LONGER FROM PIVOT TO PIVOT THAN THE STRUCTURAL PANELS. THE PANELS ALIGN TO ACCEPT COLUMN LOADS. MAY BE LATCHED AT FULL EXTENSION, USUALLY NOT RETRACTABLE ONCE LATCHED. USUALLY SPRING-LOADED; MAY HAVE SCREW JACK ASSISTANCE. COULD USE A TENSION CABLE SYSTEM AS IN NO. 3 BUT THE NUMBER OF JOINTS IS USUALLY HIGH.	THIS CONFIGURATION USED EXTENSIVELY BY LOCKHEED TO DEPLOY SOLAR PANELS. THE PEGASUS SPACECRAFT DEPLOYED FLAT-PANELS 14 BY 48 FT (EACH WING) AS METEROID DETECTORS USING THIS SYSTEM.	LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CALIFORNIA FAIRCHILD HILLER CORP., GERMANTOWN, MD.	A WORKING MODEL 8-1/2-FT LONG OF ONLY THE LAZY TONG (NO FLAT PANELS) WAS BUILT AND TESTED BY FAIRCHILD HILLER	VERY COMPACT STOWAGE. THIS BEAM IS AN EFFECTIVE DEPLOYMENT DEVICE. PROPER LOCKING OF PANELS IS REQUIRED TO CHANGE THE DEVICE INTO A STRUCTURE. THE LARGE NUMBER OF JOINTS WILL PROBABLY LEAD TO A NON-LINEAR STRUCTURE, WHICH MAKES MEANINGFUL DYNAMIC ANALYSIS DIFFICULT.	A LARGE NUMBER OF IDENTICAL SIMPLE PARTS AND HINGE ASSEMBLIES. MINIMAL SPECIAL JIGS AND FIXTURES. HINGE AND LATCH BEARING LOADS REQUIRE METALLIC CHARACTERISTICS WHICH WILL REDUCE THE EFFECTIVENESS OF COMPOSITE MATERIALS; HOWEVER, THE USE OF BERYLLIUM AND MAGNESIUM SHOULD BE INVESTIGATED.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITHOUT PERFORMANCE DEGRADATION. HOWEVER MULTIPLE JOINTS AND LATCHES MAY WEAR, CAUSING LOOSENESS. MINIMAL FIXTURES REQUIRED FOR ENVIRONMENT AND LOADS TEST	NO SPECIAL HANDLING REQUIRED. STOWS VERY EFFICIENTLY
5 TRI AXIS PANTOGRAPH		THREE LAZY TONGS TIED AT THE NODES WITH U-SHAPED CLIPS. MAY BE LATCHED AT FULL EXTENSION. AS IN NO. 4, MOSTLY USED AS A SPRING-LOADED, NON-RETRACTING DEVICE INVOLVING ONLY LIGHT COLUMN LOADS. MAY USE A SCREW JACK ASSIST WHICH WILL CONTROL DEPLOYMENT.	FLIGHT EXPERIENCE: NONE	LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CALIFORNIA	A SMALL 5-FT LONG DEMONSTRATION MODEL HAS BEEN BUILT BY LOCKHEED.	THIS IS A GOOD DEPLOYMENT DEVICE BUT A VERY POOR STRUCTURE, INHERENTLY NON-LINEAR WITH LOW LATERAL AND TORSIONAL STIFFNESS. COLUMN STRENGTH IS LIMITED BY THE EXTENSION MECHANISM; OR EVEN IF LATCHED IN THE EXTENDED POSITION, ALL OF THE STRUCTURAL MEMBERS ARE LOADED IN BENDING. THERMAL BENDING WILL BE SMALL IF BEAM SELF SHADING IS HELD TO A LOW VALUE. VERY COMPACT STOWAGE.	A LARGE NUMBER OF IDENTICAL SIMPLE PARTS AND HINGE ASSEMBLIES. MINIMAL SPECIAL JIGS AND FIXTURES. HINGE AND LATCH BEARING LOADS REQUIRE METALLIC CHARACTERISTICS WHICH WILL REDUCE THE EFFECTIVENESS OF COMPOSITE MATERIALS; HOWEVER, THE USE OF BERYLLIUM AND MAGNESIUM SHOULD BE INVESTIGATED.	SAME AS NO. 4 (ABOVE)	SAME AS NO. 4 (ABOVE)
6 EXTENSIBLE TRUSS (PROPOSAL BASELINE)		TWO LAZY TONGS CONNECTED WITH PANELS TO PRODUCE A RECTANGULAR TRUSS BEAM WHEN EXTENDED; PANELS ALIGN TO ACCEPT COLUMN LOADS. MAY BE LATCHED AT FULL EXTENSION; USUALLY NOT RETRACTABLE ONCE LATCHED. MAY USE A SCREW JACK ASSIST WHICH WILL CONTROL DEPLOYMENT.	FLIGHT EXPERIENCE: UNKNOWN	FAIRCHILD HILLER, SPACE AND ELECTRONICS SYSTEMS DIVISION, GERMANTOWN, MD.	A SMALL DEMONSTRATION MODEL HAS BEEN BUILT BY FAIRCHILD HILLER, SPACE AND ELECTRONICS SYSTEMS DIVISION. THIS CONFIGURATION IS AN EXTENSION OF THE PRINCIPLES USED TO DEPLOY THE SOLAR ARRAY IN THE PEGASUS SPACECRAFT.	VERY COMPACT STOWAGE. PRUDENT LATCH DESIGN WILL MAKE THIS A REASONABLY STIFF STRUCTURE. HOWEVER IT WILL INHERIT SOME LESS DESIREABLE STRUCTURAL QUALITIES SUCH AS NOW LINEARITY AND LOW TORSIONAL STIFFNESS. LATCHES MAKE RETRACTION MORE DIFFICULT, LESS RELIABLE. SELF SHADING MAY PRODUCE EXCESSIVE THERMAL BENDING AND MAY INDUCE BINDING IF RETRACTION IS ATTEMPTED. BEAM IS NOT RIGID UNLESS FULLY EXTENDED.	A LARGE NUMBER OF IDENTICAL SIMPLE PARTS AND HINGE ASSEMBLIES. MINIMAL SPECIAL JIGS AND FIXTURES. HINGE AND LATCH BEARING LOADS REQUIRE METALLIC CHARACTERISTICS WHICH WILL REDUCE THE EFFECTIVENESS OF COMPOSITE MATERIALS; HOWEVER, THE USE OF BERYLLIUM AND MAGNESIUM SHOULD BE INVESTIGATED.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITHOUT PERFORMANCE DEGRADATION. HOWEVER, MULTIPLE JOINTS AND LATCHES MAY WEAR CAUSING LOOSENESS. MINIMAL FIXTURES REQUIRED FOR ENVIRONMENTAL AND LOADS TEST.	NO SPECIAL HANDING REQUIRED, STOWS VERY EFFICIENTLY.
7 BOX BELLOWS (JACK-IN-THE BOX)		FLAT RECTANGULAR PANELS JOINED LONGITUDINALLY BY HINGES, INCORPORATING TORSION SPRINGS AND SUPPORTED BY FLANGES. HINGES OPEN INWARD AND OUTWARD ON ALTERNATE PANELS. MAY BE LATCHED AT FULL EXTENSION, USUALLY NOT RETRACTABLE.	FLIGHT EXPERIENCE: UNKNOWN	LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CALIFORNIA FAIRCHILD HILLER, SPACE & ELECTRONICS SYSTEMS DIVISION, GERMANTOWN, MD.	SMALL DEMONSTRATION MODELS HAVE BEEN BUILT BY LOCKHEED AND FAIRCHILD HILLER. LOCKHEED'S MODEL COMPLETED A 90° TURN WHEN DEPLOYED, YET FOLDS COMPACTLY.	VERY COMPACT STOWAGE. BASIC DESIGN PROVIDES GOOD TORSIONAL STIFFNESS. HOWEVER, THE HIGH L/B (SLENDERNESS RATIO) AND THE LOW B/T (LOCAL STIFFNESS) REQUIREMENT MAKE THIS STRUCTURE VERY INEFFICIENT FOR LONG BEAMS. HOLES, AT LEAST ON THE SUN SIDE, ARE PROBABLY REQUIRED TO MINIMIZE TEMPERATURE DIFFERENCES. EFFECT OF NONUNIFORM TEMPERATURES ON ABILITY TO REFOLD WOULD HAVE TO BE EVALUATED. BEAM IS NOT RIGID UNLESS FULLY EXTENDED.	A LARGE NUMBER OF IDENTICAL SIMPLE PARTS AND HINGE ASSEMBLIES. MINIMAL SPECIAL JIGS AND FIXTURES. HINGE AND LATCH BEARING LOADS REQUIRE METALLIC CHARACTERISTICS WHICH WILL REDUCE THE EFFECTIVENESS OF COMPOSITE MATERIALS; HOWEVER, THE USE OF BERYLLIUM AND MAGNESIUM SHOULD BE INVESTIGATED.	SAME AS NO. 6 (ABOVE)	SAME AS NO. 6 (ABOVE)
8 ASTROMAST ARTICULATED LATTICE		TRIANGULAR SECTIONS ARE RIGID; THE LONGITUDINAL LINKS PIVOT AT EACH BAY. FOLDING IS ACHIEVED BY LOOSENING ONE TENSION MEMBER (WIRE ROPE) IN EACH BAY; THE TENSION MEMBERS ARE LOCKED AS EACH BAY IS EXTENDED. RETRACTABLE.	FLIGHT EXPERIENCE: UNKNOWN	ASTRO RESEARCH CORP., SANTA BARBARA, CALIFORNIA	MANY APPLICATIONS ON EARTH FROM 30 TO 100 FT LONG; BOTH CIVIL AND MILITARY. EXCEPT FOR ONE CASE THE BOOMS ARE MANUALLY ERECTED AND RETRACTED. A DEVELOPMENTAL UNIT OF A 30-FT HIGH, REMOTELY ACTUATED (ERECTING AND RETRACTION) MODEL HAS BEEN DELIVERED TO THE US ARMY. ALUMINUM OR STAINLESS STEEL IS USED FOR THE RIGID MEMBERS AND STAINLESS STELL WIRE ROPE FOR THE TENSION MEMBERS.	COMPACT STOWAGE. THIS BEAM CAN BE MADE AS EFFICIENT AS THE BASIC TRIANGULAR TRUSS, WITH HIGH STIFFNESS TO WEIGHT RATIO. BEAM IS AT FULL STRENGTH AT ALL TIMES DURING DEPLOYMENT. REMOTE (AUTOMATIC) DEPLOYMENT MAY BE MORE COMPLICATED THAN REQUIRED FOR OTHER DEPLOYABLE STRUCTURES. UNIFORM SOLAR ILLUMINATION IS BEST ACHIEVED IN A TRIANGULAR OPEN TRUSS BEAM.	A LARGE NUMBER OF IDENTICAL SIMPLE PARTS AND HINGE ASSEMBLIES. PRODUCTION TOOLING AND TECHNIQUES ARE WELL DEFINED. SOME DEVELOPMENTAL TOOLING REQUIRED FOR THE REMOTE EXTENSION MECHANISM.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITHOUT DEGRADATION IN PERFORMANCE. MINIMAL FIXTURES REQUIRED FOR ENVIRONMENT AND LOADS TEST	CYLINDRICAL SECTION REQUIRED TO STOW; APPROXIMATELY 4 IN. LARGER THAN THE BEAM IN DIAMETER AND APPROXIMATELY (2) BAYS LONG. NO SPECIAL HANDLING REQUIRED.
9 ASTROMAST COILABLE LATTICE		FIBERGLASS CONSTRUCTION WITH WIRE ROPE TENSION MEMBERS. LONGITUDINAL SECTIONS ARE CONTINUOUS; THE TRIANGULAR BAY SECTIONS ARE RIGID AND PIVOTED ON THE LONGITUDIONAL MEMBERS. RETRACTABLE. FIBERGLASS BATTENS (SIDES OF TRIANGULAR SECTION) ARE BUCKLED TO BEGIN COILING OPERATION.	FLIGHT EXPERIENCE: UNKNOWN	ASTRO RESEARCH CORP., SANTA BARBARA, CALIFORNIA	ONE FLIGHT UNIT OF A 10 INCH BY 100 FT MAST WAS DELIVERED TO NASA, HOUSTON FOR USE IN A LUNAR EXPERIMENT AS PART OF THE APOLLO PROGRAM (EXPERIMENT CANCELLED) A 6 INCH BY 13 FOOT COILABLE MAST WILL BE DELIVERED TO GOODYEAR AEROSPACE CORP. AS PART OF A SCALE MODEL OF THE LOFT (LOW FREQUENCY RADIO TELESCOPE)	COMPACT STOWAGE, LINEAR SYSTEM, HIGH STIFFNESS TO MASS RATIO. BEAM IS AT FULL STRENGTH AT ALL TIMES DURING DEPLOYMENT. HOWEVER, THIS BEAM IS LIMITED TO LOW LOAD APPLICATIONS. AS THE LOAD INCREASES, THE REQUIRED DIAMETER OF THE LONGERON INCREASES AND QUICKLY BECOMES TOO STIFF TO COIL IN A REASONABLE STORAGE AREA. LOW TEMPERATURE BENDING CHARACTERISTICS MAY BE A PROBLEM. THE LOW THERMAL CONDUCTIVITY OF FIBERGLASS WILL ACCENTUATE TEMPERATURE NON-UNIFORMITY. PLASTIC WILL REQUIRE A PROTECTIVE – THERMAL COATING TO RESIST U.V. ETC. DAMAGE.	A LARGE NUMBER OF IDENTICAL SIMPLE PARTS AND HINGE ASSEMBLIES. PRODUCTION TOOLING AND TECHNIQUES ARE WELL DEFINED. SOME DEVELOPMENTAL TOOLING REQUIRED FOR THE REMOTE EXTENSION MECHANISM.	SAME AS NO. 8 (ABOVE)	SAME AS NO. 8 (ABOVE)
10 TRI EXTENDER LMSC		TRIANGULAR BOOM, PANTOGRAPH LINKS CONNECT THE LONGITUDIONAL MEMBERS. EACH LONGITUDIONAL MEMBER HAS A LENTICULAR SECTION BETWEEN THE LAZY TONG NODES SIMILAR TO EXT. STRUCTURE NO. 12. THE LENTICULAR SECTIONS ARE FLATTENED THEN BUCKLED ALTERNATELY INWARD/OUTWARD TO STOW. NOT RETRACTABLE	FLIGHT EXPERIENCE: NONE	LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CALIFORNIA	TWO MODELS BUILT, THE FIRST WITH 5-INCH BAYS (5 BAYS HIGH) USED LUFKINS TAPES (SEMI-LENTICULAR CROSS-SECTION) AS THE LONGITUDINAL MEMBERS. THE SECOND MODEL HAS 40-INCH SQUARE BAYS WHEN EXTENDED (3 BAYS OR 10-FEET TALL) AND IS MADE ENTIRELY OF ALUMINUM. DEVELOPMENTAL WORK IS UNDERWAY TO REPLACE SOME OF THE ALUMINUM LAZY TONG MEMBERS WITH A GRAPHITE-EPOXY COMPOSITE.	COMPACT STOWAGE, LINEAR SYSTEM. AN EXCELLENT STIFFNESS TO MASS RATIO IS ACHIEVED WITHOUT THE COMPLICATION OF LATCHES. THE LONGERONS BEND TO STOW BUT THE SECTION TO BE BENT IS FIRST FLATTENED WHICH LOWERS THE STRESSES SIGNIFICIENTLY. HOWEVER, THE BENDING WILL LIMIT THE COLUMN LOADING SOMEWHAT. BROAD LENTICULAR SECTIONS MAY CAUSE MORE SELF SHADING THAN CIRCULAR SECTIONS. THE BEAM IS NOT RIGID UNLESS FULLY EXTENDED. NO REASONABLE RETRACTION SYSTEM HAS BEEN PROPOSED FOR THIS BEAM.	A LARGE NUMBER OF SIMPLE PARTS REQUIRES ONE FORMING DIE FOR THE LENTICULAR SECTIONS AND OTHER MINIMAL TOOLING AND FIXTURES. ASSEMBLED WITH CONVENTIONAL METHODS AND TECHNIQUES. MAY PROVIDE LIMITED APPLICATIONS FOR EXOTIC MATERIALS.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITHOUT PERFORMANCE DEGRADATION, IF REASONABLE CARE IS USED IN FLATTENING THE LENTICULAR SECTIONS BEFORE BENDING. MINIMAL FIXTURES REQUIRED FOR ENVIRONMENT AND LOADS TEST	STOWS IN A LARGE TRIANGULAR AREA. UNTRAINED PERSONNEL COULD DAMAGE THE THIN WALL LENTICULAR SECTIONS.

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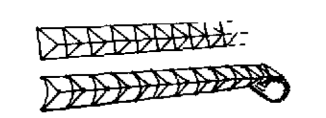
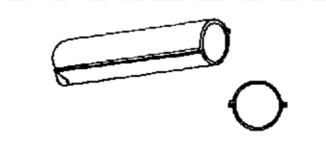
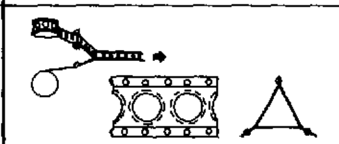
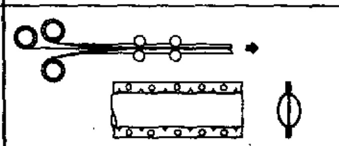
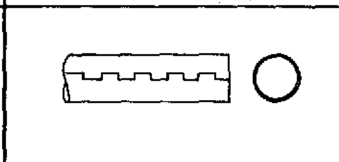
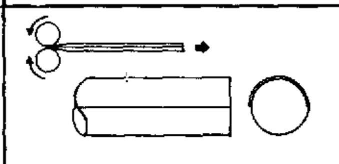
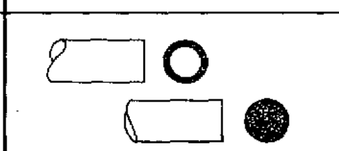
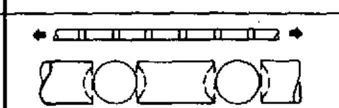
TABLE D6-6 (continued)
(Sheet 2 of 2)

NO. & NAME OF EXTENDIBLE STRUCTURE	ILLUSTRATION	DESCRIPTION & OPERATION OF STRUCTURE & MECHANISM (RETRACTION CAPABILITIES)	FLIGHT EXPERIENCE	SOURCE	DEVELOPMENT WORK	GENERAL DESIGN COMMENTS	PRODUCIBILITY	TESTING & HANDLING: GROUND DEPLOYMENT DEMO ENVIRONMENTAL TESTING STATIC LOAD TEST	TESTING & HANDLING: INSTALLATION ON SPACECRAFT
11 TRIANGULAR WIRE		SOLID SPRING WIRE CONSTRUCTION. TRIANGULAR SECTIONS WELDED TO LONGERONS. ONE LEG OF THE TRIANGULAR SECTION IS MADE TO FLEX (OR HINGED) SO THAT THE REMAINING 2 SIDES CAN BE BROUGHT TOGETHER. THE FOLDED BEAM CAN THEN BE ROLLED UP ON A REEL. REEL ROTATED BY ELECT. MOTOR & GEAR TRAIN, RETRACTION ACCOMPLISHED BY REVERSING MOTOR. IF RETRACTION IS NOT REQD, SPRING FORCE (OR MOTOR) MAY BE USED FOR EXTENSION.	FLIGHT EXPERIENCE UNKNOWN	MARTIN MARIETTA DENVER, COLO.	SOME DEVELOPMENT WORK DONE, EXACT STATUS UNKNOWN	REQUIRES DIAGONAL MEMBERS TO ACHIEVE REASONABLE TORSIONAL STIFFNESS. BENDING STRESSES IN LONGERONS DURING STOWAGE WILL LIMIT THEIR SIZE AND CONSEQUENT COLUMN LOADING CAPACITY. ANY THERMAL CONTROL SURFACES MUST RESIST ROLLING ABRASION AND FLEXING; HOWEVER, THIS IS AN EXCELLENT DESIGN TO MINIMIZE THERMAL DEFLECTIONS. MINIMUM DEPLOYMENT/RETRACTION PROBLEMS ARE ANTICIPATED. LINEAR DYNAMIC SYSTEM, FULL-BEAM STRENGTH COULD BE DEVELOPED AS THE BEAM EXTENDS. VERY COMPACT STOWAGE.	A LARGE NUMBER OF SIMPLE PARTS, MINIMAL JIGS AND FIXTURES, CONVENTIONAL FASTENING METHODS.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITHOUT PERFORMANCE DEGRADATION.	STORES ON A REEL WITH THE OUTBOARD END EXPOSED. THE EXPOSED SECTION SHOULD BE PROTECTED FROM UNTRAINED PERSONNEL.
12 LENTICULAR WELDED BEAM		TWO PIECES OF SPRING TAPES ARE PRE-FORMED TO APPROXIMATE A HAT SECTION. THE TWO TAPES ARE WELDED TOGETHER AT THE FLANGES. THE SECTION IS FLATTENED AND ROLLED UP ON A REEL FOR STOWAGE OR CAN BE LOCALLY FLATTENED AND BENT IN A FIRE HOSE FOLD. THE MOTOR DRIVEN REEL WOULD BE RETRACTABLE; THE FIRE HOSE FOLD WOULD NOT BE RETRACTABLE.	FLIGHT EXPERIENCE UNKNOWN	BOEING CO., KENT, WASH ASTRO RESEARCH CORP. SANTA BARBARA, CALIFORNIA	TRADE NAME MAST; DEVELOPMENTAL MODEL 20-FT LONG; FABRICATED AND TESTED BY BOEING. A DEVELOPMENTAL MODEL (20-FT LONG 2.3 IN. DIA) HAS BEEN DELIVERED TO MARTIN MARIETTA FOR EVALUATION. RYAN AERONAUTICAL CO. NO LONGER MANUFACTURES THIS BOOM AND MUCH OF THE RYAN TECHNOLOGY HAS BEEN ASSUMED BY THE ASTRO RESEARCH CORP.	LINEAR DYNAMIC SYSTEM, VERY COMPACT STOWAGE, BOOM, DEVELOPS FULL STRENGTH AS IT IS DEPLOYED. THIS BEAM IS GOOD FOR MEDIUM LENGTH APPLICATIONS (LESS THAN 50 FT). AS LENGTH INCREASES THE BEAM BECOMES INEFFICIENT FOR COLUMN LOADS. THE MOMENT OF INERTIA OF THE BEAM SECTION MAY BE INCREASED IN ONE DIRECTION WITH VERY LITTLE EFFECT ON STOWAGE VOLUME OR STRESSES. WELDED JOINTS SIMPLIFY THERMAL ANALYSIS. HOLE PATTERN PROBABLY REQUIRED, THERMAL COATINGS MUST WITHSTAND ROLLING ABRASION. THIS AND SIMILAR BEAMS COULD HAVE A THERMAL COMPENSATING CURVE BUILT IN.	FABRICATION AND ASSEMBLY TECHNIQUES WELL DEFINED. CONSTANT SECTION FACILITATES FORMING AND WELDING. TITANIUM HAS BEEN USED FOR DEMONSTRATION UNITS.	SAME AS NO. 11 (ABOVE)	SAME AS NO. 11 (ABOVE)
13 TRIBEAM (LMSC)		BEAM COMPOSED OF 3 SPRING TAPES WITH EDGE FLANGES CONTAINING VELCRO TAPE AND SNAP FASTENERS. TAPES ROLL-UP ON REELS ARRANGED ABOUT THE BEAM CENTERLINE. REELS ARE INTERCONNECTED & ROTATED BY ELECT. MOTOR & GEAR TRAIN, RETRACTION ACCOMPLISHED BY REVERSING MOTOR.	NO FLIGHT EXPERIENCE	LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CALIFORNIA	TWO GENERATIONS OF ENGINEERING MODELS HAVE BEEN BUILT AND DEMONSTRATED. SEVERAL BEAM SECTIONS HAVE BEEN FABRICATED AND SUBJECTED TO STRUCTURAL AND THERMAL TESTS.	HIGH DYNAMIC DAMPING, FAIRLY COMPACT STOWAGE. FOR MEDIUM LENGTH THIS IS A GOOD SELECTION. AS THE LENGTH APPROACHES 50 FT THE TRIBEAM BECOMES INEFFICIENT FOR SIGNIFICANT COLUMN LOADS. REQUIRES HOLES TO MINIMIZE THERMAL DEFLECTION. INSIDE AND OUTSIDE REQUIRE ROLLING ABRASION RESISTANT THERMAL COATINGS. POOR THERMAL CONDUCTION THROUGH THE VELCRO TAPES SHOULD CAUSE NO MAJOR PROBLEMS, IF ADEQUATE HOLE PATTERN IS USED, ESPECIALLY WHEN USED WITH A CONSTANT SUN ANGLE.	FABRICATION AND ASSEMBLY TECHNIQUES WELL DEFINED. REQUIRES SIMPLE PROGRESSIVE PUNCH PRESS DIES FOR QUALITY PARTS. CONSTANT SECTION FACILITATES FORMING. CONVENTIONAL ASSEMBLY TECHNIQUES.	SAME AS NO. 11 (ABOVE)	SAME AS NO. 11 (ABOVE)
14 INSTARECT (SANDERS)		3 PIECE BEAM, TWO OUTER PRE-FORMED SPRING TAPES ARE FLATTENED & ROLLED-UP ON REELS. THE CENTER (FLAT) SPRING TAPE WITH EDGE INDEX HOLES & SLOTS IS ALSO STORED ON A REEL. THE EDGES OF THE 3 TAPES INTERLOCK AS THE BEAM EXTENDS. REELS ARE INTERCONNECTED & ROTATED BY AN ELECT. MOTOR & GEAR TRAIN. RETRACTION ACCOMPLISHED BY REVERSING MOTOR.	FLIGHT EXPERIENCE UNKNOWN	SANDERS ASSOCIATES INC. NOSHAU, N.H.	TWO GENERATIONS OF ENGINEERING MODELS HAVE BEEN BUILT, TESTED AND DEMONSTRATED. BEAM MATERIAL FULL HARD 302 STAINLESS STEEL, 40 FT LONG BY APPROX. 3 BY 4 INCHES CROSS SECTION.	LINEAR DYNAMIC SYSTEM, FAIRLY COMPACT STOWAGE. AGAIN A MEDIUM-LENGTH BEAM CANDIDATE. HIGH B/T RATIOS IN THE CURVED SHEETS AND HIGH B/T RATIO ON FLAT SHEET LIMIT THE COLUMN LOAD CAPACITY. NOT LIKELY EFFICIENT IN LENGTHS GREATER THAN 50 FT. THE BEAM MOMENT OF INERTIA CAN BE INCREASED IN ONE DIRECTION WITH LITTLE EFFECT ON STOWAGE VOLUME OR STRESSES. SUBJECT TO LARGE THERMAL DEFLECTIONS IF CENTER IS SOLID. TEMPERATURE GRADIENTS DIFFICULT TO PREDICT BECAUSE OF UNCERTAINTY IN EDGE CONTACTS AND COMPLEX INNER STRUCTURE. HOLES MAY BE REQUIRED IN ALL THREE TAPES.	FABRICATION AND ASSEMBLY TECHNIQUES WELL DEFINED. REQUIRES SIMPLE PROGRESSIVE PUNCH PRESS DIES FOR QUALITY PARTS. CONSTANT SECTION FACILITATES FORMING. CONVENTIONAL ASSEMBLY TECHNIQUES.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITH MINIMUM PERFORMANCE DEGRADATION. MINIMAL FIXTURES REQD FOR ENVIRON AND LOADS TESTS.	STORES ON A REEL WITH THE OUTBOARD END EXPOSED. THE EXPOSED SECTION SHOULD BE PROTECTED FROM UNTRAINED PERSONNEL.
15 INTERLOCKING EXTENDIBLE REEL STORED		2 PIECES OF PRE-FORMED SPRING TAPES ARE FLATTENED & ROLLED-UP ON REELS. THE EDGES OF THE TAPES INTERLOCK AS THE BEAM EXTENDS. REELS ARE INTERCONNECTED & ROTATED BY AN ELECT. MOTOR & GEAR TRAIN. RETRACTION ACCOMPLISHED BY REVERSING MOTOR.	SIX UNITS (60 TO 120 FT LONG) WERE FLOWN ON NRL GRADIENT EXPERIMENT SATELLITES. FOUR (750 FT LONG) EDGELOCK TEES WERE USED ON RAE, 38 FT LONG HINGELOCK USED ON OGO AND FRENCH SATELLITE FR-2 EOLE.	SPAR AEROSPACE PRODUCTS LTD. ONTARIO, CANADA FAIRCHILD HILLER, GERMANTOWN, MD.	TRADE NAME INTERLOCKED BI STEM. TWO INCH DIA MODEL COMPLETED AND DEMONSTRATED. STUDIES IN MATERIAL AND LARGER DIA MODELS. TRADE NAMES, EDGELOCK AND HINGELOCK TEE. A SIX INCH DIA MODEL COMPLETED AND DEMONSTRATED. A TWO INCH MODEL IN NON-MAGNETIC STAINLESS STEEL COMPLETED FOR NASA, GODDARD CONTAINS 22 CONDUCTORS.	LINEAR DYNAMIC SYSTEM, VERY COMPACT STOWAGE. THIS BEAM (CONSIDERED AS A SOLID TUBE) IS GOOD FOR SHORT TO MEDIUM LENGTH APPLICATIONS (LESS THAN 50 FT). AS LENGTH INCREASES THE BEAM BECOMES INEFFICIENT FOR COLUMN LOADS. TEMPERATURE PREDICTION UNCERTAINTY IS INCREASED IF THE SUN DOES NOT SHINE SYMMETRICALLY ON THE INTERLOCKING LINE. HOLE PATTERN MAY BE REQUIRED TO OBTAIN REASONABLE THERMAL DEFLECTIONS. ROLL ABRASION RESISTANT THERMAL COATINGS ARE REQUIRED.	FABRICATION AND ASSEMBLY TECHNIQUES WELL DEFINED. REQUIRES SIMPLE PROGRESSIVE PUNCH PRESS DIES FOR QUALITY PARTS. CONSTANT SECTION FACILITATES FORMING. CONVENTIONAL ASSEMBLY TECHNIQUES.	SAME AS NO. 14 (ABOVE)	SAME AS NO. 14 (ABOVE)
16 EXTENDIBLE REEL STORED		PRE-FORMED SPRING TAPE (OR TAPES) ARE FLATTENED AND ROLLED UP ON A REEL FOR STOWAGE. THESE ARE THE SIMPLEST OF THE REEL STORED BEAMS. THE REEL IS ROTATED BY AN ELECT. MOTOR & GEAR TRAIN. RETRACTION IS ACCOMPLISHED BY REVERSING MOTOR.	USED AS ANTENNA, GRAVITY GRADIENT BOOMS, ACTUATORS, ETC. APOLLO, ATS, DODGE, MARINER AND MANY MORE SPACECRAFT APPLICATIONS. USED AS ANTENNAS, GRAVITY GRADIENT BOOMS ETC. ON RAE, OGO, NIMBUS & OTHERS. UNKNOWN. UNKNOWN. UNKNOWN.	SPAR AEROSPACE PRODUCTS LTD. ONTARIO, CANADA FAIRCHILD HILLER GERMANTOWN, MD. GENERAL ELECTRIC CORP. MSD, VALLEY FORGE, PA. GENERAL DYNAMICS/CONVAIR DIV., SAN DIEGO, CA WESTINGHOUSE DEFENSE & SPACE CENTER, AEROSPACE DIV. BALTIMORE, MD.	TRADE NAME STEM AND BI STEM (STORABLE TUBULAR EXTENDIBLE MEMBER). SELF-ERECTING MODEL THAT IS STOWED BY COILING INSIDE A CYLINDER IS CALLED "JACK-IN-THE-BOX". TRADE NAME TEE (TUBULAR EXTENDIBLE ELEMENTS) A DOUBLE MODEL WITH A CROSS-SECTION RESEMBLING THE FIGURE 8 FABRICATED AND DEMONSTRATED. TRADE NAME MOLY ROD TRADE NAME SCREEN BOOM	LINEAR DYNAMIC SYSTEM, VERY COMPACT STOWAGE, LOW TORSIONAL STIFFNESS. AS ABOVE, INEFFICIENT IN LONGER LENGTHS. TEMPERATURE PREDICTION IS MORE DIFFICULT BECAUSE THE JOINT THERMAL CONDUCTANCE IS UNLIKELY TO BE REPEATABLE. HOLE PATTERN MAY BE REQUIRED TO OBTAIN REASONABLE THERMAL DEFLECTIONS. ROLL ABRASION RESISTANT THERMAL COATINGS REQUIRED.	FABRICATION AND ASSEMBLY REQUIREMENTS WELL DEFINED. CONSTANT SECTION FACILITATES FORMING. CONVENTIONAL ASSEMBLY TECHNIQUES.	CONSTRUCTION ALLOWS REPEATED DEPLOYMENT/RETRACTION WITHOUT PERFORMANCE DEGRADATION	STORES ON A REEL WITH THE OUTBOARD END EXPOSED. THE EXPOSED SECTION SHOULD BE PROTECTED FROM UNTRAINED PERSONNEL
17 SPRING HELIX		TUBE IS FORMED BY A HELICALLY PRE-STRESSED SPRING TAPE WHOSE OVERLAPPING COILS FORM A RIGID TUBE WHEN EXTENDED. MAY BE SELF-EXTENDING OR MOTOR DRIVEN. THE MOTOR DRIVE CONTROLS DEPLOYMENT SPEED AND PERMITS REMOTE RETRACTION.	USED TO ERECT FOIL SUNSHIELD OF CENTRAL CONTROL STATION ON APOLLO LUNAR SURFACE EXPERIMENTS PACKAGE.	AMETEK/HUNTER SPRING CO. HATFIELD PA.	TRADE NAME STACER, TWIN MOTOR-DRIVEN STACERS WERE USED TO EXTEND A NASA EXPERIMENTAL SOLAR ARRAY APPROX. 9 FT.	VERY COMPACT STOWAGE, VERY LOW AXIAL AND TORSIONAL STIFFNESS. COLUMN LOAD CAPACITY, LATERAL AND TORSIONAL STIFFNESS DEPEND ON FRICTIONAL FORCES EXISTING BETWEEN OVERLAPPING LAYERS. NO RELIABLE METHOD OF ANALYSIS HAS BEEN ESTABLISHED. STIFFNESS WILL BE DERIVED MAINLY BY TESTS. ROLL ABRASION-RESISTANT THERMAL COATINGS REQUIRED. MATERIAL CONTINUITY AND THE RESULTING SPIRAL THERMAL CONDUCTANCE PROBABLY RESULTS IN LOWER THERMAL DEFLECTIONS THAN A NON CONTINUOUS TUBE SECTION.	MINIMUM SPECIAL TOOLING REQUIRED. CONVENTIONAL ASSEMBLY TECHNIQUES.	SAME AS NO. 16 (ABOVE)	SAME AS NO. 15 (ABOVE)
18 INFLATABLES		GAS TIGHT TUBES (MYLAR, FOIL, MYLAR) ARE FLATTENED AND FOLDED FOR STORAGE; AN EXTERNAL GAS SUPPLY INFLATES AND ERECTS (AND REMOVES THE WRINKLES) THE TUBES. THE ALUM. FOIL SANDWICHED IN MYLAR THEN IS A THIN-WALLED TUBE AND LENDS ITSELF TO ANALYSIS. GAS PRESSURE IS RELIEVED WHEN THE SYSTEM REACHES EQUILIBRIUM. MAY BE USED AS A MULTIPLE-TUBE SYSTEM STIFFENED BY SPACERS AND GUY WIRES. ARE USUALLY NOT RETRACTABLE.	SEVERAL LOOP ANTENNAS, 6 TO 9 FT DIA, WERE FLOWN ON THE OGO SERIES (STANFORD UNIVERSITY EXPERIMENTS). ALL WERE SINGLE TUBES 1 TO 2 IN. DIA. A MECHANISM CONTAINING A COLUMN OF MULTIPLE TUBES 10 FT LONG WAS SUCCESSFULLY DEMONSTRATED ON CLASSIFIED MISSIONS.	LOCKHEED M.S.C. SUNNYVALE, CALIFORNIA		HIGH DAMPING; PROBABLY A NON-LINEAR SYSTEM; VERY COMPACT STOWAGE. STRENGTH AND STIFFNESS VARY GREATLY AS THE STRUCTURE IS FOLDED MORE OR LESS, I.E., THE WRINKLED CONDITION OF THE FOIL. EMPIRICAL RESOLUTION MUST BE USED TO ESTABLISH FOLDING TECHNIQUES AND LIMITS. MYLAR DEGRADES WHEN EXPOSED TO U.V., SO A PROTECTIVE COATING MUST BE USED. LARGE FRONT-TO-BACK TEMP. GRADIENTS ARE LIKELY, PARTICULARLY IF MULTIPLE TUBE SYSTEM IS USED. ADHESION OF THERMAL CONTROL SURFACE TO THE MYLAR MAY BE DIFFICULT TO ACHIEVE.	MINIMUM TOOLING REQUIRED; HOWEVER, A GREAT AMOUNT OF HAND CRAFTSMANSHIP IS REQUIRED.	PERFORMANCE DEGRADES NOTICEABLY WITH EACH DEPLOYMENT/RETRACTION. CAREFUL HANDLING AND PRUDENT FIXTURES REQD FOR TESTING.	STORES WELL; MUST HAVE A GAS SUPPLY. VERY DELICATE; MUST BE PROTECTED FROM UNTRAINED PERSONNEL.
19 RIGIDIZED INFLATABLES		TWO SYSTEMS ARE SHOWN: (A) A SOLID CORE OF RIGID FOAM IS FORMED INSIDE A FABRIC FORM WHILE RESTRAINED BY A DIE. THE PRESSURE OF THE FOAM FEEDS IN THE FABRIC FORM AS THE RIGID FOAM IS FORCED OUT THE OPPOSITE END; (B) PRE-TREATED GELATINE-GLASS FIBER LAMINATED TUBES MADE FLEXIBLE WITH A SOFTENING AGENT. THE TUBES ARE GAS-INFLATED IN SPACE AND THE SOFTENING AGENT EVAPORATES, LEAVING THE TUBES STIFF. COMPLETE RIGIDITY IS ACHIEVED IN 10 TO 20 HOURS. IS NOT RETRACTABLE.	FLIGHT EXPERIENCE UNKNOWN FLIGHT EXPERIENCE UNKNOWN FLIGHT EXPERIENCE UNKNOWN	GOODYEAR AEROSPACE CORP. AKRON, OHIO LOCKHEED M.S.C. SUNNYVALE, CALIFORNIA MESSERSCHMITT-BOLKOW-BLOHM GMBH, MUNICH, GERMANY	DEVELOPED A SERIES OF INFLATABLE RIGIDIZED STRUCTURES FOR AERO PROPULSION LAB. USING DACRON FABRIC RIGIDIZED BY EXPOSING A URETHANE RESIN TO MOISTURE IN THE INFLATING SYSTEM. DEVELOPED FOR NASA AN ORBITAL ESCAPE DEVICE USING IMPREGNATED FIBERGLASS THAT HARDENED BY APPLICATION OF HEAT OR VACUUM. DEVELOPED A RIGIDIZED STRUCTURE TO SUPPORT A 215 SQ FT SOLAR ARRAY. USES GELETINE-GLASS TUBES AND INFLATION SYSTEM EVAPORATES THE SOFTENING AGENT.	HIGH DAMPING, LINEAR SYSTEM, CONVENIENT STOWAGE SYSTEM. FOAM MATERIALS HAVE A VERY LOW YOUNG'S MODULUS. TO MAKE UP THAT DEFICIENCY, A LARGE AMOUNT OF FOAM MUST BE PROVIDED, THEREIN DEFEATING THE ADVANTAGE OF USING A LOW DENSITY MATERIAL. LARGE FRONT-TO-BACK THERMAL GRADIENTS ARE LIKELY. THERMAL CONTROL SURFACE APPLICATION MAY BE A PROBLEM.	MINIMUM TOOLING REQUIRED; HOWEVER, A GREAT AMOUNT OF HAND CRAFTSMANSHIP IS REQUIRED.	NOT RETRACTABLE; DEPLOYMENT TESTS CAN NOT BE MADE ON FLIGHT HARDWARE. DEVELOPMENT TESTS AND OTHER QUALITY ASSURANCE TESTING MUST BE USED.	STORES WELL, BUT DOES REQUIRE ATTENDING PRESSURIZED CONTAINERS.
20 FLEXIBLE TETHER		CYLINDRICAL SECTIONS WITH SPHERICAL SEATS ON EACH END, ALTERNATE WITH BALLS; ENTIRE ASSEMBLY HAS CENTER HOLE TO ACCEPT FLEXIBLE TENSION MEMBER. THE TENSION MEMBER IS FIXED TO ONE END; TENSION REACTED AGAINST THE OPPOSITE END CAUSES THE LOOSE PARTS TO ALIGN AND FORM A STRAIGHT COLUMN (THE SHORTEST LENGTH OF CABLE).	FLIGHT EXPERIENCE UNKNOWN FLIGHT EXPERIENCE UNKNOWN	GENERAL ELECTRIC MSD VALLEY FORGE, PA. ILLINOIS INSTITUTE OF TECHNOLOGY, MECHANICAL ENGINEERING DIV. CHICAGO, ILL.	WORKING MODELS HAVE BEEN DEMONSTRATED ON THE GROUND AND UNDER WATER WITHOUT ANY REPORTED PROBLEMS. DEVELOPED A COLLAPSIBLE CANE THAT WORKS ON THIS PRINCIPLE.	POOR STORAGE CHARACTERISTICS (THE STOWED VOLUME IS EQUAL TO THE EXTENDED VOLUME). THE TETHER REQUIRES THE CONCENTRATION OF MASS TO BE NEAR THE CENTER OF THE BEAM, RESULTING IN A POOR STRUCTURE FOR STIFFNESS. THERMAL DEFLECTIONS ARE DEPENDENT UPON MATERIAL AND THICKNESS OF STRUCTURE.	DEPENDENT UPON DETAIL DESIGN; COULD EITHER BE VERY EASY OR NEARLY IMPOSSIBLE TO FABRICATE.	REPEATED DEPLOYMENTS CAN BE MADE; MAY CRACK THE WHIP IF ACTUATED RAPIDLY.	EXTENSIVE DEVELOPMENT WORK REQUIRED TO OPTIMIZE PACKAGING/DEPLOYMENT TECHNIQUES.

1

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TABLE D6-7

CHARACTERISTICS OF EXISTING SPAR AEROSPACE STEM-TYPE BOOMS

Program	FRUSA	Apollo 15/16 Mass Spectrometer	15/16 Gamma Ray	Apollo 17 Lunar Sounder	AEG-Telefunken	NASA-Langley
Type	Bi-Stem	Bi-Stem	Bi-Stem	Bi-Stem	Bi-Stem	MTS Boom
Diameter	.86 in	2.0	2.0	1.34	.86	.86
Element Length	16.0 ft	25.0 ft	27.0 ft	34.0 ft^2	16.0 ft	11.0 ft
Mechanism Size	4.0x11.OD	10.ODx73.5L	10.Dx18.0L	7.5"x8.0"x14.5"	16.0x6.0x4.0	5.0x16.0x4.0
Mechanism Weight	17.0 Lb	57.0 Lb	45.0 Lb	22.5 Lb	16.0 Lb	12.0 Lb
Element Material	301 S.S.	455 S.S.	455 S.S.	455 S.S.	301 S.S.	301 S.S.
Thermal Coating	Silver Plate	Silver Plate	Silver Plate		No Coating	No Coating
Motor Type	DC Motor	2 Motors DC	2 Motors DC	DC Motor	DC Motor	DC Motor
Extension Rate	1/2"/sec	1.8"/sec	1.8"/sec	6.0"/sec	1.6"/sec	7.3"/sec
Number of Boom(s)/ Mech.	2	1	1	2	2	4
Element Thickness	.005	.012	.012	.007	.005	.005
Number of Units (Production)	2	3	3	4	1	1

C-4

TABLE D6-8
CHARACTERISTICS OF EXISTING ASTROMASTS

Application	Antenna Support Jeep Mounted (Prototype)	Erector/ Support for S/C Helical Antennae	Central Support for Parabolic Mesh Antenna (Subscale Model)	Antenna Support for use on Lunar Surface (Eng. Model)	Support for Space Station Solar Cell Array (Eng. Model)	Support Boom for Antennae of Orbiting Interferometer (Test Segment)
Mast type	Articulated longeron	Continuous longeron	Continuous longeron	Continuous longeron	Articulated longeron	Continuous longeron
Mast diam (in.)	13.4	4	6	10	20	8
Mast length (ft)	40	15	8	100	84	10 (1)
Approx weight						
Mast (lb)	46	0.30	2.0	20	214	1.3
Canister (2) (lb)	128	(3)	20	30	186	(3)
Package size (4)	25 x 43	4.25 x 6 (5)	7 x 20	11 x 42	24 x 52	8.5 x 4 (5)
Motors	1-1/4 hp 28 V DC	None	1-Globe 28 V DC	2-Globe 28 V DC	3-12 amp 28 V DC	None
Extension rate	1 ft/sec	--	4 in./sec	2 in./sec	2.5 in./sec	--
Bending stiffness ($lb\text{-}in.^2$) x 10^{-6}	77	0.12	0.70	5.5	280	2.04
Bending strength (in.-lb)	7800	25	80	460	36,000	200

(1) 10 ft test segment of 125 ft required length
(2) No significant effort made to minimize canister weight
(3) No canister supplied
(4) Cylindrical volume - cyl. diam (in.) x cyl. height (in.)
(5) Size of retracted boom alone - no canister supplied

APPENDIX E

MMU CARGO TRANSFER CAPABILITY

MMU CARGO TRANSFER CAPABILITY

MMU Cargo Transfer--General

Transfer of large massive cargo items, including the large free-flying payloads, does not appear to impose significant problems to the MMU from the standpoint of force requirements. Table E-1 provides thruster time and fuel requirements to attain desired velocities with various masses using different thrust levels. Notice that the larger masses can be accelerated to normal translation velocities within a matter of minutes by relatively small thruster forces.

Figure E.1 graphically illustrates thruster time and fuel requirements to attain given velocity levels with varying cargo masses based on a 22.2 N. (5 lbs.) force capability from the MMU.

In conclusion, the force requirement for cargo transfer does not appear to be critical for most Shuttle operations. However, a 22.2 N. (5 lbs.) force capability allows the crewman more reaction time to stop his translation than the smaller forces, a factor which becomes significant in transferring the larger masses and appears to be a representative design guideline based on the capabilities of maneuvering units from previous programs (i.e., Skylab M509 ≈4.8 lbf.).

MMU Cargo Transfer Capability--Utility Category

An attempt to place a limit on the mass and size of cargo that the MMU-crewman combination can handle/transport in a "gravity-free" environment would be futile. An EV crewman with a versatile man-maneuvering system, given adequate visibility and time, can transport any size and mass article man can launch into space. Example: The EV crewman equipped with an MMU capable of 22.2 N. (5 lbs.) thrust can accelerate the Space Shuttle vehicle and its 29,500 kg. (65,000 lb.) payload to a velocity of .03 m/sec (.1 ft/sec) in 134 sec. The propellant consumption would be approximately 5.1 kg. (11.3 lbs.) GN_2 or 46.1 ft/sec assuming propellant consumption rate at .043 kg. (.095) lb.) per sec.

TABLE E-1: Cargo Transfer -- Time and Propellant Requirements

MASS - 500 kg. (1103 lbs.)*

VELOCITY m/sec (ft/sec)	1 lb force time (sec)	2 lb force time (sec)	3 lb force time (sec)	4 lb force time (sec)	5 lb force time (sec)	Fuel Req'd lbs N2
.03 (.1)	3.5	1.8	1.2	.9	.7	.06
.06 (.2)	7.0	3.5	2.3	1.7	1.4	.12
.09 (.3)	11.0	5.5	3.6	2.7	2.2	.21
.12 (.4)	14.0	7.0	4.6	3.5	2.8	.26
.15 (.5)	17.5	8.8	5.8	4.4	3.5	.30
.18 (.6)	22.0	11.0	7.3	5.5	4.4	.42

MASS - 1000 kg. (2205 lbs.)*

VELOCITY m/sec (ft/sec)	1 lb force time (sec)	2 lb force time (sec)	3 lb force time (sec)	4 lb force time (sec)	5 lb force time (sec)	Fuel Req'd lbs N2
.03 (.1)	7	3.5	2.3	1.8	1.4	.14
.06 (.2)	14	7	4.6	3.4	2.8	.29
.09 (.3)	22	11	7.2	5.4	4.4	.43
.12 (.4)	28	14	9.2	7.0	5.6	.57
.15 (.5)	34	17	11.6	8.8	7.0	.72
.18 (.6)	44	22	14.6	11.0	8.8	.86

*Includes MMU-crewman system

TABLE E-1: Cargo Transfer -- Time and Propellant Requirements (continued)

MASS - 5000 kg. (11,025 lbs.)*

VELOCITY m/sec (ft/sec)	1 lb force time (sec)	2 lb force time (sec)	3 lb force time (sec)	4 lb force time (sec)	5 lb force time (sec)	Fuel Req'd lbs N_2
.03 (.1)	35	17.5	11.5	9	7	.71
.06 (.2)	70	35	23	17	14	1.43
.09 (.3)	110	55	36	27	22	2.14
.12 (.4)	140	70	46	35	28	2.85
.15 (.5)	170	85	58	44	35	3.57
.18 (.6)	220	110	73	55	44	4.28

MASS - 10,000 kg. (22,050 lbs.)*

VELOCITY m/sec (ft/sec)	1 lb force time (sec)	2 lb force time (sec)	3 lb force time (sec)	4 lb force time (sec)	5 lb force time (sec)	Fuel Req'd lbs N_2
.03 (.1)	70	35	23	18	14	1.43
.06 (.2)	140	70	46	34	28	2.89
.09 (.3)	220	110	72	54	44	4.28
.12 (.4)	280	140	92	70	56	5.70
.15 (.5)	340	170	116	88	70	7.13
.18 (.6)	440	220	146	110	88	8.55

*Includes MMU-crewman system

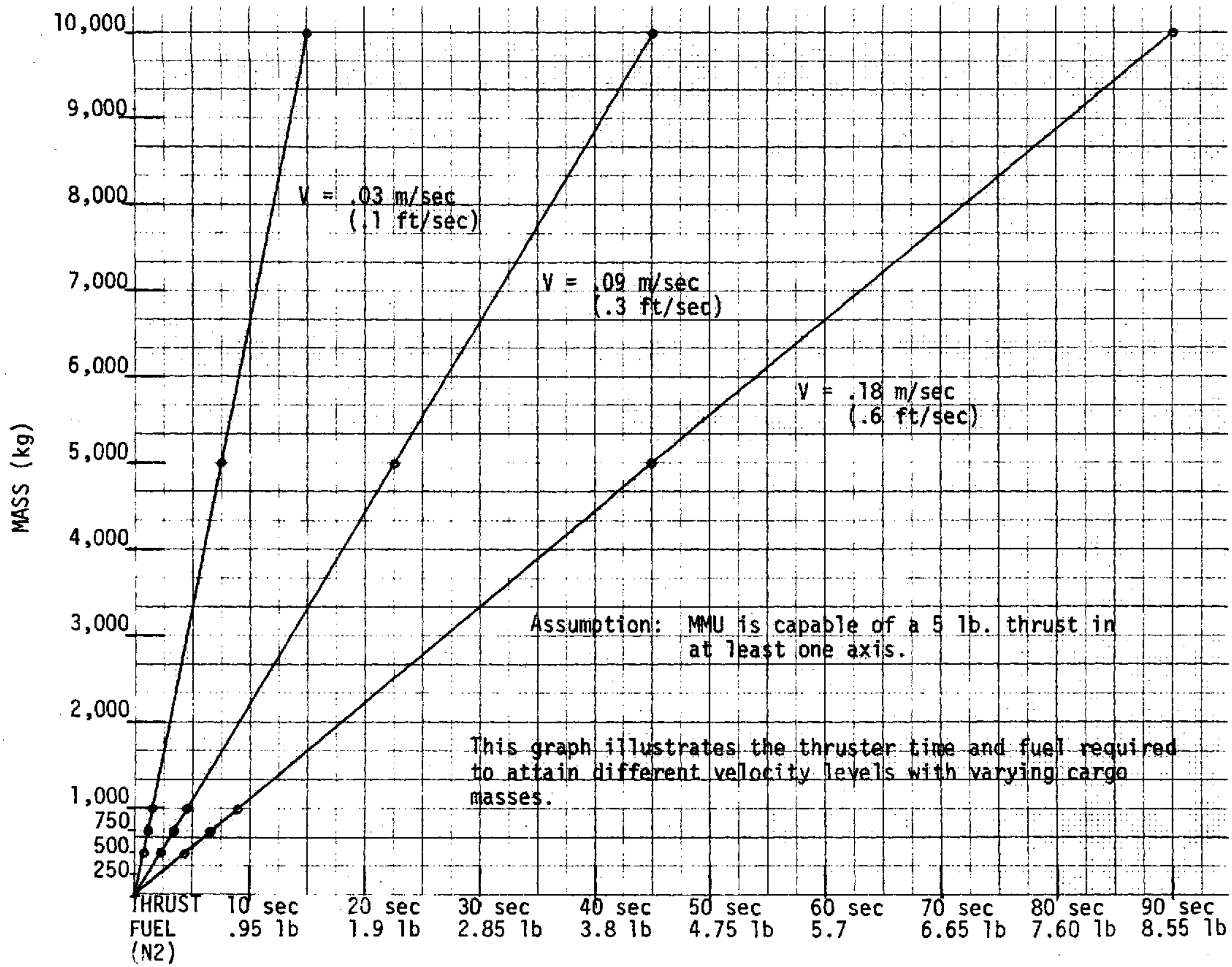

FIGURE E.1: Thruster Time and Fuel Requirements for Cargo Transfer Using a Five Pound Force Capability

However, the major factors involved in MMU cargo transportation in space are crew safety, cargo maneuverability, time and MMU propellant consumption. In considering the MMU for Space Shuttle applications, the objective is not in identifying tasks in an attempt to exceed maneuvering unit capability but to define tasks in which the MMU will serve in a "utility" category to economically enhance mission safety and experiment success.

In applying the MMU in a utility category for transporting equipment for Orbiter repair or payload servicing/refurbishment, assigning an upper limit on the MMU for cargo transport again becomes difficult. Until data has been compiled on the MMU system in various space activities, the following suggestions are submitted:

- A maximum mass designation for MMU transfer should not be assigned
- A maximum size (assuming visibility) for MMU transfer should not be assigned
- A guideline for MMU cargo transfer assignments in early applications should be:
  - The MMU will accommodate in a utility category 125% cg migration along the x-axis (primary translation axis) where 100% is equal to the distance from the MMU-crewman cg to the MMU-cargo interface point. This suggested guideline is depicted in Figure E.2.
  - Cargo attached to the sides should be located to minimize lateral or vertical cg migration.

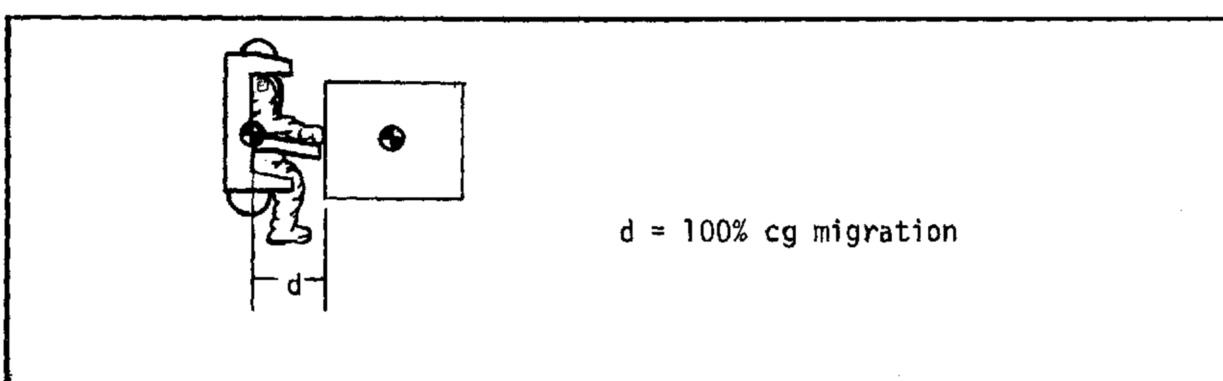

FIGURE E.2: MMU CG Migration Accommodation

MMU WEIGHT SUMMARY

Item	Weight
Space Suit Assembly (wet)	129.1 lbs.
ALSA (wet)	76.0 lbs.
Crewman	165.0 lbs.
MMU	165.0 lbs.
TOTAL	535.1 lbs.

APPENDIX F

QUESTIONNAIRE SENT TO PAYLOAD COMMUNITY

APPENDIX F INTRODUCTION

Appendix F contains a Payloads MMU-EVA Requirements Questionnaire package. This questionnaire consists of three parts and was designed to benefit the payloads community, the NASA-JSC MMU Working Group, and the contractor. The first part consists of a questionnaire to aid the contractor in gaining the detailed level of information desired but unavailable in accessible documentation. The remainder of the questionnaire package provides the payloads population with a brief overview of the EVA requirements and capabilities and projected Shuttle MMU characteristics. A separate "package" was assembled for each of the automated and sortie payloads contained in the NASA-MSFC payloads description documents (SSPD), and all packages were submitted to the MSFC Program Development, Payload Studies Office through the Manned Maneuvering Unit Working Group (MMUWG). To date, there has been no response to this effort.

PART A -- GENERAL INFORMATION

PAYLOAD NO. __________

PAYLOAD DISCIPLINE __________	PAYLOAD NAME: __________

1. Current EVA Requirements Status:	Planned ☐	Contingency ☐	No Application ☐
2. Current MMU Requirements Status:	Planned ☐	Contingency ☐	No Application ☐
3. Payload Checkout On-Orbit:	Yes ☐	No ☐	
4. Payload Retrieval From Orbit:	Yes ☐	No ☐	
5. Payload Designed For Servicing:	On-Orbit ☐	Return to Earth ☐	No Servicing ☐
(a) Free-Flying	☐		
(b) Orbiter Attached	☐		
6. Payload Systems FMEA's Available:	Yes ☐	No ☐	
7. As presently configured, if payload malfunctions on-orbit or during orbital checkout, are on-orbit repairs possible:	Yes ☐	No ☐	

Document Title and Number: __________

Explain: __________

PAYLOAD NO. ____________

8. Would payload be lost/discarded if malfunctions are detected on-orbit or during orbital checkout and on-orbit repair/servicing cannot be performed: Yes ☐ No ☐

EXPLAIN: ____

____

9. Would a real-time manned servicing/refurbishment capability enhance mission success over automated systems: Yes ☐ No ☐

EXPLAIN: ____

____

10. Is on-orbit servicing/refurbishment of payload:
    (a) Desirable: Yes ☐ No ☐
    (b) Feasible: Yes ☐ No ☐

11. Is payload design firm or can design still be modified to optimize accommodation of MMU/EVA servicing/refurbishment: Firm ☐ Optimizable for MMU/EVA ☐

12. Based on present payload development status, can the payload economically be designed for on-orbit servicing: Yes ☐ No ☐

EXPLAIN: ____

____

Prepared by: ____________________ Code: ____________________

PAYLOAD NO.__________

PART B -- PAYLOAD SPECIFIC/QUANTITATIVE INFORMATION

NOTE: <u>DO NOT</u> COMPLETE REMAINING QUESTIONS IF PAYLOAD PRECLUDES MMU/EVA APPLICATION.

13. Is contamination from Orbiter Reaction Control System a factor in payload rendezvous: Yes ☐ No ☐

14. Is propulsion contamination from an MMU a factor in payload rendezvous:

    (a) Cold Gas (Nitrogen or Oxygen): Yes ☐ No ☐

    (b) Hot Gas (Probably catalytically decomposed hydrazine): Yes ☐ No ☐

15. Is contamination from EVA suit leakage and EVLSS sublimator operation a factor in payload rendezvous: Yes ☐ No ☐

16. Is thruster impingement from the Orbiter (vernier thruster--25 lbf each; RCS thruster--900 lbf each) a factor in payload rendezvous (payload disturbance): Yes ☐ No ☐

    Minimum Safe Distance:____________________

17. Is thruster impingement of MMU magnitude (approximately 2 1/2 lbf/thruster) a factor in payload rendezvous (payload disturbance): Yes ☐ No ☐

    Minimum Safe Distance:____________________

PAYLOAD NO.

18. Would servicing tasks involve multiple worksites: Yes ☐ No ☐

Number of Worksites: ____________________

19. Is the payload (free-flying) attitude control system intended to be operational during servicing: Yes ☐ No ☐

20. Are redundant attitude control systems incorporated in payload design: Yes ☐ No ☐

21. Is redundancy sufficient and the systems modularity so arranged as to keep the payload operational during servicing operations: Yes ☐ No ☐

22. If attitude control system is inhibited during servicing, will payload remain "docile" or stable during "coast" to complete servicing operations: Yes ☐ No ☐

EXPLAIN: ____________________

23. Maximum MMU travel distance to reach payload from Shuttle Orbiter: ____________________

PAYLOAD NO. ______

24. Assuming MMU's were available on the Orbiter, which task categories listed would be candidates for MMU/EVA employment in connection with your payload:

- Rendezvous ☐
- Attach/Capture ☐
- Cargo Transfer ☐
- Inspect/Diagnose ☐
- Clean/Decontaminate ☐
- Deploy/Retract ☐
- Assemble/Mate ☐
- Disassemble/Demate ☐
- Other: ______
- Operate/Monitor ☐
- Remove/Replace Modules ☐
- Data Retrieval ☐
- Satellite Deploy/Recover ☐
- Satellite Despin ☐
- Recharge Pneumatic/Propellant Systems ☐
- Spray Paint/Coatings On Exterior Surfaces ☐

25. Provide physical characteristics of modules/cargo/equipment "handled" during servicing operations:

NOMENCLATURE	DIMENSIONS	MASS

PAYLOAD NO. ____________

26. Provide estimates of force/torque application requirements:

TASK DESCRIPTION	FORCE	TORQUE

27. Estimated time to complete payload servicing task:

____

____

28. List of tools required to complete servicing task:

____

____

____

PAYLOAD NO.

29. List potential hazards to EVA crewman during payload servicing: ____________________

30. Identify (provide, if feasible) documents/drawings which identify task worksite locations on payload:

DRAWING TITLE	DRAWING NUMBER

31. Are present MMU/EVA capabilities sufficient to support payload servicing operations: Yes ☐ No ☐

EXPLAIN: ____________________

PREPARED BY: ____________________

LOCATION/CODE/EXTENSION: ____________________

MANNED EXTRAVEHICULAR ACTIVITY (EVA) REQUIREMENTS/CAPABILITIES

FOR

SPACE SHUTTLE APPLICATION (PRELIMINARY)

EVA CREWMAN EQUIPMENT REQUIREMENTS

EQUIPMENT ITEM	WEIGHT	PROVIDED BY ORBITER	COMMENTS
• Space Suit Assembly (SSA)	75 lbs.	2	Pressurizable enclosure
• Astronaut Life Support Assembly (ALSA)			
- Extravehicular Life Support System (EVLSS)	TBD	2	Provides oxygen and cooling to crewman during EVA
- Secondary Oxygen Pack (SOP)	TBD	2	Back-up oxygen
- Service and Cooling Umbilical Assembly (SCUA)	TBD	2 (tentative)	Provide oxygen and cooling to crewman during preps
• Portable Oxygen System (POS)	12.5 lbs.	yes	Pre-breathe emergency oxygen
• Tool Kit	TBD	yes	Common tools provided by Orbiter Special tools provided by P/L
• Personnel Rescue System (PRS)	37 lbs.	2	Provides a means of transferring crewmen between vehicles in space. Used for crew rescue only.
- Personnel Rescue Enclosure (PRE)			
- Portable Oxygen System (POS)			
- Cooling System (LCG)			
- PRS Umbilicals			
- Tether			

EVA TRANSLATION HARDWARE REQUIREMENTS

HARDWARE ITEM	WEIGHT	PROVIDED BY ORBITER	COMMENTS
• Fixed Aids - Hand Rails/holds	.25-.35 lb/ft (est.)	Access to bulkheads and through bay	Installed preflight or inflight to predetermined locations. Orbiter supplies hardware to support vehicle only
• Adjustable Aids - Remote Manipulator System	TBD	1 Second optional and charged to P/L	Not presently man-rated, used for cargo transfer only
- Extendable Booms, etc.	TBD (Skylab ≈90 lb)	TBD	No <u>current</u> requirements identified
• Manned Maneuvering Unit (MMU)	≈165 lbs. (est.)	Tentatively, in early operation flights	See Enclosure III for capabilities

EVA WORKSITE HARDWARE REQUIREMENTS

HARDWARE ITEM	WEIGHT	PROVIDED BY ORBITER	COMMENTS
• Handholds/Rails	.25-.35 lb/ft (est.)	For Orbiter worksites only	Required for crewman translation and stabilization
• Foot Restraints	TBD	For Orbiter worksites only	Frees crewman's hands to perform tasks
• Lighting	TBD	Minimum for workstations and translation	Orbiter does not provide sufficient lighting for most P/L tasks

EQUIPMENT INTEGRAL TO ORBITER

EQUIPMENT ITEM	WEIGHT	PROVIDED BY ORBITER	COMMENTS
• Airlock	-	yes	Allows crew compartment to remain press. for EVA
• EVA Mission Kit Tunnel	-	no	Provides passage to press. P/L, provides hatch for EVA exit
• Docking Module	-	no	Provides docking capabilities to other vehicles. Provides EVA exit. Not flown unless required.
• EVLSS Service	27 lbs	no*	Recharge oxygen and water, recharge batteries
- LCG Loop Service	TBD	no*	Recharge water
- SSA Purge	1.66 lbs	no*	
- Prebreathing	TBD	no*	Oxygen required
- Airlock Depress.	2.3 lbs O_2 8.5 lbs N_2		
- PLSS Deservice	4.0 lbs	no*	Waste water must be returned
- Space Suit Assembly Drying	-	no*	Electrical power TBD
• Space Suit Assembly Support	TBD	no*	Provide cooling water to suited crewmen during preps

* Orbiter provides for 2 planned - 2 man EVAs and 1 - 2 man contingency EVA. Additional EVAs are charged to the payload.

EVA PROVEN CAPABILITIES

- Exchange experiment packages (film/cameras, etc.)
- Transfer cargo and equipment
- Mount equipment on vehicle structure
- Free restrained solar array using cable cutters
- Pin aperture doors open
- Free sticking relay by impacts on outside of housing (CBRM on Skylab ATM)
- Clean lenses or occulting discs
- Assemble emergency thermal shield over the vehicle (analogous to deployment of large antenna array)
- Assemble work platforms
- Operate cameras and experiments
- Deploy clothesline (cargo transfer system)
- Visually inspect exterior of satellite or vehicle
- Remove and replace bolts and screws
- Connect and disconnect electrical connectors
- Install jumper box in electrical subsystem to alter as-launched hard-wired configuration (ATM rack mounted rate gyros, S-193 antenna)
- Pin malfunctioning antenna by removing allen screws, removing launch lock and inserting gimbal lock fabricated on ground after launch of malfunctioning system (S-193 antenna)
- Use a small screwdriver to adjust experiment filters
- Check temperature of experiments in situ with digital thermometer

EVA OPERATIONAL LIMITATIONS/CONSTRAINTS

- Contamination tolerance of experimental hardware from SSA leaks & EVLSS sublimator (unless umbilical used)
- Duration: 4 hours (present baseline) duration for each EVLSS (consumables - expendables charge) unless umbilical used
- Extreme temperatures - TBD
- Radiation hazards to the EVA crewman
- EVA preparation and shutdown activities (crew time and schedule impact)

MANNED MANEUVERING UNIT (MMU) REQUIREMENTS/CHARACTERISTICS FOR SPACE SHUTTLE APPLICATION (PRELIMINARY)

OPERATIONAL REQUIREMENTS/CHARACTERISTICS

- Mission Duration: 6 hours
- Range:
  - 100 m (330 ft) nominal
  - maximum: TBD
- Delta V: 16 m/sec (52 ft/sec); total includes attitude control requirements
- 10 - 12 hour turn-around between EVA missions
- Fail Safe
- One-man Service, Don/Doff EVA
- Self-contained System
- Safety Tether (Optional)
- EVA Applications
- Worksite Attachment Provisions
- Cargo Transfer Capability

SYSTEM REQUIREMENTS/CHARACTERISTICS

- Control System
  - Six Degree of Control Authority
  - Spacecraft-type Piloting Logic
  - Automatic Attitude Hold: Rate Gyro (Prime)
    * Rate/Displacement Deadband: $\pm 2°$/sec; $\pm 2°$ (tentative)
    * Drift: 0.05°/sec
  - Attitude Rate Command: Acceleration Command
  - Manual Attitude Hold (Backup)
- Propulsion
  - Cold Gas (GN_2 Prime, GO_2 Backup)
  - Acceleration
    * Translational: $0.1 \pm .01$ m/sec^2 ($0.3 \pm .05$ ft/sec^2)
    * Rotational: $10 \pm 3°$/sec^2
  - Hot Gas Module Provision [TBD Addition Delta V Capability in $\pm$x Direction (Fore and Aft) At the Expense of Higher Levels of Potential Contamination.]
- Weight
  - MMU: 75 kg (165 lbs)
  - Total: TBD

MMU INTERFACE REQUIREMENTS

- ORBITER
  - Avionics
    * Performance Monitoring System for Data (thru ALSA)
    * Radar for Range and Range Rate (TBD)
  - Electrical
    * Power for Battery Charger
  - Fluid
    * GN_2 for Propellant
    * 4000 N/cm^2 (5800 psi)
  - Lighting
    * Don/Doff/Checkout/Service Station Illumination
  - Mechanical
    * Launch, On-orbit, and Return Stowage
    * Don/Doff/Checkout/Service Station in Payload Bay

- ASTRONAUT LIFE SUPPORT ASSEMBLY (ALSA)
  - Electrical
    * Transmit MMU Data
    * Caution and Warning
    * Displays (TBD)
    * Backup Power (TBD)
  - Fluid
    * GO_2 for Backup Propellant (TBD)
  - Mechanical
    * Attachment Provisions

APPENDIX G

INFORMATION SOURCES

APPENDIX G

TABLE OF CONTENTS

APPENDIX G1

PERSONNEL AND WORKING GROUPS CONTACTED

PAYLOAD COGNIZANT PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
H. G. Craft (205) 453-3425	MSFC/PD-MP-T	All payloads; Payload Description Documents (SSPD)	• Most recent data are contained in SSPDs
P. J. Schwintz (205) 453-3430	MSFC/PD-MP-A	Astronomy; Payload Integration	• LST studying EVA but not firm on payload configuration or hardware location
J. R. Dabbs (205) 453-2818	MSFC/PD-MP-P	High Energy Astro-physics; Payload Integration	• Considering contingency EVA but payload design not available
M. E. Nein (205) 453-3429	MSFC/PD-MP-A	Solar Physics; Pay-load Integration	• Contingency EVA being considered - no details
W. T. Roberts (205) 453-3433	MSFC/PD-MP-S	Atmospheric Physics, Payload Integration	• No current requirement for EVA--automated
M. A. Page (205) 453-3424	MSFC/PD-MP-T	Earth Observations and Earth and Ocean Physics; Payload Integration	• Considering EVA but no detail data available for Shuttle integration

PAYLOAD COGNIZANT PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
K. R. Taylor (205) 453-3426	MSFC/PD-MP-T	Space Processing Applications; Payload Integration	• No detailed information other than SSPD • No planned EVAs • Too early to address contingencies
J. D. Hilchey (205) 453-3432	MSFC/PD-MP-S	Life Sciences, Payload Integration	• For Life Sciences Lab, but no details at this point
H. J. Dudley (205) 453-2813	MSFC/PD-MP-P	Space Technology; Payload Integration	• LDEF considering EVA for contingency but tasks or equipment not defined
C. W. Quantock (205) 453-3426	MSFC/PD-MP-T	Comm/Nav.; Payload Integration	• Pallet access for contingency--no details • No planned EVAs
T. C. French (205) 453-4265	MSFC/PD-DO-PM Computer Data Bank	All payloads; data bank	• Only concepts at this point--no details • MSFC funding allocated 1/3 to payloads development--not enough to even start
Dr. K. Henize (713) 483-2311	JSC/CB	Astronomy; Working Group Panel Member	• Did not think detail payloads data was available--ref. Dr. Y. Kondo
Dr. Y. Kondo (713) 483-6467	JSC/KN23	Astronomy; Consultant	• Indicated data was not available--recommended MSFC LST studies

PAYLOAD COGNIZANT PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
Dr. R. L. Golden (713) 483-5176	JSC/TN2	High Energy Astrophysics; Working Group	• EVA/MMU level of detail not available but "pushing" EVA, referenced May 1973 Payload Planning Working Group Report
R. A. Moke (713) 483-3666	JSC/HC	Earth Observations; works with O. G. Smith	• Detailed information not available, ref. B. R. Hand
J. C. Heberlig (713) 483-6361	JSC/LP	All payloads; Payload Coordination	• Ref. to SSPD
C. H. Lambert (713) 483-5226	JSC/LP	All payloads; Payload Coordination	• Not available for EVA application
L. M. Jenkins (713) 483-2428	JSC/EW141	All payloads; Payload Interface	• No data
S. H. Nassiff (713) 483-2428	JSC/EW141	All payloads; Payloads Interface	• No data

PAYLOAD COGNIZANT PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
C. W. Casey (205) 453-3154	MSFC/PD-SL	Operations; Chief--LST	• EVA is definitely planned for on-orbit servicing of the LST payload • The LST will be serviced in the payload bay • Details of EVA servicing have not been established
S. B. Hall (205) 453-4196	MSFC	LST information	• Referred to Phase B LST Report
M. A. Horst and L. B. Weaver (205) 453-0515 (205) 453-4196	MSFC/NA51	Spacelab; Working Group	• No EVAs currently planned • Contingency EVAs are unlikely • Experimenters feel that pre-breathe time is too costly on such short missions • No requirements have been identified for EVAs • If the airlock is chargeable to the payloads, the weight penalty for EVA will be too great, and the airlock will only be carried if mandatory

SHUTTLE SUBSYSTEMS PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER/ ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
R. D. Langley (713) 483-4446	NASA/JSC/EW5	External doors	• Payload bay doors: - one large door on either side - each hinge is a single point failure - no provisions are being made for manual operation of the doors - EVA will be required to free jammed doors • RCS, star tracker doors: - no external access is being provided - possibility that the doors may jam, requiring an EVA/MMU mission - no drawings available at this time
R. L. Dotts (713) 483-2376	NASA/JSC/ES3	TPS	• The tiles are not strong enough to attach any type of retention device to them (8 psi in tension--max.) • Idea of removing bolts and tile plugs and attaching a device to the access panels has merit • Three different "plug concepts" are presently being studied. Two may allow EVA/MMU workstation attachment.

SHUTTLE SUBSYSTEMS PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER/ ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
R. L. Dotts (continued)			• There is a danger of tile damage when removing the TPS plugs from the bolts • Some thought has been given to a TPS repair kit; however, no work is presently being performed • One repair consideration is a "putty-ablative" that could be spread on • Tests are being conducted to determine the effect of different percentages of tile loss
J. M. Janney (713) 483-5589	NASA/JSC/ES3	Purge, vents, and drainage	• Five vents per side along the mid-fuselage from x_0 764 to x_0 1128. Each vent is 7 1/2 x 20 in. • Two vents per side along forward fuselage: 3 x 6 in. and 3 x 13 in. - vents operated by any one of three motors (no single point failures identified for vent operation) • Doors open inward

SHUTTLE SUBSYSTEMS PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER/ ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
J. M. Janney (continued)			• Vent doors are too weak for rentention devices. Available structure for attachment of devices would require investigation. • Vent drawings will not be available until mid-July or early-August (baseline has just been established) • Just beginning to look at FMEAs • Vent operating sequence - launch: closed - on-orbit: open for molecular venting - re-entry: closed - 70,000 ft.: open
Dr. A. N. Levine (713) 483-6156	NASA/JSC/ES2	Structure; mid-fuselage	• The Convair PDR drawings of the main frames are still accurate. - The main frames will be either extruded or machined T-beams.

SHUTTLE SUBSYSTEMS PERSONNEL/ORGANIZATIONS CONTACTED

NAME	NASA CENTER/ ORGANIZATION	RESPONSIBLE DISCIPLINE OR PAYLOAD SYSTEM	REMARKS (Data or comments on availability of detail payload design)
H. D. Myers (713) 483-4614	NASA/JSC/EJ4	Docking Study	• Docking study completed approximately two years ago--9 degrees of freedom: 6° Orbiter, 3° target • Did not address problems such as contamination, plume impingement, etc. • Have not identified problems associated with the capture of payloads • More studies will be performed later, pending available funds.

APPENDIX G2

MAJOR SOURCE DOCUMENTS

MAJOR SOURCE DOCUMENTS

1. Martin Marietta Corporation: Astronaut Maneuvering Equipment, M509 Astronaut Maneuvering Equipment Hardware Assessment Report, JSC-05547, Contract NAS 8-24000, June 1974.

2. NASA: Johnson Space Center Briefing on Shuttle Docking, EVA and Rescue Systems, LA 12-14-73, presented to NASA Headquarters, December 20, 1973.

3. NASA: Space Shuttle System Payload Accommodations, Level II Program Definition and Requirements, JSC 07700, Volume XIV, Revision C, July 3, 1974.

4. Martin Marietta Corporation: Shuttle Remote Manned Systems Requirements Analysis, Final Report, MCR-73-337, Contract NAS 8-29904, Volumes I, II and III, February 1974.

5. NASA: Payload Descriptions, Volume II, Sortie Payloads, SSPD Document (no reference numbers), October 1973

6. NASA: Summarized NASA/ESRO Payload Descriptions, Sortie Payloads, SSPD Document (no reference numbers), October 1973.

7. NASA: Payload Descriptions, Volume I, Automated Payloads, SSPD Document (no reference numbers), October 1973.

8. NASA: Summarized NASA Payload Descriptions, Automated Payloads, SSPD Document (no reference numbers), October 1973.

9. NASA: Payload Descriptions, Volume I, Automated Payloads, Level B Data, SSPD Document (no reference numbers), July 1974.

10. NASA: Summarized NASA Payload Descriptions, Automated Payloads, Level A Data, SSPD Document (no reference numbers), July 1974.

11. NASA: Payload Descriptions, Volume II, Sortie Payloads, Level B Data, SSPD Document (no reference numbers), July 1974.

12. NASA: Summarized NASA Payload Descriptions, Sortie Payloads, Level A Data, SSPD Document (no reference numbers), July 1974.

13. ERNO-VFW-FOKKER: Spacelab Payload Accommodation Handbook, Intermediate Issue (Revision A), April 1974.

14. ERNO-VFW-FOKKER: Proposal for the Spacelab, Design and Development Contract to ESRO/ESTEC, RFP AO/600, April 16, 1974.

15. ERNO-VFW-FOKKER: Proposal Baseline Briefing Manual, Kick-off Meeting Phase C/D (no reference numbers), June 24-28, 1974.

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