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MANNED MANEUVERING UNIT MISSION DEFINITION STUDY

NASA CR-
141631

FINAL REPORT

VOLUME I

MMU APPLICATIONS ANALYSIS AND PERFORMANCE REQUIREMENTS

NAS9-13790
MOD. NO. 1S

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 I:
MMU APPLICATIONS ANALYSIS AND PERFORMANCE REQUIREMENTS

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 enhance 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 will be presented in 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 I) contains the results of the MMU applications analyses and defines the general MMU performance and control requirements to satisfy potential MMU missions identified in the analyses.

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. Edward L. Saenger, Mr. G. Lloyd Philpot, and Mrs. Betty K. Bielat.

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ACRONYMS AND ABBREVIATIONS

ALSA	ASTRONAUT LIFE SUPPORT ASSEMBLY
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

OFT	ORBITAL FLIGHT TEST
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

1.0 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 under consideration 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 this volume with supporting material contained in Volume II of the final report, "Appendices to the MMU Applications Analyses." To describe a versatile utility-type maneuvering unit, conceptual designs of MMU support subsystems and ancillary equipment were prepared. Concepts for attaching and securing the MMU crewman to various vehicles, structural configurations, and rescue systems were developed. Concepts for incorporating ancillary hardware, such as cargo attachment mechanisms, cameras, lights, tools, tethers and safety provisions, were addressed.

The conceptual designs are presented in Volume III of the final report, "MMU Ancillary Support Equipment and Attachment Concepts." As a result of the MMU applications analyses, it was concluded that an MMU capability could be the decisive element in returning a Shuttle Orbiter and its crew to safety, and also an economical-operational tool for numerous Orbiter and payload applications.

1.1 MANEUVERING UNIT QUALIFICATION OVERVIEW

An Astronaut Maneuvering Unit (AMU) was developed by the U.S. Air Force for evaluation during the Gemini Program as experiment D012. The unit, a predecessor to the Skylab astronaut maneuvering equipment, was a backpack device which permitted an EVA crewman to maneuver in space independent of spacecraft systems. The

AMU was carried on the Gemini IX-A flight but was not evaluated because of problems with other systems.

Skylab Experiment M509 consisted of a backpack mounted control system designated as the Automatically Stabilized Maneuvering Unit (ASMU) and a hand-held thruster system called the Hand-Held Maneuvering Unit (HHMU). Major flight support equipment included a donning station, telemetry receiver, battery charger, and propellant supply stowage rack. The maneuvering units and support equipment were evaluated within the Skylab pressurized Orbital Workshop. Emphasis was placed on obtaining both man and ASMU performance data for future integration of control sensors, control laws, and actuators. The backpack unit incorporated three attitude control modes and a translational control. The attitude control modes consisted of: (1) direct mode; (2) rate gyro mode; and (3) control moment gyro mode. Translation control was by thruster acceleration command. The prime attitude control system for the proposed Shuttle manned maneuvering units will be a manual rate command with automatic attitude hold.

Eleven (11) evaluation runs were conducted during the Skylab SL-3 and SL-4 missions following prescribed on-orbit flight maneuvering procedures. Five different crewmen flew the backpack for a total of 13 hours, 55 minutes flight time. The evaluations generated quantities of reliable data for analyses of the backpack systems, support equipment, control modes, man-machine interfaces, and human performance aspects (ref. 1). The results of extensive ground testing and the Skylab evaluations were considered sufficient to classify the basic maneuvering systems, supporting subsystems and controls as operational hardware for future space applications.

2.0 MMU SHUTTLE APPLICATIONS ANALYSES

The MMU applications analyses consisted of two areas of study--Orbiter subsystems and Shuttle payloads. A detailed and systematic study was conducted of the Orbiter exterior mechanical and passive subsystems considered critical to loss of life or vehicle while on-orbit or during reentry. The analyses also considered the Shuttle payloads from a standpoint of: (1) restoring the payload to operational status following a malfunction; (2) retrieval of payload data and equipment from scientific and economic aspects; and (3) assistance in deploying/retrieving satellites. The interrelationship of the analyses to the total study is shown in Figure 2.1.

Many space flight ancillary support items classified as "backup capability" are warranted on reliability estimates that critical failures will occur. Several MMU Shuttle applications identified by the study are based on performing corrective action following a specific failure. However, many of the candidate MMU applications defined may allow more effective and economical-operational missions than with other proposed systems. Many MMU applications now considered as candidates may become the only method to satisfactorily accomplish critical missions when the capabilities of other systems [e.g., remote manipulator system (RMS), free-flying teleoperator spacecraft (FFTS), automation] are completely defined.

The Orbiter subsystems information/data for the applications analyses were obtained primarily from documentation resulting from meetings and working groups directed by NASA and Rockwell International personnel with responsible management assignments within the Orbiter Project WBS (Work Breakdown Structure). Additional information was compiled from current reports, presentations, engineering change proposals, minutes of meetings, drawings, and personal NASA contacts. A partial list of the material reviewed is contained in the references to this document.

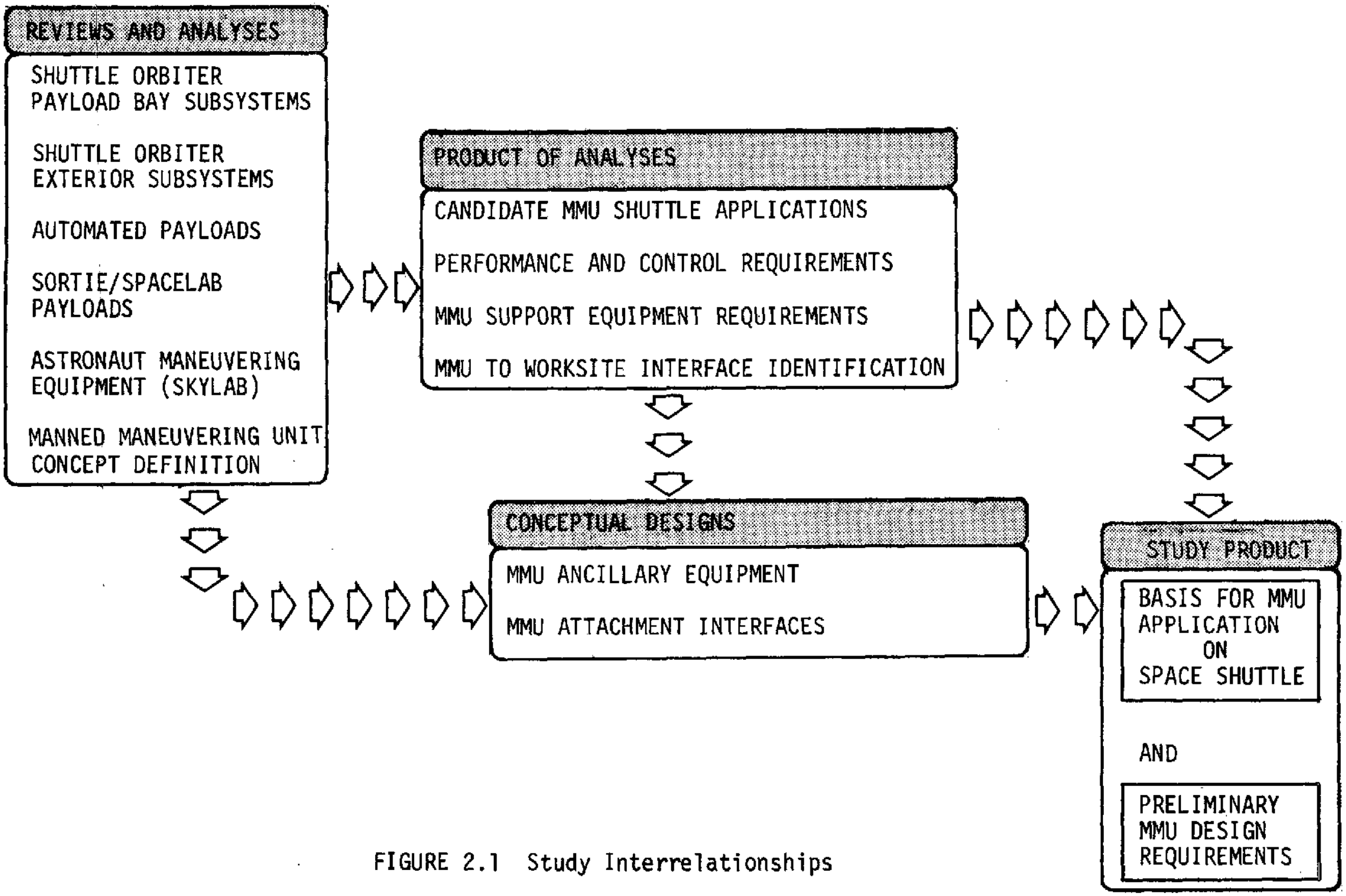

FIGURE 2.1 Study Interrelationships

The payloads and experiments information was derived from several major sources: (1) the October 1973 Space Shuttle Traffic Model, January 1974 revision; (2) NASA Automated and Sortie Space Shuttle Payload Descriptions (SSPD) documents; and (3) various detailed reports on specific payloads. Eighty-three (83) payloads within the automated disciplines and 96 payloads within the sortie disciplines (including revisits), were reviewed for potential MMU applications.

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. Table 2-1 lists each NASA Automated and Sortie Payload contained in the July 1974 issue of the MSFC Space Shuttle Payload Descriptions (SSPD) documents with potential MMU applications identified across all payloads. DoD payloads were not included in the analyses; only those applications considered within current maneuvering unit technology were acknowledged.

Upon completion of the list of potential MMU applications across all payloads, an attempt was made to rigorously define each potential MMU activity. A set of MMU application analysis forms was developed and completion efforts initiated by the contractor. Because of the fluid state of payload definition and the application similarities among payloads, each potential MMU activity on every payload was not defined. A voluminous set of repetitive MMU tasks was not in the best interest of the contract since the goal of the MMU applications analyses could be satisfied by well-defined representative applications. The completed forms on the representative payloads utilized for the analyses are contained in the Appendices, Volume II of the final report.

A set of questionnaire forms was also developed and submitted to the NASA Payload Studies Office at the Marshall Space Flight Center. The questionnaires were formatted to compile detailed information relative to each payload MMU

TABLE 2-1: MMU Potential Applications to Shuttle Payloads--Automated Payloads

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								●				

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
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 2-1: MMU Potential Applications to Shuttle Payloads--Automated Payloads (continued)

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
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 EQP 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								●				

● MMU Potential Application X EVA Status

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	3 m Ambient Temperature IR Telescope
AS-11-A	1.5 m IR Telescope
AS-13-A	UV Survey Telescope
AS-14-A	1.0 m UV-Optical Telescope
AS-16-A	Large Radio Observatory Array (LROA)
AS-17-A	30 m 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 (1.2 m X-Ray Telescope)
HE-12-A	Cosmic Ray Laboratory

SOLAR PHYSICS

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

LIST OF AUTOMATED PAYLOADS REVIEWED (continued)

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

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 Gradiometer
OP-03-A Mini-LAGEOS
OP-04-A GRAVSAT

LIST OF AUTOMATED PAYLOADS REVIEWED (continued)

EARTH AND OCEAN PHYSICS (continued)

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

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 Probe
PL-13-A Pioneer Jupiter Probe

LIST OF AUTOMATED PAYLOADS REVIEWED (continued)

PLANETARY (continued)

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 2-1: MMU Potential Applications to Shuttle Payloads--Sortie Payloads

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
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

● MMU Potential Application   X EVA Status

TABLE 2-1: MMU Potential Applications to Shuttle Payloads--Sortie Payloads (continued)

PAYLOAD NO.	INSPECT/CHECK	SUBSATELLITE DEPLOY/RETRIEVE	CONTINGENCY EQP. 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
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												

NO MMU APPLICATIONS IDENTIFIED SINCE EQUIPMENT IS LOCATED INSIDE SPACELABS AND ON PALLETS WITH NO EQUIPMENT EXTENDING BEYOND THE PAYLOAD BAY DOORS. (SP-05-S through SP-22-S)

● MMU Potential Application X EVA Status

LIST OF SORTIE PAYLOADS REVIEWED

ASTRONOMY

AS-01-S 1.5 m Cryogenically-Cooled IR Telescope
AS-03-S Deep Sky UV Survey Telescope
AS-04-S 1 m 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 0.5 m Telescope
AS-09-S 30 m 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 1.0 m Uncooled IR Telescope
AS-15-S 3.0 m Ambient Temperature IR Telescope
AS-18-S 1.5 km IR Interferometer
AS-19-S Selected Area Deep Sky Survey Telescope
AS-20-S 2.5 m 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)

LIST OF SORTIE PAYLOADS REVIEWED (continued)

ASTRONOMY (continued)

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
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

LIST OF SORTIE PAYLOADS REVIEWED (continued)

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)
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)

LIST OF SORTIE PAYLOADS REVIEWED (continued)

SPACE PROCESSING APPLICATIONS (continued)

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

LIST OF SORTIE PAYLOADS REVIEWED (continued)

COMMUNICATIONS AND NAVIGATION (continued)

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

and EVA support requirements. However, the effort was abandoned because of lack of response (see Appendix F, Volume II of the final report).

The payload analysis has resulted in a representative set of potential MMU applications and typical tasks derived from both the automated and sortie disciplines. The typical tasks will be found as activities associated with many operational scenarios to be accomplished with an MMU. The overall applications analyses provided the basis for developing general MMU performance and control requirements.

3.0 MMU APPLICATIONS SELECTION CRITERIA

3.1 ORBITER AND ORBITER SUBSYSTEMS

The initial Orbiter subsystems and payloads analyses disclosed a number of practicable MMU applications on both the initial and operational Shuttle missions. The initial Shuttle missions beginning in March 1979 consisting of six flights will not have a standby or backup vehicle in the event an on-orbit contingency situation occurs. The seventh flight in May 1980 will be classified as an operational mission. Other candidate systems being developed for on-orbit servicing functions will not be operational until later in the Shuttle Program. The Orbiter-attached Remote Manipulator System (RMS) is scheduled to be operational in 1981. An experimental Free-Flying Teleoperator Spacecraft (FFTS) is also scheduled for orbital evaluation in 1981. Several credible Orbiter contingencies, categorized as a Class I criticality (see Appendix A, Volume II of the final report) are identified within the Shuttle verification and early operational flights in which the MMU will be the only available system capable of performing tasks outside the payload bay. The MMU may also prove the most effective means of performing certain tasks after all Orbiter-based support systems are operational.

The major selection criteria for MMU applications to the Orbiter and Orbiter subsystems are summarized as:

- Criticality relative to crew safety
- Criticality relative to vehicle safety on-orbit and during reentry
- Availability of candidate systems for supporting contingencies
- Capability of proposed systems for supporting contingencies.

3.2 SHUTTLE PAYLOADS--AUTOMATED AND SORTIE

Based on the payloads being considered in mid-1974 for Space Shuttle utilization, numerous MMU applications under a Class II or III criticality were defined (see Appendix A, Volume II of the final report). These payload applications were predicated on the malfunctions of a payload system in which: (1) on-orbit corrective action would restore the payload to operational status--e.g., satellite capture, despin, stabilization; (2) access to the experiment would enhance mission success--e.g., payload repair, servicing, refurbishment; and (3) retrieval of experiment data and/or flight hardware appeared economical--i.e., retrieval of experiment data and equipment from malfunctioned systems prior to jettison. Comparison studies of the economic aspects of data or equipment retrieval via MMU versus equipment cost and experiment relaunch was beyond the scope of this study. The weight, volume and associated costs of providing MMUs were automatically and confidently assumed more economical than a second Shuttle launch.

The MMU applications to the payloads cannot, at the present, be designated as the sole means of performing the candidate payload tasks. The full capabilities of systems, such as the Orbiter-attached RMS and FFTS, are not presently defined. These systems, when operational, will have weight and cost penalties for each flight. A premature assumption that these systems can perform all tasks, planned or contingency, outside the payload bay could be excessively costly to the payloads community in terms of loss of payload, data, etc.

4.0 MMU APPLICATIONS SUMMARY

The initial analyses provided MMU applications on many of the Shuttle payloads and Orbiter subsystems, however, the contract did not allow thorough investigation of each MMU potential application on every payload and Orbiter subsystem. Such overall analyses were not considered necessary to establish representative MMU applications within the Shuttle Program. Therefore, the number of Orbiter subsystems, Automated Payloads and Sortie Payloads selected for detailed analysis was limited to eleven--one Orbiter exterior inspection task, three associated with Orbiter subsystems, one rescue application, and six payload applications.

Based on the overall Shuttle analysis, the following Orbiter subsystems were selected for representative MMU applications:

- Orbiter exterior inspection to determine reentry status
- Thermal Protection System (TPS) repair for reentry capability
- Orbiter exterior door closure for reentry capability (e.g., RCS, payload bay)
- Personnel rescue from disabled Orbiter
- Remote Manipulator System (RMS) backup capability

The payload selection criteria for potential MMU applications involved: (1) types of stabilization systems used by the payloads; (2) low earth orbit versus high earth orbit missions; (3) payloads which require on-orbit servicing; (4) payloads which require retrieval for earth return; (5) contamination-sensitivity of the payloads; (6) hazardous conditions of the payloads which would preclude EVA/MMU application; and (7) payloads in which elaborate hardware, extendible members, and deployable subsatellites could benefit from MMU capabilities. The better defined payloads were also a consideration in selecting the MMU applications to provide a more meaningful end product.

The payloads defined as typical candidates for MMU applications are listed below:

AUTOMATED

- Long Duration Exposure Facility (LDEF)
- Large Space Telescope (LST)
- Large High Energy Observatory D (HE-11-R)

SORTIE

- Atmospheric, Magnetospheric and Plasmas in Space (AMPS)
- Shuttle Imaging Microwave System (SIMS)
- Advanced Technology Laboratory (ATL)

The payloads studied within the automated disciplines were limited to those carried into or retrieved from Low Earth Orbit (LEO) by the Orbiter vehicle. MMU applications to payloads requiring a second-stage for orbit insertion or planetary fly-by were considered only up to the point of second-stage activation. Special emphasis was placed on establishing the role of MMUs in support of the Orbiter vehicle and both the Automated and Sortie Payloads. Applications analyses forms were developed for a number of the Orbiter subsystems and payloads that were considered representative MMU applications across the Shuttle Program. These completed forms are contained in Volume II of the final report, "Appendices to the MMU Applications Analyses." The Appendices document contains other supporting data for the study.

Each of the Orbiter subsystems and payloads cited above were critically appraised to determine MMU applications and define MMU performance and control requirements. Table 4-1 categorizes the general types of tasks involved in the specific MMU applications, identifies mission criticality, and ranks the MMU requirements.

TABLE 4-1: General MMU Task Categories Across Representative Applications

CANDIDATE MMU TASKS	ORBITER SYSTEMS				PAYLOADS					
					AUTOMATED			SORTIE		
	TPS	DOORS	RMS	RESCUE	LDEF	LST	HE-11-R	AMPS	SIMS	ATL
INSPECTION	2A				3 B-C*	3 B-C	3 B-C		3 B-C	
REPAIR	1A	1A	2C			3C	3C	3 B-C	3 B-C	3 B-C
RESCUE SUPPORT				1 B-C						
SERVICE						3 B-C	3 B-C		3 B-C	
DATA ACQUISITION								3 A-C	3 B-C	3 A-C
JETTISON			2C		3C	2C		2C	2B-C	2C
PAYLOAD DEPLOY/RETRIEVE			3C		3B	3C				

LEGEND

1. Directly Critical to Safety - Criticality I
2. Indirectly Critical to Safety
3. Not Critical to Safety but Affects Mission Success

(2. and 3.) - Criticality III

A. MMU is Required

B. MMU is Best Method

C. MMU Considered an Option

*Multiple letters reflect more than one MMU application.

4.1 MMU ORBITER EXTERIOR INSPECTION

MISSION IMPACT: INDIRECTLY CRITICAL--MMU REQUIRED

At the time of report preparation, no exterior inspection tasks were planned for routine execution on the Orbiter missions. However, two external systems currently recognize Class I critical failure modes--the Orbiter thermal protection system (TPS) and the Orbiter external doors (e.g., RCS, star tracker, payload bay). Each door is adequately instrumented to determine its status prior to reentry. However, the status of the TPS cannot be adequately determined by on-board instrumentation or visual inspection from the cabin, including the use of on-board video aids. An MMU would provide an EVA crewman the capability to directly inspect and document the condition of the vehicle exterior. The availability of an MMU would enhance mission success by assuring reentry status of the Orbiter exterior systems through on-orbit repairs. This capability is especially important on the early flights where a rescue capability is nonexistent.

4.1.1 Orbiter Exterior Characteristics

The Orbiter vehicle is 34.1 m. (122 ft.) long, 17.4 m. (57 ft.) high (from main landing gear to vertical stabilizer), and has a delta wing system with a span of 23.8 m. (78 ft.). Approximately ninety-five percent of the exterior surface is covered with small "ceramic coated tiles" bonded to the surface to provide thermal protection to the vehicle. The most critical area of the vehicle, the underside, is obstructed from the crew's direct field-of-view. The RMS/remote video combination allows inspection of more surface area than does direct viewing; however, its field-of-view does not include the aft heat shield areas. RMS reach envelopes are shown in Volume XIV of the Space Shuttle Level II Program Definitions and Requirements document, JSC 07700.

4.1.2 MMU Application

The MMU/EVA crewman combination can be used to inspect the complete exterior of the Orbiter vehicle either as a routine operation or as an unscheduled task. Critical systems in addition to the TPS and exterior doors may involve various thruster engines, windows, control surfaces, antennas, external tank attachments, etc. Should a complete inspection be required, an MMU is currently the only means of adequately gaining access to all areas. The FFTS may be capable of performing inspection tasks, but an operational unit will not be available for early Shuttle flights. In addition, if an inspection indicates a requirement for repairs, the capability of an FFTS to perform close work may be limited. In the event the payload bay doors are inoperable, the FFTS or RMS cannot reach the vehicle exterior while the MMU can egress the Orbiter via the side hatch.

4.1.3 MMU Performance and Control Requirements

The MMU performance and control requirements for conducting an Orbiter exterior inspection were derived from a typical mission scenario. The scenario involved the development of a translation route (Figure 4.1), estimated travel distance, starts/stops, attitude changes, preliminary timeline, etc. The translation route selected allows the MMU crewman to perform "level" flight and simple directional changes for MMU flight familiarization. However, the more critical areas of the Orbiter may be inspected first in a time critical situation. A summary of the MMU performance and control requirements for inspection of the Orbiter is shown in Table 4-2. The complete mission scenario is contained in Appendix B, Volume II of the final report.

TABLE 4-2: Orbiter Exterior Inspection--
Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
Orbiter Exterior Inspection	370	(1210)	±.06	(±.2)	±3	±.03	(±.1)	±3	16.2	(53.0)

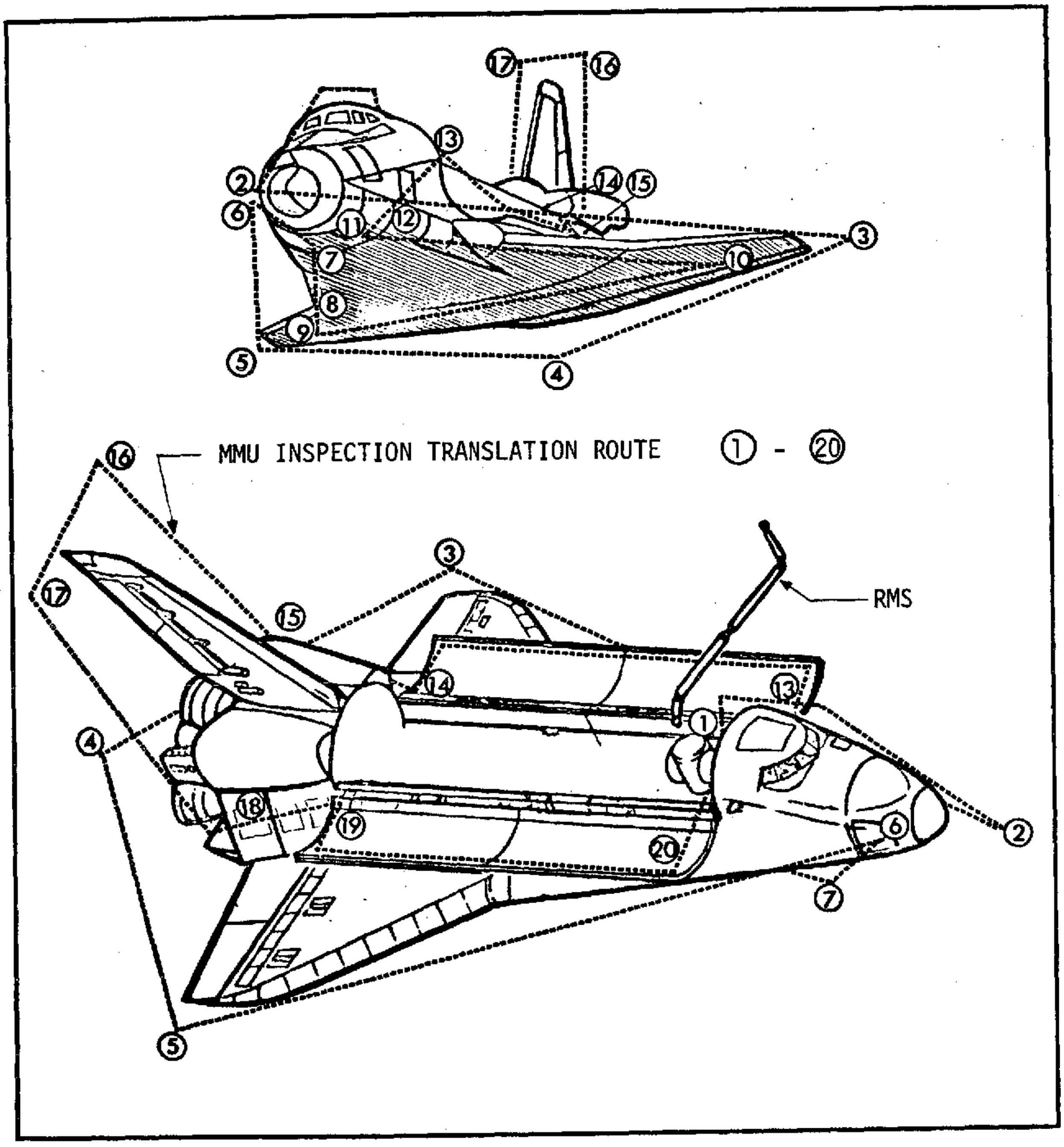

FIGURE 4.1: Typical Orbiter Exterior Inspection Route Using MMU

4.2 THERMAL PROTECTION SYSTEM (TPS) REPAIR

MISSION IMPACT: CLASS I CRITICALITY--MMU REQUIRED

The intact, operational condition of the TPS is essential to the safety of the crew and the vehicle during reentry of the Orbiter. Currently, the MMU is the only system which will allow an EVA crewman to access and repair the TPS at any point on the surface of the vehicle during orbital operations.

4.2.1 Orbiter TPS Characteristics

The Orbiter thermal protection system consists of reinforced carbon-carbon (RCC) and silica coated reusable surface insulation (RSI) to maintain air-frame temperatures below 350° F during launch and reentry. These thermal materials are in the form of small tiles which are individually bonded to the vehicle. The reusable surface insulation covers approximately 95% or 1,022 m^2 (11,000 ft^2) of vehicle surface area. There are approximately 34,900 tiles and 9,000 different tile configurations comprising the current system. The tiles, inlaid to provide laminar flow on reentry, require special ground facilities and skills for replacement and maintenance.

The tile surfaces are considered extremely fragile and can be damaged from induced environments such as acoustic vibration, structural deflection, shear/compression buckling, tile venting, cold soak, thermal structural strain, etc. Tile loss and/or damage have been identified as credible failure modes with resulting vehicle loss a possibility. Damage on-orbit cannot sufficiently be determined due to inadequate instrumentation and limited visual, including remote video, capabilities. TPS problem areas will become apparent from cabin instrumentation only during launch and reentry, not during orbital operations. The number of damaged or missing tiles critical to reentry has not been determined; however, turbulent flow from a single tile could propagate loss of additional tiles. Since the tiles are not designed for replacement on-orbit, studies are being conducted by NASA-JSC to develop kits for on-orbit repair of the TPS using RTV or other chemically or thermally cured "plastic" compounds.

4.2.2 MMU Application

The MMU/crewman combination can be used to repair the TPS at any point on the Orbiter exterior. Ablative materials to be applied by the crewman are being considered as a temporary on-orbit fix to allow safe return. An ablative material in a mat, pressurized container or caulking form could be used by the MMU-equipped crewman to effect repairs. Simple repairs may be performed from a tethered or free-flying MMU. As depicted in Figure 4.2, the crewman may require the use of a stabilization system, such as handholds or foot restraints, to aid in repair operations. The MMU would be equipped with sufficient ancillary support equipment to transport necessary supplies to the repair worksite. Although a two-man EVA would be the most desirable method of conducting the repair tasks, one man could fully accomplish repairs, if necessary (e.g., during OFT flights with a two-man crew).

4.2.3 Other TPS Repair Candidates

The MMU and EVA crewman combination is considered the only system sufficiently versatile to perform TPS repairs at all exterior points of the Orbiter. The Orbiter Remote Manipulator System (RMS) is unable to reach all areas of the Orbiter exterior or perform the fine manipulative tasks required to achieve the smooth surface condition required to prevent turbulent flow. The control/stability characteristics of the proposed free-flying teleoperator spacecraft (FFTS) would also eliminate it from consideration. Man's visibility, diagnostic, and adaptability capacities are mandatory in such critical repair operations.

4.2.4 MMU Performance and Control Requirements

The MMU performance and control requirements for conducting TPS repairs were derived from a typical mission scenario. The scenario involved the development of a translation route (Figure 4.3), estimated travel distance, starts/stops, attitude changes, preliminary timeline, etc. A summary of the MMU performance and control characteristics for Orbiter TPS repair are shown in Table 4-3.

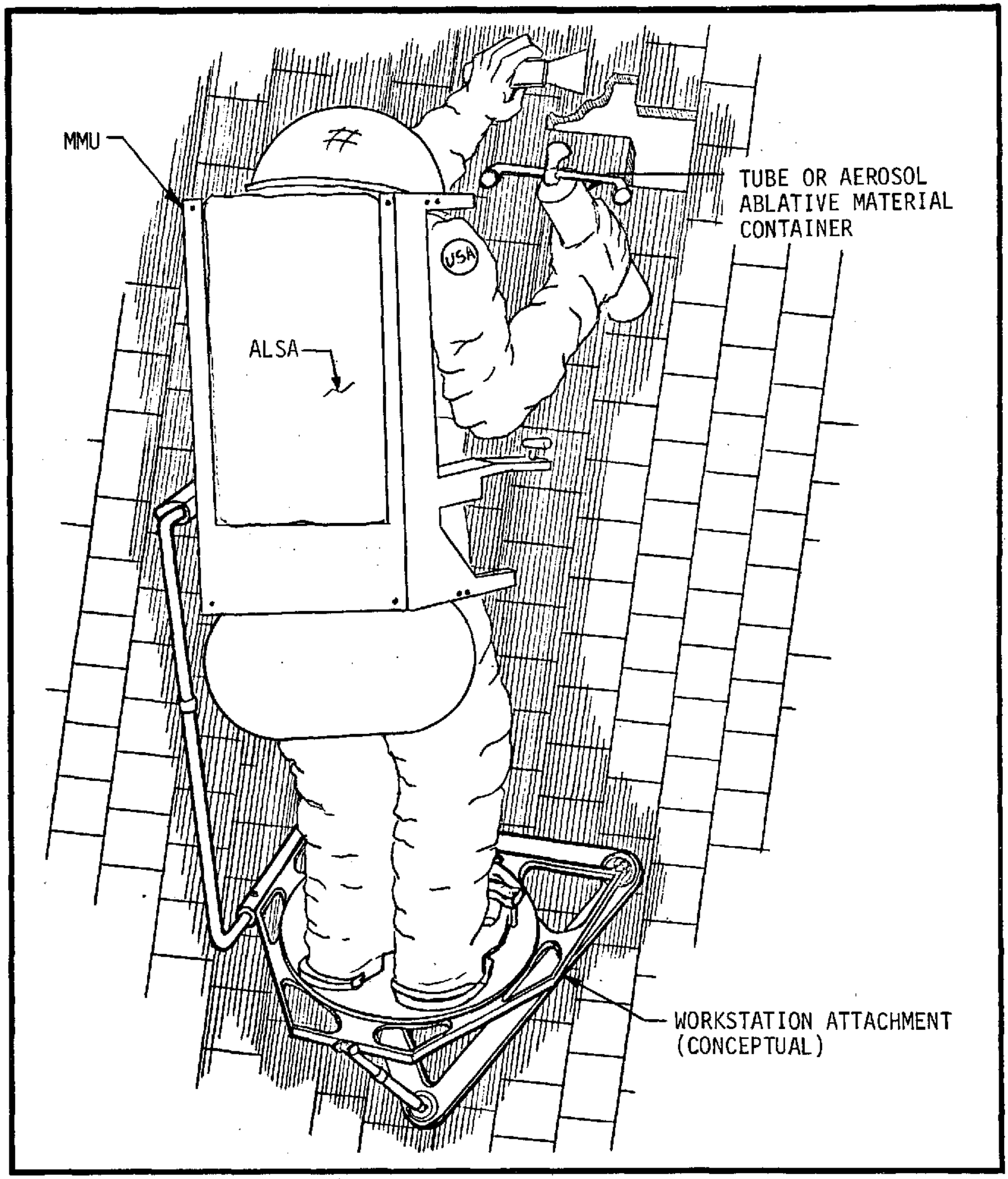

FIGURE 4.2: On-Orbit TPS Repair via MMU

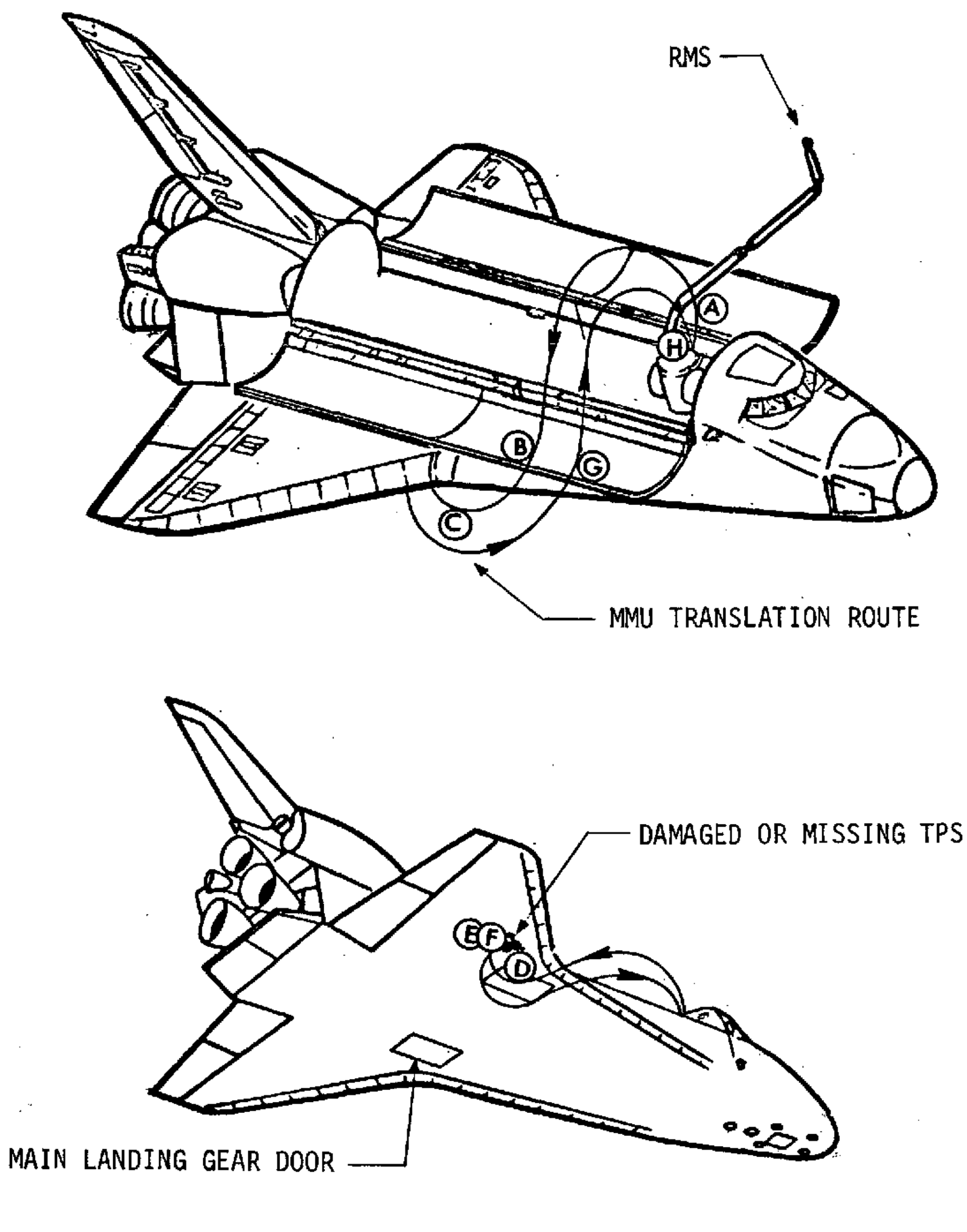

FIGURE 4.3: MMU Translation Route for TPS Repair

TABLE 4-3: Thermal Protection System--
Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
TPS Repair	110	(360)	±.06	(±.2)	±4	±.03	(±.1)	±2	5.9	(19.2)*

*Includes 4.5 ft/sec ΔV for MMU checkout.

4.3 ORBITER EXTERIOR DOOR REPAIRS

MISSION IMPACT: CLASS I CRITICALITY--MMU REQUIRED

The proper operation of several external doors on the Orbiter vehicle prior to reentry is critical to the safety of the vehicle and the crew. Mechanical jamming is a recognized failure mode which could prevent the doors from closing. The repair of malfunctioning or a jammed door may require manual operation of the door. However, there are presently no means of accessing all the critical door areas from inside the vehicle. The MMU is the only system under study that will provide an EVA crewman the capability to inspect and repair all doors.

4.3.1 Orbiter Door Characteristics

Full closure of the payload bay main doors, the RCS doors, external tank attach doors, and the star tracker door is currently recognized as critical to the safety of the crew and Orbiter during reentry. The remaining exterior doors within the door system are currently being assessed (late 1974) by NASA-JSC for their criticality. All doors are mechanically operated units and contain the risk of malfunctioning on-orbit. The doors are adequately instrumented to allow the crew to determine, on-orbit, which door has failed to close properly. The prime contractor for the Orbiter vehicle is presently investigating methods of manual operation of the doors to correct malfunctions should they occur in flight; however, reaching the doors for repair tasks is not being addressed.

4.3.2 MMU Application

The EVA/MMU combination provides the necessary link to the contingency operation of the Orbiter doors. A critical failure mode has been identified, and a method of correcting such failures will be devised prior to the first Shuttle launch. Possible malfunction candidates may include electrical component failure, gear reduction failure, mechanical linkage binding or breaking, and various obstructions from loose or foreign material. Corrective methods may require such EVA operations as linkage pin/bolt removal and securing the doors from the outside.

4.3.3 MMU Performance and Control Requirements

The MMU performance and control requirements for conducting a contingency door closing task were derived from a typical mission scenario assuming a failure of an aft external tank attach door. The scenario involved the development of a translation route (Figure 4.4), estimated travel distance, starts/stops, attitude changes, preliminary timeline, etc. A summary of the resulting performance and control requirements appears in Table 4.4. The complete mission scenario is contained in Appendix B, Volume II of the final report.

TABLE 4-4: Orbiter Door Repair--Summarized
MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
Door Repair	110	(360)	±.06	(±.2)	±2	±.03	(±.1)	±1*	6.34	(20.8)

*Special case for removing door pins/linkage in free-flying mode. Precision not required when crewman is stabilized at worksite.

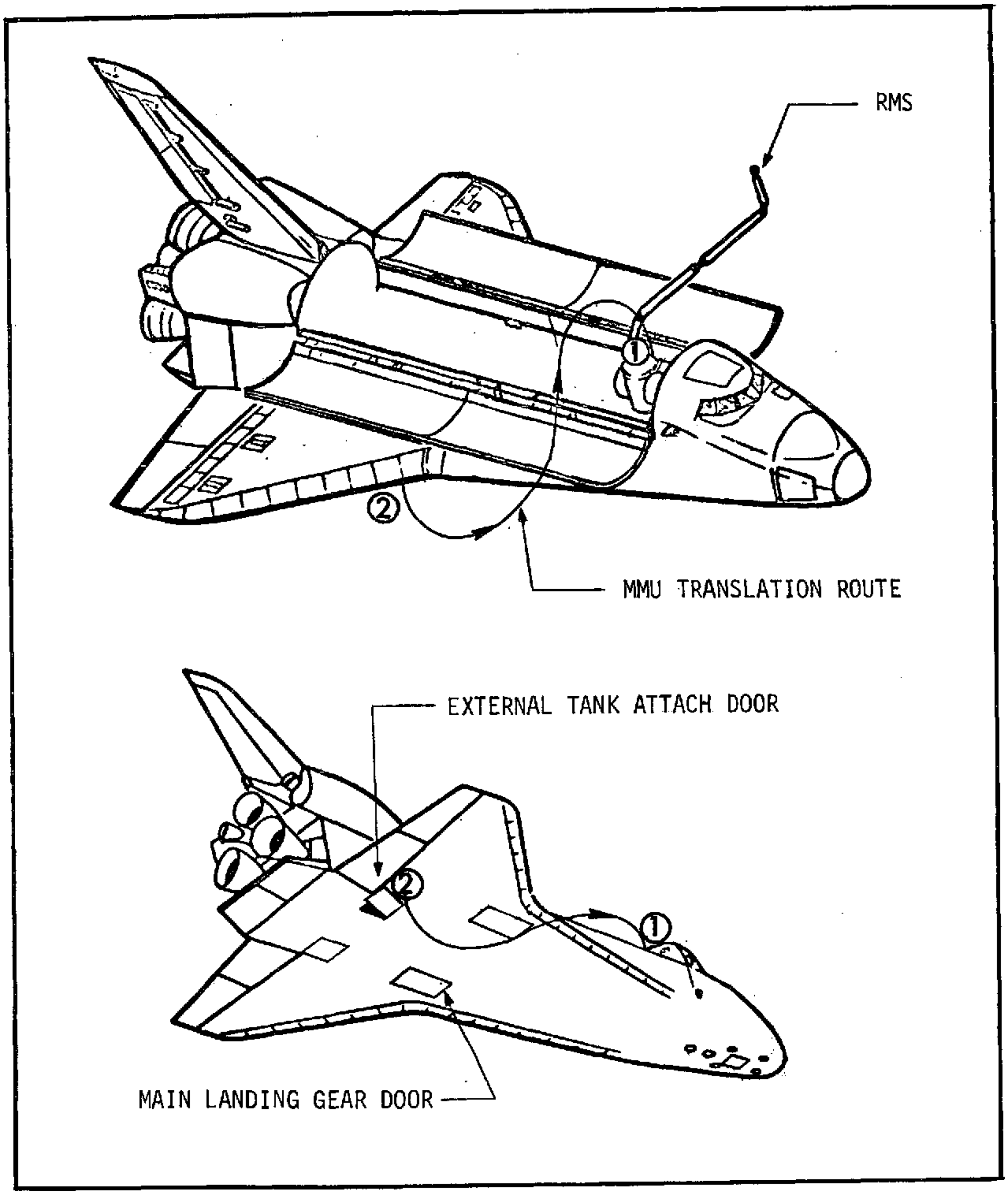

FIGURE 4.4: MMU Translation Route for Orbiter Door Repair

4.4 RESCUE

MISSION IMPACT: CLASS I CRITICALITY--MMU IS OPTIONAL--MAY BE BEST METHOD

When the Shuttle Program enters its operational phase, a rescue capability will be provided. This includes launch of a rescue vehicle to recover the crew members and, perhaps, scientific or operational data from a disabled Orbiter. Efficient methods and systems for recovery and transfer of the crew between vehicles is an essential requirement in the Space Shuttle Program. Use of the MMU in rescue operations is currently indicated where translation aids cannot be deployed between the vehicles.

4.4.1 Shuttle Rescue Mission Characteristics

The basic method of personnel rescue currently being proposed for the Shuttle Program will be accomplished by extravehicular transfer (ref. 2). The required EVA life support equipment will be provided to accommodate this method. The techniques to accomplish the transfer include use of the attached remote manipulator system (RMS) to provide a direct translation path between two stable vehicles, use of a tether system deployed between the two vehicles, or use of the MMU to transfer the crewmen to the rescue vehicle.

4.4.2 MMU Application

The MMU can be used by an EVA crewman as a rescue vehicle to transfer crew and equipment between Orbiters in either a tethered or free-flying mode. The MMU rescue applications may involve the following:

- Deployment of rescue systems between Orbiter vehicles (e.g., translation devices, life lines, tethers)
- Transfer crewmen and equipment between vehicles using MMU tethered or free-flying modes (includes the case of a slowly tumbling Orbiter)
- Free-space pickup of crewmen in which "bail-out" procedures are used to egress an unstable disabled Orbiter

The MMUs to be used for a rescue operation could be delivered to orbit by the rescue vehicle and used on an "as required" basis (Figure 4.5). Since the requirement for MMUs can be established prior to launch of the rescue vehicle, a minimum of two units are recommended to be available for the rescue operation.

4.4.3 MMU Performance and Control Requirements

The MMU performance and control requirements for conducting a rescue mission were derived from a typical mission scenario assuming a four-man crew in the disabled craft. The scenario involved the development of a translation route, estimated travel distance, starts/stops, attitude changes, preliminary timeline, etc. A summary of the resulting performance and control requirements for an unstable Orbiter "bail-out" rescue appears in Table 4-5. The complete mission scenario is contained in Appendix B, Volume II of the final report.

TABLE 4-5: Personnel Rescue--Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
MMU Personnel/ Equipment Rescue	640	(2100)	±.03	(±.1)	±4	±.015	(±.05)*	±1*	15.3	(50.0)

*Precision may be required in isolated cases to deactivate propulsive gas flow on a disabled MMU during rescue attempts.

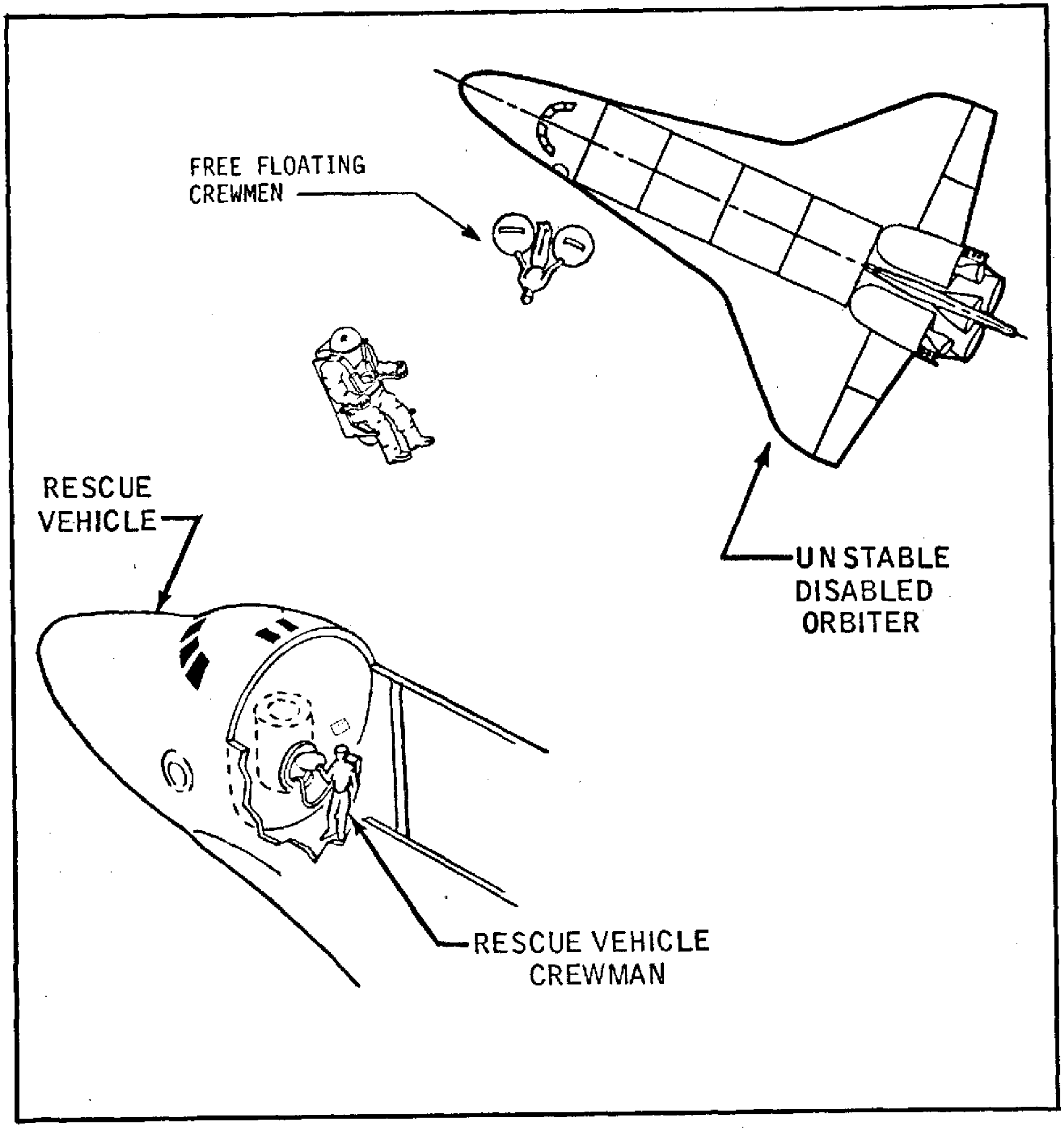

FIGURE 4.5: MMU Used in Personnel Rescue Capacity

4.5 REMOTE MANIPULATOR SYSTEM (RMS)

MISSION IMPACT: INDIRECTLY CRITICAL--MMU MAY BE BEST METHOD

The RMS currently has no backup system for both deploying and retrieving payloads on-orbit. EVA crewmen were considered as a possibility for payload deployment in early Shuttle studies. Studies of non-EVA backup methods to RMS payload retrieval, other than a second Shuttle launch, are unknown to the author.

4.5.1 RMS Characteristics

Currently, the RMS is the only method of deploying and/or retrieving automated payloads and for handling massive cargo items. The 15.24 m. (50 ft.) long RMS is configured in three sections plus an end effector. The present baseline calls for one arm located on the left side of the payload bay above the longeron. An additional arm may be provided on the right side of the Orbiter at payload expense. The stowage receptacles for each segment of the arm contain jettison devices which can be actuated from the cabin. The arm will be provisioned with TV cameras for remote video inspection of payloads and Orbiter exterior surfaces; however, the reach of the RMS is somewhat limited. The current operational characteristics of the RMS (see Appendix B, Volume II of the final report) prevent it from being used for fine manipulative tasks or for use as an EVA translation device unless the RMS is secured at the end effector (i.e., both ends secured). The functions that the RMS performs are essential to the success of missions requiring orbital deployment and/or retrieval.

4.5.2 MMU Application

A failure of the RMS during on-orbit operations could prevent closing the payload bay doors, which is critical for reentry. A credible failure may be one in which the RMS end effector is attached to an external object and cannot be released. RMS jettison, under this condition, could also be hazardous to the Orbiter. The MMU can provide a backup to the automated RMS jettison mode by providing disassembly, removal and manual ejection capabilities.

In addition, the MMU can be used to restow the disabled RMS arm in the Orbiter payload bay. Figure 4.6 shows a typical application of the MMU in support of an RMS failure. The MMU may also be used to stabilize a payload to within the capability of RMS capture. The RMS is capable of capturing a payload inertially or local vertically stabilized under the following conditions: maximum limit cycle rates of ±0.1 deg/sec about any axis within a limit cycle which results in a ±76 mm. (±3.0 in.) or less motion of the attach point (ref. 3). The MMU in a payload stabilization role is discussed in later sections of this report.

4.5.3 MMU Performance and Control Requirements

The MMU performance and control requirements to support an RMS control or end effector failure were derived from a typical mission scenario. The scenario involved development of a translation route (Figure 4.6), estimated travel distance, starts/stops, attitude changes, preliminary timeline, etc. The scenario includes disengaging the RMS end effector, positioning and releasing the payload and stowing the RMS in the payload bay. A summary of the resulting performance and control requirements is shown in Table 4.6. The complete mission scenario is contained in Appendix B, Volume II of the final report.

TABLE 4-6: Remote Manipulator System--Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
RMS Contingency Support	305	(1000)	±.06	(±.2)	±3	±.03	(±.1)	±3	12.7	(41.8)

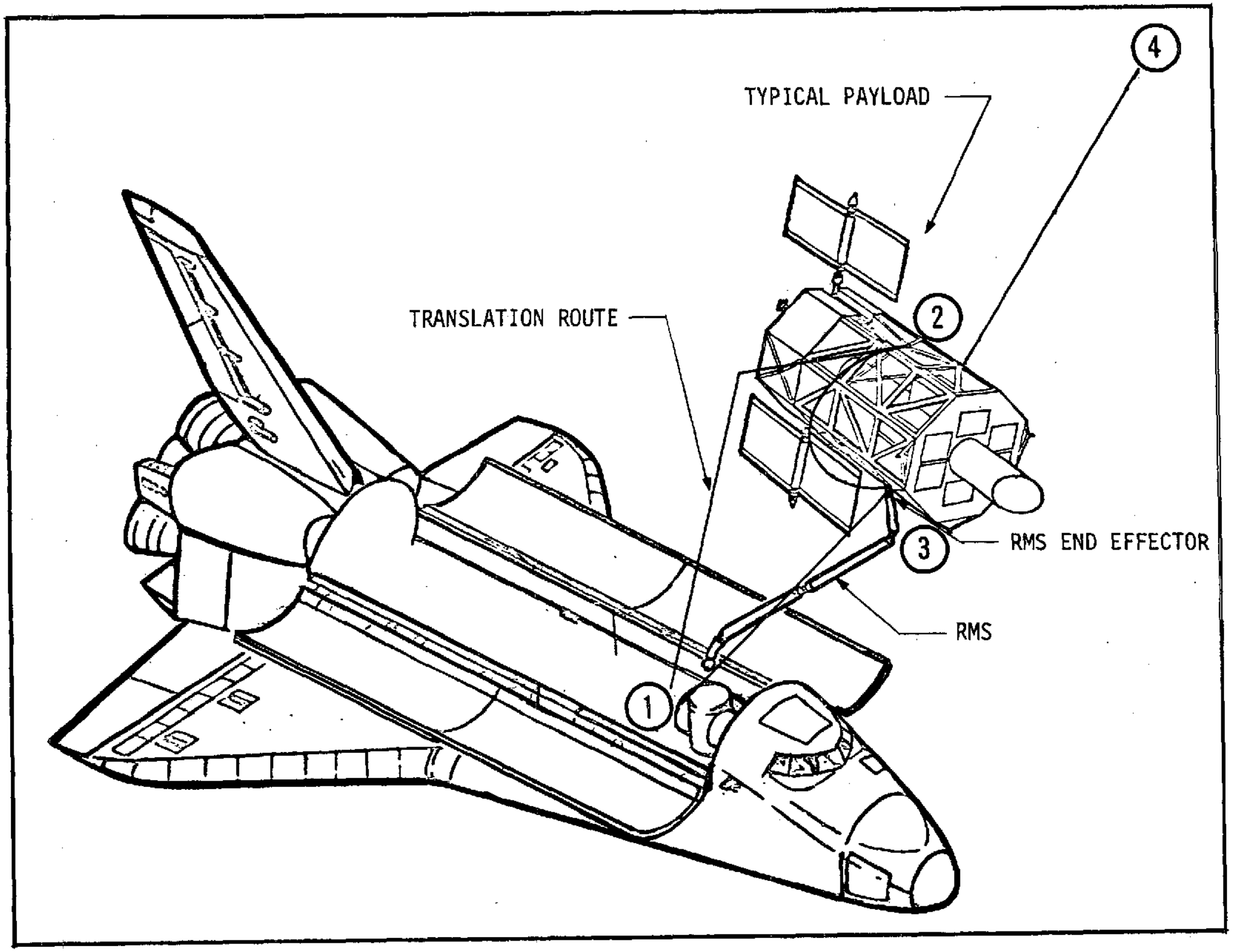

FIGURE 4.6: MMU Backup to Orbiter Remote Manipulator System

4.6 LONG DURATION EXPOSURE FACILITY (LDEF)--ST-01-A

MISSION IMPACT: CLASS III CRITICALITY

The Long Duration Exposure Facility (LDEF) does not identify requirements for orbital operations to be performed other than on-board checkout and RMS deployment/retrieval by the RMS. EVA, however, is identified as a contingency backup to deployment and retrieval activities. The MMU could enhance mission success in payload contingency situations by: (1) payload stabilization; (2) capture assistance; (3) sample retrieval/replacement; and (4) payload status inspection and repair activities.

4.6.1 Payload Characteristics

The LDEF is approximately 4.23 m. (14 ft.) in diameter by 9.25 m. (30 ft.) in length, with a mass of 4,170 kg. (9,200 lbs). It is scheduled to be inserted into and retrieved from orbit by the Orbiter and returned to earth after six to nine months. Its purpose is to provide a test bed for exposure of various types of sample specimens and coatings to the space environment. The payload is essentially passive and does not require thermal control or contamination control; only limited internal battery power for specific experiment panels is required. Since the payload is designed for gravity gradient stabilization, problems such as excessive tumbling could be anticipated in orbital and deployment/recovery operations. The possibility also exists of damage or degradation to the experiment panels or attitude disturbances from Orbiter thruster impingement during Orbiter rendezvous and docking.

4.6.2 MMU Application

One of the stronger MMU applications to the LDEF appears to be payload stabilization. Corrective action may be required following RMS deployment to assist on-orbit LDEF damping or aid during RMS retrieval operations. Malfunctions or miscalculations during deployment may induce undesirable spin or tumble rates. On-orbit corrections may be required if the proper stabilization is not acquired or maintained. Stabilization prior to retrieval may be necessary to bring the LDEF within RMS capture capability.

Utilizing the MMU in LDEF capture roles to prevent possible experiment contamination from the Orbiter may be a viable application. The MMU could be used to rendezvous, attach tether lines and position the LDEF for RMS capture without firing the Orbiter thrusters in the near vicinity of the payload. LDEF positioning by tether lines would be accomplished via EVA from the payload bay.

Other candidate applications are based solely on payload requirements to increase mission versatility and efficiency. These include: (1) on-orbit sample retrieval and replacement to provide an intermediate time-in-space exposure capability; and (2) payload status inspection and repair applications.

4.6.3 MMU Performance and Control Requirements

The MMU performance and control capabilities necessary to conduct LDEF sample retrieval and replacement tasks were considered the driver in MMU reaction control requirements for this specific payload. MMU performance and control requirements for stabilizing the LDEF were also studied using data from previous contractor reports on free-flying teleoperator spacecraft (FFTS) (ref. 4). The FFTS preliminary analyses indicated that a 146 kg. (322 lbs.) FFTS with four 23 N. (5 lbs.) force thrusters could stabilize an LDEF type satellite (4,170 kg. - 9,200 lbs.) from a 0.0018 rad/sec (0.1 deg/sec) angular velocity with a 0.4 sec. thruster impulse. The stabilization task assumes a condition in which the FFTS center of gravity is located 1.0 m. (3.3 ft.) from the payload attachment point and the payload moment of inertia about the axis is 34,500 $kg\text{-}m^2$ (29,000 $slug\text{-}ft^2$). It was assumed that no additional angular momentum was imparted to the system during FFTS docking for the example above. The fuel consumed for stabilization was 0.036 kg. (0.08 lb.) GN_2.

Stabilizing a nonconing-spinning satellite is not considered a major technical problem with the MMU when the satellite is not in a radically uncontrolled state. The MMU reaction control system would be required to rendezvous, capture, and null all system rotational rates to within the satellite control system limits. In calculating the above example using the MMU, the time for payload stabilization was .63 seconds with a fuel consumption of .06 lbs GN_2 (see reference 4).

MMU performance and control requirements to conduct LDEF retrieval missions were derived from a typical mission scenario. The retrieval mission involves attaching a tether retrieval system to the LDEF and "guiding" the payload into the payload bay. The scenario involved development of a translation route (see Figure 4.7), estimated starts/stops, attitude changes, preliminary timeline, etc. A summary of the typical performance and control requirements to accomplish the LDEF retrieval task is shown in Table 4-7. The complete mission scenario is contained in Appendix C, Volume II of the final report.

TABLE 4-7: Long Duration Exposure Facility:
Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
LDEF Retrieval*	191	(625)	±.06	(±.2)	±2**	±.03	(±.1)	±1	10.5	(34.6)

*The MMU can despin (flat spin) the LDEF from 3 rpm in 129.3 sec while consuming 10.9 lbs. of GN_2.

**Stabilizing the LDEF to within the required tip-off rate could require an MMU attitude hold precision of ±.05° for a short time period. Instrumentation is required on the LDEF.

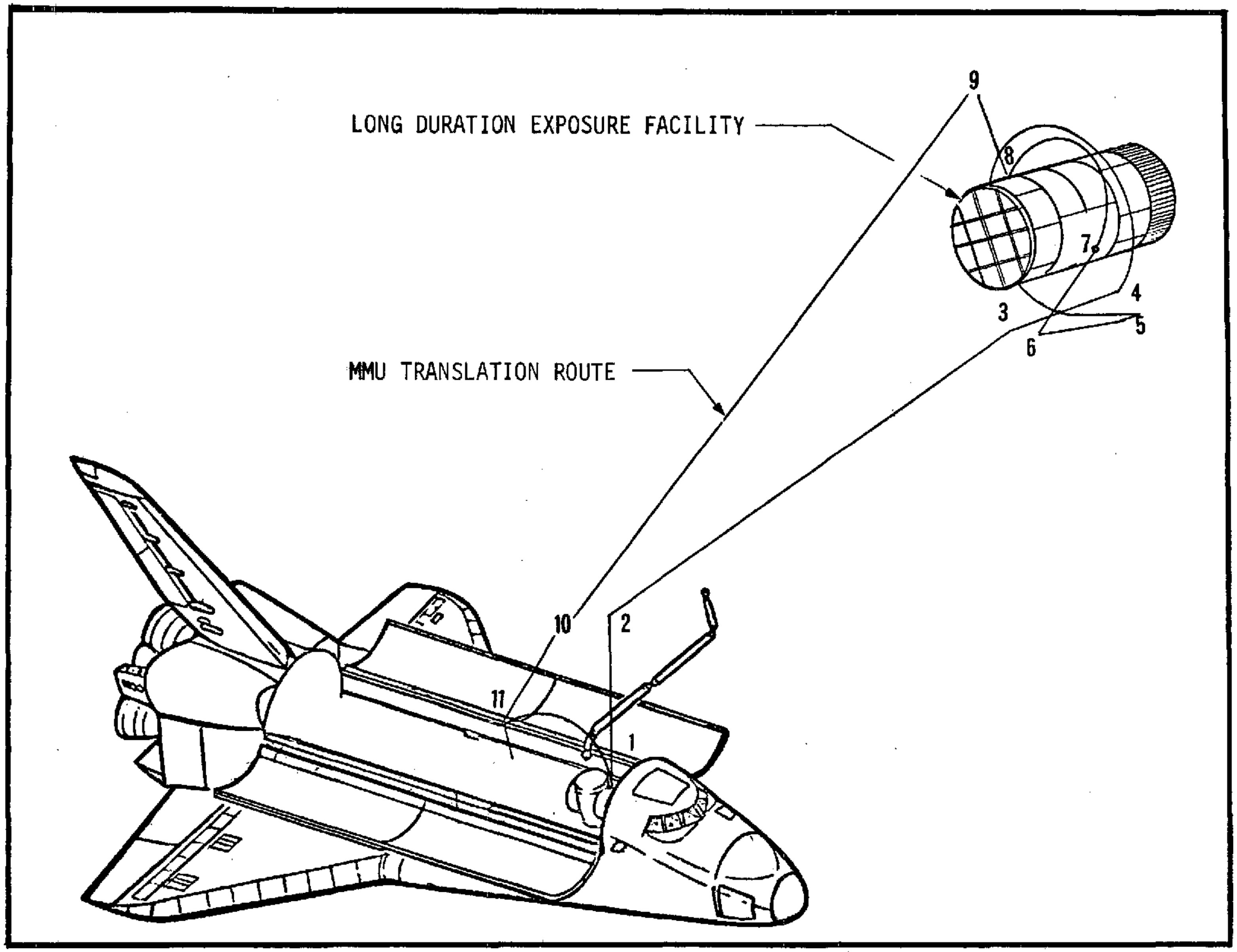

FIGURE 4.7: MMU Applications to the Long Duration Exposure Facility (LDEF)

4.7 LARGE SPACE TELESCOPE (LST)--AS-01-A

MISSION IMPACT: CLASS III CRITICALITY

The LST is an automated payload that is presently scheduled for on-orbit servicing while berthed in the payload bay. Both the Shuttle RMS and EVA may be involved in the servicing operations. The LST is deployed and retrieved by the RMS. Possible MMU applications include: (1) on-orbit servicing; (2) payload stabilization; (3) inspection and monitoring tasks; and (4) payload retrieval and deployment assistance. The MMU may also serve as a backup to payload jettison should the RMS malfunction, and aid in deployment of LST mechanisms (e.g., solar cells, antennas, aperture doors, sun shields) prior to or following orbital release.

4.7.1 LST Description

The LST is an automated payload stabilized in three axes using CMGs and cold gas thrusters. It is 4.27 m. (14 ft.) in diameter, 12.7 m. (41.7 ft.) in length, with a mass of 10,401 kg. (22,934 lbs.). It will be serviced on-orbit, as required, and retrieved for ground refurbishment twice during its design life. The present servicing plans are to discontinue LST operations, retract the deployable mechanisms, and berth the payload to the Orbiter. Components of the LST are sensitive to hydrocarbons, sulfides and humidity; therefore, precautions must be taken prior to servicing activities. The LST payload contains contamination covers, solar arrays, a sun shield, louvers, a star tracker, etc. that can be serviced on-orbit.

4.7.2 MMU Application

Servicing the LST via MMU may be accomplished as a "piggy-back" function, thus avoiding a dedicated Shuttle launch. Servicing tasks, such as replacement of batteries, recorders, digital processors, gyros, etc., may be accomplished if EVA access to the LST support systems module (SSM) is provided. An MMU temporary stowage/donning station could be attached to the LST exterior and the MMU stowed during EVA servicing operations inside the unpressurized payload. Some servicing operations, both inside and outside the payloads, could be accomplished without interrupting the experiment. Additional study is required in this area.

Another important consideration relative to MMU applications to the LST is stabilizing the payload to within the limits of its attitude control systems. Should both of the LST's attitude control systems be inoperable, an MMU could be employed to capture and stabilize the payload for RMS retrieval. Visual inspection and monitoring LST systems' operations at a noncontaminating distance from the Orbiter may be effective in diagnosing payload malfunctions without committing the Shuttle Orbiter to an impact-potential environment.

4.7.3 MMU Performance and Control Requirements

The MMU performance and control requirements to support an LST servicing mission were derived from a typical mission scenario. This involved development of a translation route (see Figure 4.8), estimated travel distance, starts/stops, attitude changes, preliminary timeline, etc. Typical tasks involved transporting equipment modules to the LST, inspections and hardware replacement as a "piggy-back" MMU operation to avoid a dedicated on-orbit berthing mission. A summary of the resulting performance and control requirements is shown in Table 4-8. The complete mission scenario is contained in Appendix C, Volume II of the final report.

TABLE 4-8: Large Space Telescope--Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
LST Servicing	671	(2200)	±.06	(±.2)	±3	±.03	(±.1)	±3	12.9	(42.2)*

*Despinning the LST from 1 rpm will require approximately 7.4 lbs. of GN_2-- not included in the 35.0 ft/sec Δvelocity.

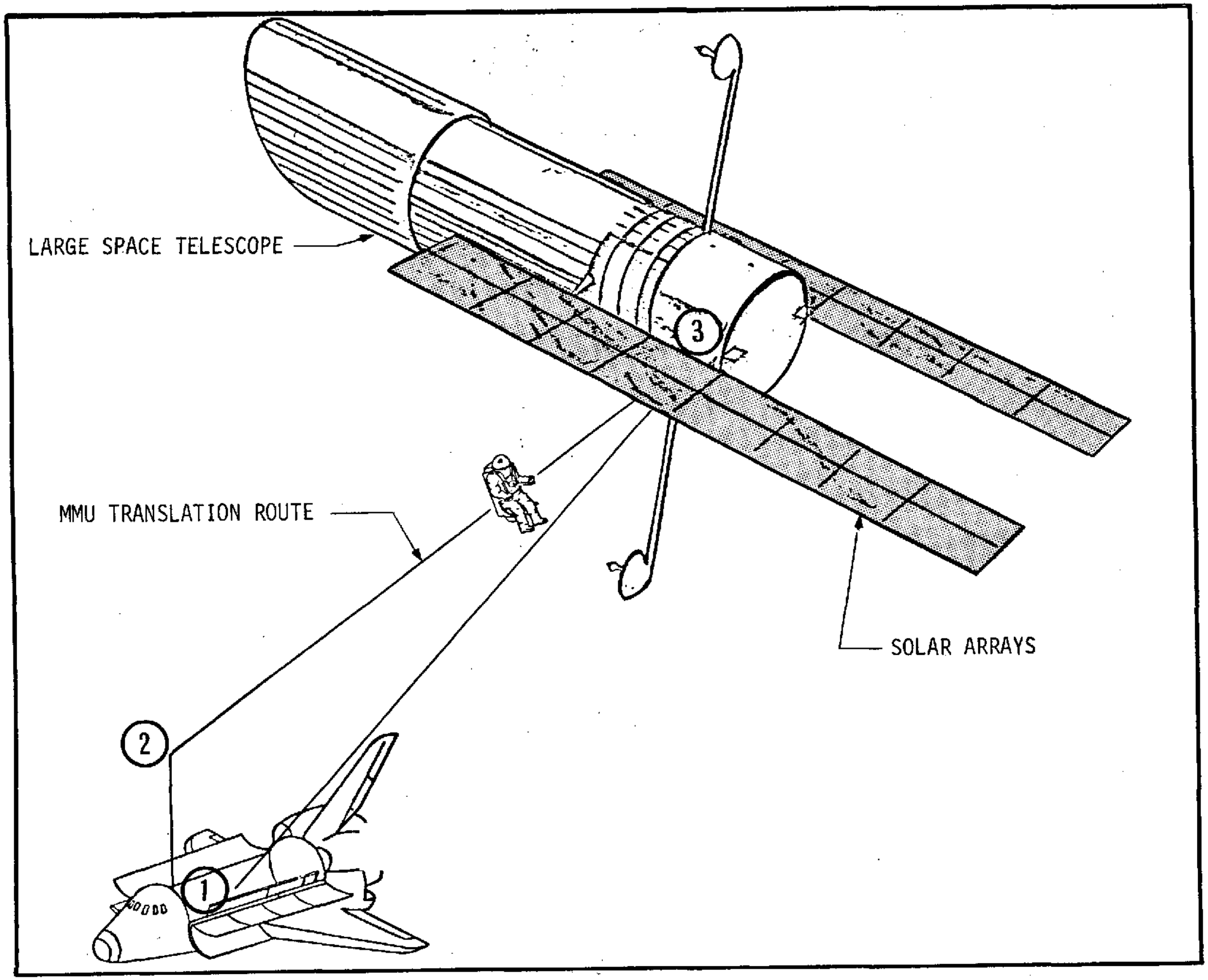

FIGURE 4.8: MMU Applications to the Large Space Telescope

4.8 LARGE HIGH ENERGY OBSERVATORY D--HE-11-R

MISSION IMPACT: CLASS III CRITICALITY

At the time of report preparation, the HE-11-R did not identify a requirement for an MMU to support payload operations although a requirement for EVA support during nominal on-orbit servicing is included. Requirements for contingency EVA are also acknowledged. An MMU could assist on-orbit servicing by providing a capability of remote inspection, servicing, and repair operations.

4.8.1 HE-11-R Description

The HE-11-R mission is a revisit to the previously deployed Large High Energy Observatory D--an automated payload stabilized in 3 axes. The payload contains a 1.2 m. x-ray telescope which is expected to raise x-ray astronomy to a qualitative level previously attained only in space optical studies. The overall dimensions are 10.0 m. (32.8 ft.) x 10.0 m. (32.8 ft.) x 14.3 m. (46.9 ft.); the weight is 6,217 kg. (13,700 lbs.). The system is designed for a ten-year life with a capability for service on-orbit, recovery and refurbishment. The present plan is to service the payload while it is berthed in the payload bay via EVA. The payload is contamination-sensitive.

4.8.2 MMU Application

Assuming a malfunction in an HE-11-A deployable system [e.g., solar arrays, tracking and data relay satellite (TDRS) antennas, sun shade], servicing/repair operations may be required in order to berth the payload prior to servicing. An MMU could be employed to inspect the HE-11-A systems and perform the tasks necessary for payload retrieval by the RMS. Candidate tasks may involve retracting or removing a TDRS antenna or solar array, and aiding sun shade retraction. Repair, removal and retraction of HE-11-A deployable systems may require special tools to gain the necessary mechanical advantage. Standard mechanic's tools and equipment--such as a block and tackle, hoist and reduced reaction torque tools--may be required.

As in the two preceding candidate MMU applications, the MMU may also be useful in stabilizing the HE-11-A for RMS capture or performing operations remote from the Orbiter to minimize payload contamination.

4.8.3 MMU Performance and Control Requirements

The MMU performance and control requirements to support the HE-11-R mission were derived from a typical mission scenario based on a remote servicing task. The scenario involved development of a translation route (Figure 4.9), estimated travel distance, determination of number of stops/starts, attitude changes, preliminary timeline, etc. Typical tasks may involve manual retraction of solar arrays, sun shade or antennae to allow payload retrieval by the RMS. Servicing of the retractable systems could also be accomplished while the HE-11-A is attached to the RMS. A summary of the resulting performance and control requirements appears in Table 4-9. The complete scenario is contained in Appendix C, Volume II of the final report.

TABLE 4-9: HE-11-R Observatory--Summarized MMU Performance and Control Requirements

MMU TASK \ PARAMETERS REQ'D.	TOTAL TRAVEL DISTANCE m	(ft)	HOLD PRECISION: TRANSLATION m	(ft)	HOLD PRECISION: ROTATION deg	RATE PRECISION: TRANSLATION m/sec	(ft/sec)	RATE PRECISION: ROTATION deg/sec	DELTA VELOCITY (TOTAL) m/sec	(ft/sec)
HE-11-R Observatory Servicing (one trip)	335	(1100)	±.06	(±.2)	±3	±.03	(±.1)	±3	11.3	(37.2)

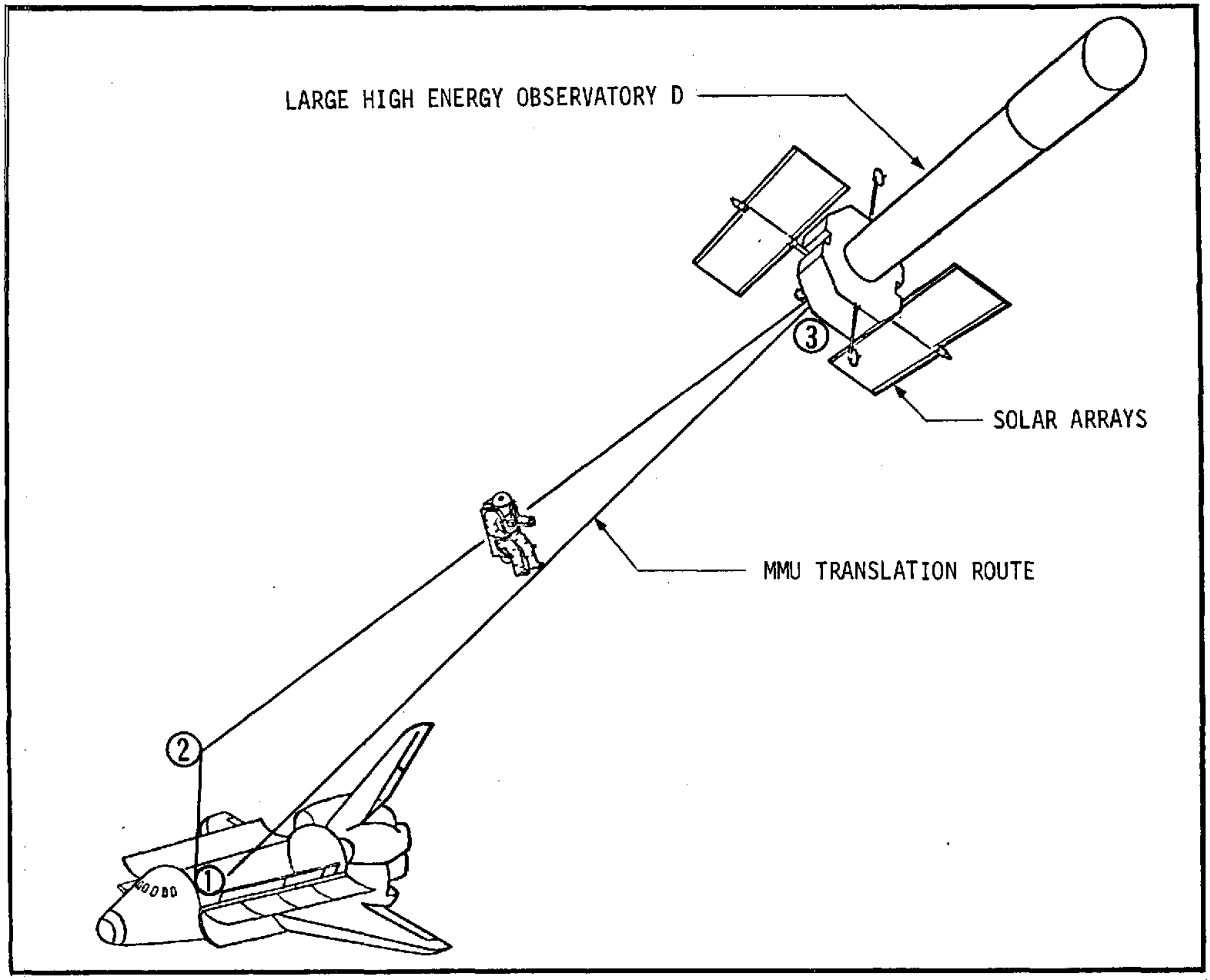

FIGURE 4.9: MMU Applications to the HE-11-A Observatory (Revisit)

4.9 ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE (AMPS)--AP-06-S

MISSION IMPACT: CLASS III CRITICALITY

The AMPS payload does not identify requirements for an MMU to support payload operations. However, the payload contains a combination of pallet-mounted equipment and deployable devices which would benefit from MMU support in a payload contingency situation.

4.9.1 AMPS Description

The AMPS is a sortie-type payload which consists of a pressurized lab plus a pallet containing experiment support equipment. Major assemblies requiring external mounting include a remote sensing platform (housing both optical instrumentation and field and particle sensors); a laser radar (LIDAR); extendible booms (50 m.) for remote measurements of the ambient environment and for work studies; and transmitters and particle accelerators for stimulation of the ionosphere and magnetosphere. The payload also contains subsatellites and a variety of deployable devices, including those designed to release chemicals into the upper ionosphere and magnetosphere. The payload is being designed to make maximum use of equipment by employing it on multiple missions with other experiments.

4.9.2 MMU Application

Fifty meter (164 ft.) and 5 m. (16.4 ft.) booms are used to deploy AMPS experiments from the payload bay. Utilizing an MMU to extend/retract and repair the booms, or retrieve costly experiment hardware, appears to be economically feasible. If the boom malfunctions in an extended position and cannot be jettisoned safely, an MMU may be required to aid in dismantling and clearing the AMPS disabled hardware from the Shuttle area. The 50 m. and other booms under consideration to deploy the AMPS experiment hardware do not appear sufficiently rigid to support EVA crewman translation. (Additional boom data is contained in Appendix C, Volume II of the final report.) The MMU could also aid in the deployment and retrieval of AMPS subsatellites.

4.9.3 MMU Performance and Control Requirements

The MMU performance and control requirements to aid the AMPS payload contingency situation were derived from a typical mission scenario based on recovery of equipment from the end of a failed boom prior to jettison. This involved development of a translation route (Figure 4.10), estimated travel distance, determination of starts/stops, attitude changes, preliminary timeline, etc. A summary of the resulting performance and control requirements is shown in Table 4-10. The complete mission scenario is contained in Appendix D, Volume II of the final report.

TABLE 4-10: AMPS Payloads--Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
AMPS Mast Servicing (Equipment Retrieval)	460	(1500)	±.045	(±.15)	±2	±.23	(±.08)	±2	9.22	(30.2)

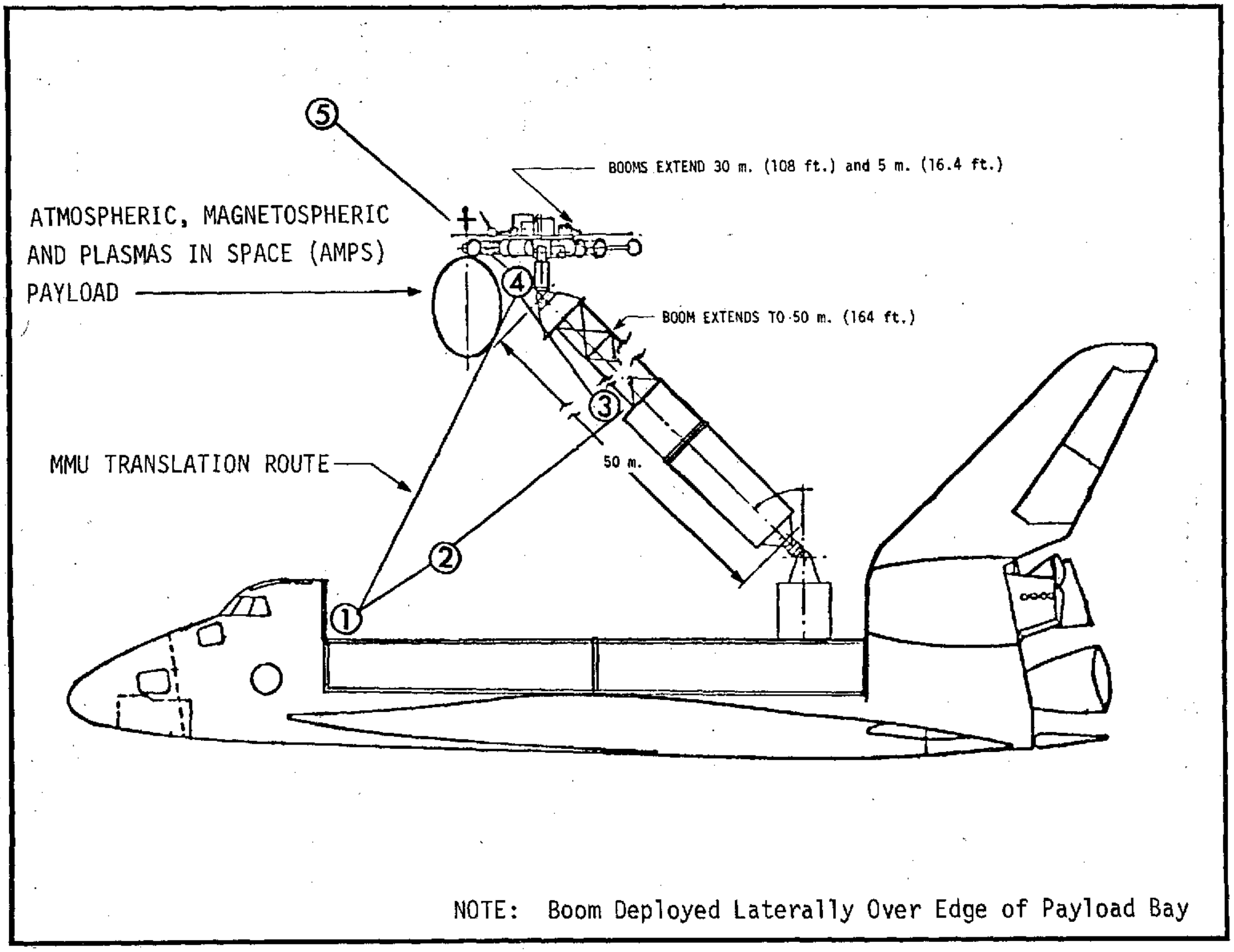

FIGURE 4.10: MMU Applications to the AMPS Payloads

4.10 SHUTTLE IMAGING MICROWAVE SYSTEM (SIMS)--EO-05-S

MISSION IMPACT: CLASS III CRITICALITY

One of the major objectives of this experiment is to determine the feasibility of erecting antenna systems in space. The present plan calls for use of EVA to deploy and retract the antenna and to record the operation via TV cameras. An MMU can complement this operation by assisting the deployment/retraction tasks in a contingency capacity or by providing a remote capability for optimum camera coverage. In addition, the MMU can provide a backup jettison capability to the experiment hardware should the need arise.

4.10.1 SIMS Description

The SIMS is a pallet only, sortie payload. It provides a high resolution, multifrequency-multiwave system to be used in application-oriented and scientific studies of earth and its near environment. The antenna being investigated for use is referred to as the SIMS B antenna. It is stored on a pallet in a package approximately 2.0 x 4.5 x 18 m. (6.6 x 14.8 x 59.1 ft.) and deploys to 18 x 18 m. (59.1 x 59.1 ft.). The mission objectives include: (1) determining the feasibility of assembly and deployment of large antenna systems in space; (2) performing passive microwave earth observations of the solid earth, ocean and atmosphere; and (3) determining the proper frequency band to use for each application. The SIMS will be important in investigations related to earth resources, earth physics and space physics. EVA will be used to deploy and stow the antenna array and to set up cameras for TV coverage and documentation.

4.10.2 MMU Application

An MMU could be used on the SIMS missions to aid in the erection and retraction of the SIMS B antenna in both nominal and contingency support capacities. Tasks would include assistance in the deployment and retraction of the antenna and contingency retrieval to prevent jettison in the event of a malfunction. The MMU could also be used to obtain video/TV coverage of the antenna erection procedures from optimum vantage points. Utilizing the MMU in major erection and retraction operations will provide significant data on assembly and maintenance of large structures in space for evaluating the role of man-rated maneuvering devices.

4.10.3 MMU Performance and Control Requirements

The MMU performance and control requirements to support the SIMS were derived from a typical mission scenario assuming a requirement for assistance in deploying and retrieving/stowing antennas in the payload bay. This involved development of a translation route (Figure 4.11), estimated travel distance, determination of number of stops/starts, attitude changes, preliminary timelines, etc. A summary of the resulting performance and control requirements appears in Table 4-11. The complete mission scenario is contained in Appendix D, Volume II of the final report.

TABLE 4-11: SIMS Payloads--Summarized MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
SIMS Antenna Deployment	230	(750)	±.06	(±.2)	±4	±.03	(±.1)	±2	7.9	(26.0)

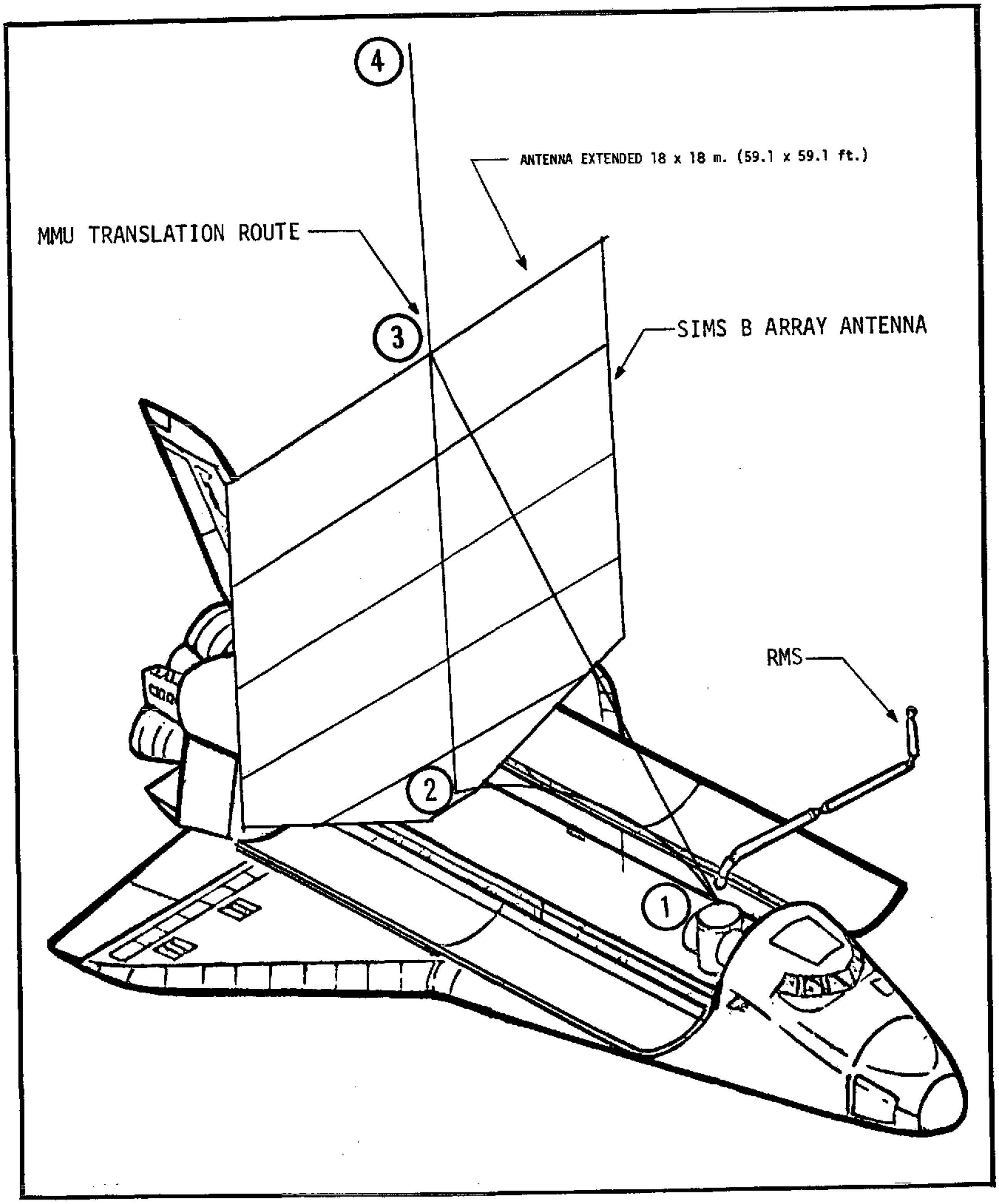

FIGURE 4.11: MMU Applications to SIMS Payloads

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

MISSION IMPACT: CLASS III CRITICALITY

The ATL payloads do not identify a requirement for an MMU to support payload operations. These payloads, similar to the AMPS, contain a myriad of pallet-mounted equipment, including extendible booms, trusses and tethers which could benefit from the capabilities of an MMU in contingency situations.

4.11.1 ATL Description

The ATL payload series consists of dedicated modules being developed by the NASA Langley Research Center. The payloads are multi-disciplinary and include navigation, earth observations, physics and chemistry, microbiology, component and system test, and environmental effects disciplines. The payloads consist of either a lab with pallet-mounted support equipment or a pallet-only arrangement. The payloads will utilize booms which extend from the pallet to distances of 40 m. (131 ft.) and 450 m. (1,476 ft.) equipment-carrying tethers. Since the booms extend beyond the envelope of the payload bay, a failure to fully retract would prevent closing the payload bay doors. Jettison of the extendible member and experiment equipment may be required. However, the need to jettison a failed system might be prevented by manual boom retraction. The boom structures presently under consideration may not support translation of an EVA crewman, and their lengths preclude access via the RMS. Should a boom fail during deployment, mission objectives may not be attained.

4.11.2 MMU Application

The MMU could be a cost effective backup system to the extendible mechanisms on the ATL payloads. The MMU may be used to salvage equipment and experiment data that might otherwise be jettisoned into space due to a minor mechanical failure. The MMU can also be used to aid extension of partially deployed booms to allow nominal mission operations. An additional application of the MMU would be failed boom disassembly and jettison/stowage of the parts to avoid possible Orbiter damage during automatic jettison. This condition assumes that experiment equipment would be in an off-nominal position relative to the Orbiter, and when automatically jettisoned, the dynamics may cause equipment impact with the Orbiter.

4.11.3 MMU Performance and Control Requirements

The MMU performance and control requirements to support the ATL payloads were derived from a typical mission scenario based on deployment and retraction of a failed extendible boom. This involved development of a translation route (Figure 4.12), estimated travel distance, determination of number of stops/starts, attitude changes, preliminary timeline, etc. A summary of the resulting performance and control requirements is shown in Table 4-12. The complete mission scenario can be found in Appendix D, Volume II of the final report.

TABLE 4-12: ATL Payloads--Summarized
MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
ATL Mast Deploy (4)	685	(2230)	±.06	(±.2)	±3	±.03	(±.1)	±3	12.3	(40.4)

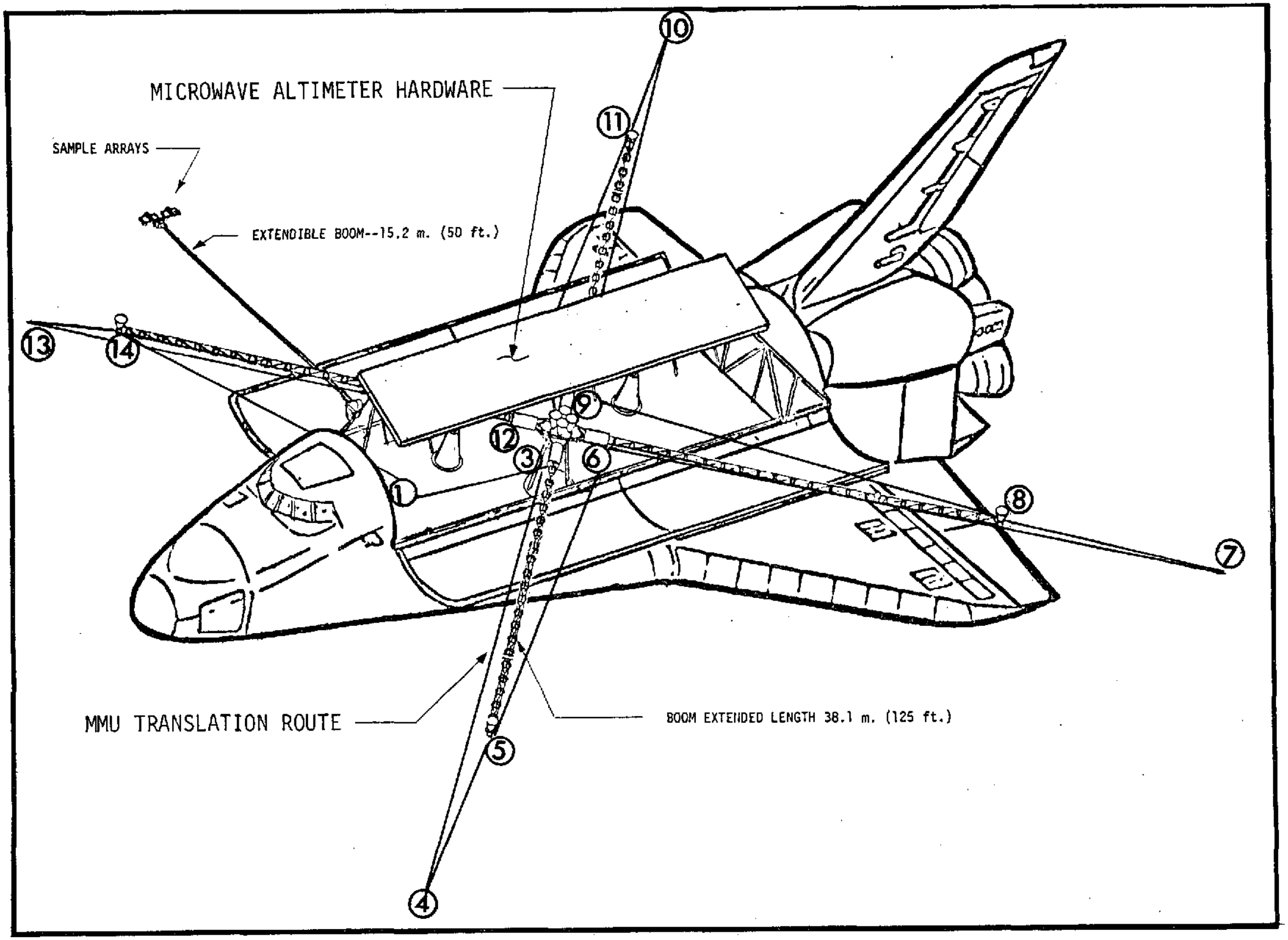

FIGURE 4.12: MMU Applications to ATL Sortie Payloads

5.0 MMU PERFORMANCE AND CONTROL REQUIREMENTS

The MMU applications analyses included typical on-orbit maneuvering operations and candidate EVA tasks associated with the representative MMU-EVA missions identified. The representative applications provided the basis for defining preliminary MMU performance and reaction control requirements. The major sources used in defining the performance and control requirements included the following:

- Shuttle Orbiter and payloads MMU applications analyses
- Automated and Sortie payload physical, operational and performance characteristics
- Free-Flying Teleoperator Spacecraft (FFTS) reaction control system, manipulator and safety requirements/characteristics
- Shuttle Remote Manipulator System (RMS) operating characteristics
- Skylab M509 astronaut maneuvering equipment assessment

A composite (Table 5-1) of the MMU performance and control requirements across the Orbiter subsystems and payloads analyzed is presented to emphasize the driving characteristics.

The quantitative results of the MMU preliminary performance and control requirements defined by the study are summarized in Table 5-2. This table contains the MMU design recommendations to satisfy a wide range of potential Shuttle applications while eliminating only the most "taxing" applications. The payload parameters driving these rigorous applications may be relaxed as payload designs progress. Table 5-3 contains general MMU operational and safety requirements.

Since many of the payloads and Orbiter subsystem physical, operational and performance characteristics are fluid, detailed requirements are likely to change. The final MMU performance and control requirements will be the results of a series of iterative cycles in which the requirements are defined to increasingly finer levels of detail as the program progresses and the flight hardware and operational considerations become better known.

TABLE 5-1: Composite of MMU Performance and Control Requirements

PARAMETERS REQ'D. / MMU TASK	TOTAL TRAVEL DISTANCE		HOLD PRECISION			RATE PRECISION			DELTA VELOCITY (TOTAL)	
			TRANSLATION		ROTATION	TRANSLATION		ROTATION		
	m	(ft)	m	(ft)	deg	m/sec	(ft/sec)	deg/sec	m/sec	(ft/sec)
Orbiter Exterior Inspection	370	(1210)	±.06	(±.2)	±3	±.03	(±.1)	±3	16.2	(53.0)
TPS Repair	110	(360)	±.06	(±.2)	±4	±.03	(±.1)	±2	5.9	(19.2)
Door Repair	110	(360)	±.06	(±.2)	±2	±.03	(±.1)	±1	6.34	(20.8)
MMU Personnel/ Equipment Rescue	640	(2100)	±.03	(±.1)	±4	±.015	(±.05)	±1	15.3	(50.0)
RMS Contingency Support	305	(1000)	±.06	(±.2)	±3	±.03	(±.1)	±3	12.7	(41.8)
LDEF Retrieval	191	(625)	±.06	(±.2)	±2	±.03	(±.1)	±1	10.5	(34.6)
LST Servicing	671	(2200)	±.06	(±.2)	±3	±.03	(±.1)	±3	12.9	(42.2)
HE-11-R Observatory Servicing (one trip)	335	(1100)	±.06	(±.2)	±3	±.03	(±.1)	±3	11.3	(37.2)
AMPS Mast Servicing (Equipment Retrieval)	460	(1500)	±.045	(±.15)	±2	±.23	(±.08)	±2	9.22	(30.2)
SIMS Antenna Deployment	230	(750)	±.06	(±.2)	±4	±.03	(±.1)	±2	7.9	(26.0)
ATL Mast Deploy (4)	685	(2230)	±.06	(±.2)	±3	±.03	(±.1)	±3	12.3	(40.4)
DRIVING PARAMETERS FROM MMU APPLICATIONS	695	(2230)	±.03	(±.1)	±2	±.015	(±.05)	±1	16.2	(53.0)

TABLE 5-2: Preliminary MMU Performance and Control Requirements Summary*

	PARAMETER	UNITS SI (METRIC)	UNITS ENGLISH	REMARKS
PERFORMANCE AND CONTROL REQUIREMENTS	Total Velocity Change Capability	≈20 m/sec	65.0 ft/sec	Includes attitude change capability (based on a combined Orbiter inspection and TPS repair)
	Velocity Precision (each axis)	±0.03 m/sec	±0.1 ft/sec	Manual
	Translation Hold Precision (each axis)	±0.06 m.	±0.2 ft.	Manual
	Rate Gyro Attitude Rate Precision (each axis)	--	±2°/sec	Automatic (rate gyro) mode --Rate Deadband
	Rate Gyro Attitude Hold Precision (each axis)	--	±2°	Automatic (rate gyro) mode --Hold Deadband
	Special Case Attitude Hold Precision	--	±0.05°	Manual (momentary)--Hold Deadband
	Normal Velocity:			
	Linear	--	--	Function of total translation distance and obstructions in route (.2 to .6 ft/sec used on Skylab for short transfer)
	Rotational	.17 rad/sec	10.0°/sec	Rate used on Skylab M509

*Recommended for MMU design based on capability to satisfy all but "special" applications.

TABLE 5-2: Preliminary MMU Performance and Control Requirements Summary (continued)

	PARAMETER	UNITS		REMARKS
		SI (METRIC)	ENGLISH	
PERFORMANCE AND CONTROL REQUIREMENTS	Maximum Velocity Required:			
	Linear	--	--	Control/safety consideration only
	Rotational	.45 rad/sec^2	26.4°/sec^2	Required to stabilize satellites at 4 rpm
	Nominal Acceleration:			
	Linear	0.1±.01 m/sec^2	0.3±.05 ft/sec^2	Sufficient for most applications
	Rotational	.17 rad/sec^2	10±3°/sec^2	
	Maximum Acceleration (special case):			
	Linear	0.15±.01 m/sec^2	0.5±.05 ft/sec^2	Useful in rescue operations
	Rotational	.17 rad/sec^2	10±3°/sec^2	
	Force Capability (thrust--min. one axis)	22.2 N.	5.0 lbf.	Useful in rescue operations --total thrust
	Torque Capability (min. one axis)	10.9 N-m	8.0 ft-lb	Useful in satellite stabilization

TABLE 5-2: Preliminary MMU Performance and Control Requirements Summary (continued)

	PARAMETER	UNITS		REMARKS
		SI (METRIC)	ENGLISH	
PERFORMANCE AND CONTROL REQUIREMENTS	Maximum Range	--	--	Depends on visual only or use of navigation gear
	Size of Modules Transported (max.)	--	--	Within safety limits
	Mass of Modules Transported (max.)	--	--	Within safety limits

TABLE 5-3: MMU General Characteristics

	PARAMETER	DATA/REMARKS
SAFETY	Total Accumulated Momentum:	
	Translational	Safety consideration to be studied
	Rotational	Safety consideration to be studied
	Navigation Equipment	Yes, consideration for advanced units
	Relative Geometry to Satellite Measuring Capability	Yes, consideration for advanced units
	Relative Velocity Indicating Capability	Yes, consideration for advanced units
GENERAL OPERATING REQUIREMENTS	Weight	75 kg. (165 lbs.) estimate--does not include propellant or don/doff station
	Volume	TBD
	Mission Duration	6 hrs.--support EVA application
	Turn-Around Time Between Missions	10 - 12 hrs. (battery recharge)
	Control Authority	Six Degrees
	Piloting Logic	Spacecraft Type

TABLE 5-3: MMU General Characteristics (continued)

	PARAMETER	DATA/REMARKS
GENERAL OPERATIONAL REQUIREMENTS	Self-Contained System	Yes
	Worksite Attachment Provisions	Yes
	Attitude Hold	Rate gyro (automatic) with manual backup
	Attitude Rate Command	Acceleration command
	Propellant	GN_2 (O_2 backup)
	Satellite Capture Capability	Yes (desirable)
	Satellite Stabilization Capability	Yes (desirable)
	Satellite Service/Repair Capability	Yes (desirable)
	Fail-Safe	Yes
	One-Man Servicing On-Orbit	Yes
	One-Man Don/Doff On-Orbit	Yes

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