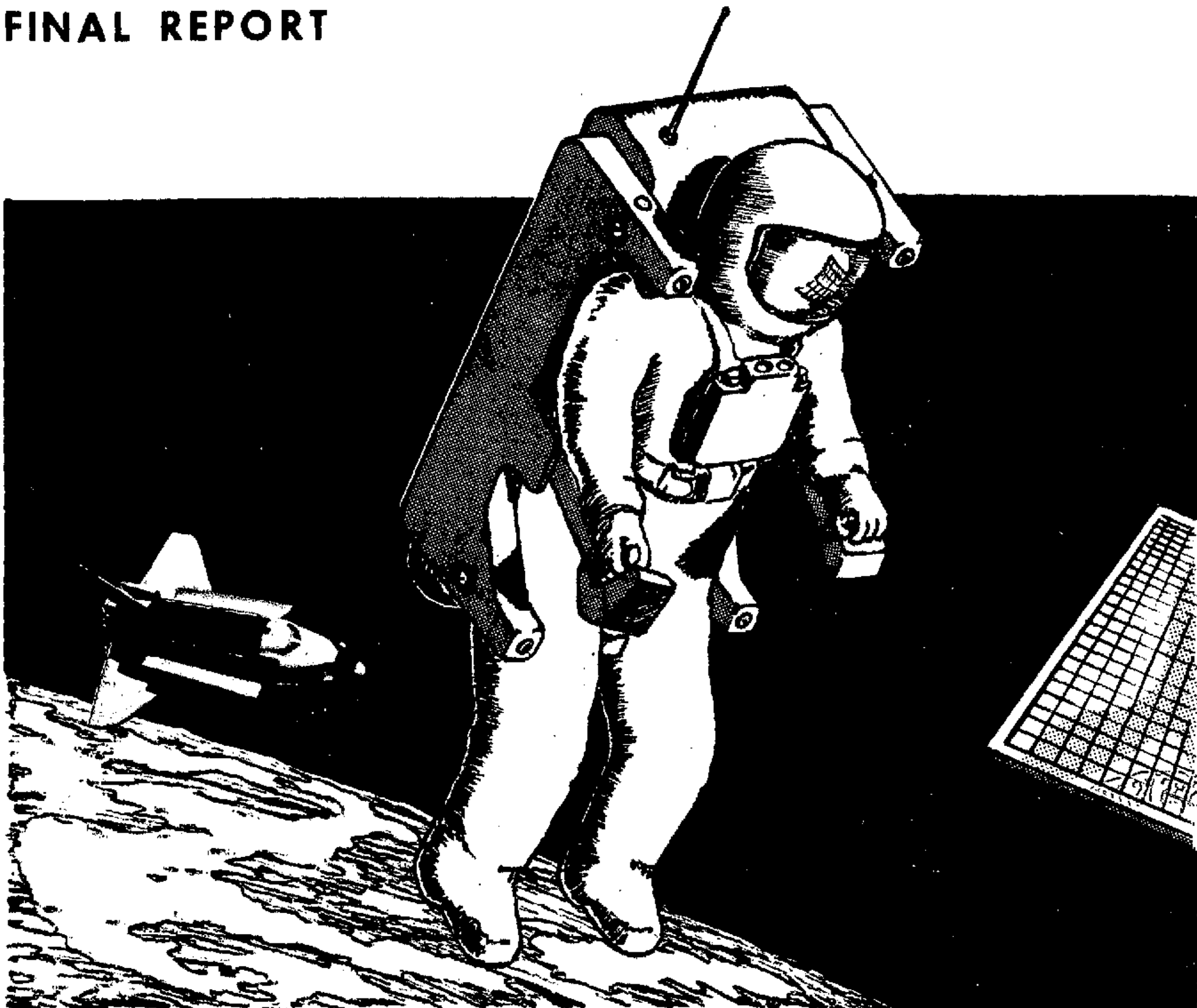
MANNED MANEUVERING UNIT MISSION DEFINITION STUDY

NASA CR-
141633

FINAL REPORT



VOLUME III

MMU ANCILLARY SUPPORT EQUIPMENT AND ATTACHMENT CONCEPTS

(NASA-CR-141633) MANNED MANEUVERING UNIT MISSION DEFINITION STUDY. VOLUME 3: MMU ANCILLARY SUPPORT EQUIPMENT AND ATTACHMENT CONCEPTS Final Report (URS/Matrix Co., Houston, Tex.) 129 p HC $5.75 CSCL 06K G3/54

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NAS9-13790
MOD. NO. 1S

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JANUARY 1975

MANNED MANEUVERING UNIT MISSION DEFINITION STUDY

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

VOLUME III:

MMU ANCILLARY SUPPORT EQUIPMENT AND ATTACHMENT CONCEPTS

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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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 III) provides the findings of the conceptual design milestones of the contract.

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, Mr. Kem B. Robertson III, and Mrs. Betty K. Bielat.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

FIGURE PAGE

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

ACRONYMS AND ABBREVIATIONS

ALSA	Astronaut Life Support Assembly
AMPS	Atmospheric, Magnetospheric and Plasmas in Space
AMU	Astronaut Maneuvering Unit
ASMU	Automatically Stabilized Maneuvering Unit
C/D	Control and Display
cm	Centimeter
CMG	Control Moment Gyro
CRT	Cathode Ray Tube
deg	Degree
DoD	Department of Defense
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
FFTO	Free-Flying Teleoperator
FFTS	Free-Flying Teleoperator Spacecraft
ft	Foot
in	Inch
JSC	Johnson Space Center
kg	Kilogram
lb	Pound
m	Meter
MMU	Manned Maneuvering Unit
NASA	National Aeronautics and Space Administration
OWS	Orbital Workshop

ACRONYMS AND ABBREVIATIONS (continued)

PLSS	Portable Life Support System
PRS	Personnel Rescue System
QD	Quick Disconnect
RMS	Remote Manipulator System
sec	Second
TPS	Thermal Protection System

1.0 INTRODUCTION

The Manned Maneuvering Unit (MMU) mission definition study primary objectives were to identify and describe candidate applications of MMUs to the Space Shuttle Program and to develop conceptual designs of MMU ancillary support equipment and attachment hardware/interfaces. The MMU 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. The results of the MMU applications analyses and the general MMU performance and control requirements identified are presented in Volume I of this final report with supporting material contained in Volume II, "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 this volume of the final report. 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 STUDY OBJECTIVES--CONCEPTUAL DESIGNS

The objectives specified for the conceptual design phase of the MMU study were:

- Develop concepts for the attachment interface between the MMU and other major orbital elements of the Space Shuttle Program: Attachment and stabilization concepts encompassed interfacing the MMU-crewman combination to the Shuttle Orbiter, free-flying payloads, personnel rescue systems (PRS) and other MMUs. Attaching the MMU to the Shuttle Orbiter for launch, servicing and reentry were included in the conceptual designs.

- Develop concepts for ancillary equipment required to support potential MMU missions and provide preliminary concepts for the attachment interface between the MMU and the ancillary equipment: Supporting subsystems and equipment, such as auxiliary lighting, cameras, tools, tethering devices, cargo attachment mechanisms, etc. were considered during conceptual development. Conceptual design of modular, add-on ancillary equipment with standardized interfaces received primary consideration.

1.2 VOLUMES I AND II OVERVIEW

The MMU mission definition study final report is contained in three volumes. Volumes I and II report the findings of an MMU Shuttle applications analysis and defines preliminary MMU performance and control requirements. The conceptual designs of MMU supporting subsystems were derived based on the potential applications defined in Volumes I and II. These volumes should be reviewed by the reader prior to assessing the concepts presented in this volume. A brief overview of Volume I and II contents are provided below.

Volume I: Volume I, "MMU Applications Analyses and Performance Requirements," presents the findings of a detailed and systematic study of the Orbiter exterior mechanical and passive subsystems considered critical to loss of life or vehicle while on-orbit or during reentry. Numerous 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 stronger MMU applications to the Shuttle Orbiter were defined as:

- Inspection of the Orbiter exterior to determine reentry status
- Repair of Orbiter exterior subsystems to ensure safe reentry
- Crewman rescue from a disabled, unstable Orbiter.

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. Eighty-three (83) payloads within the automated disciplines and 96 payloads within the sortie disciplines (including revisits) were reviewed for potential MMU applications. DoD payloads were not included in the analyses.

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. The payloads analysis has resulted in a representative set of potential MMU applications and typical tasks derived from both the automated and sortie disciplines. The overall applications analyses provided the basis for developing general MMU performance and control requirements. The interrelationship of the analyses to the total study is shown in Figure 1.1

Volume II: This volume presents the detailed supporting material and computations for the MMU Applications Analysis and Performance Requirements presented in Volume I. Volume II should be used in conjunction with the other volumes of the final report if additional supporting information is required.

1.3 MMU-ORBITAL SYSTEMS INTERFACES

The ancillary support equipment identified and the attachment conceptual designs were provided to support MMU applications relative to the orbital

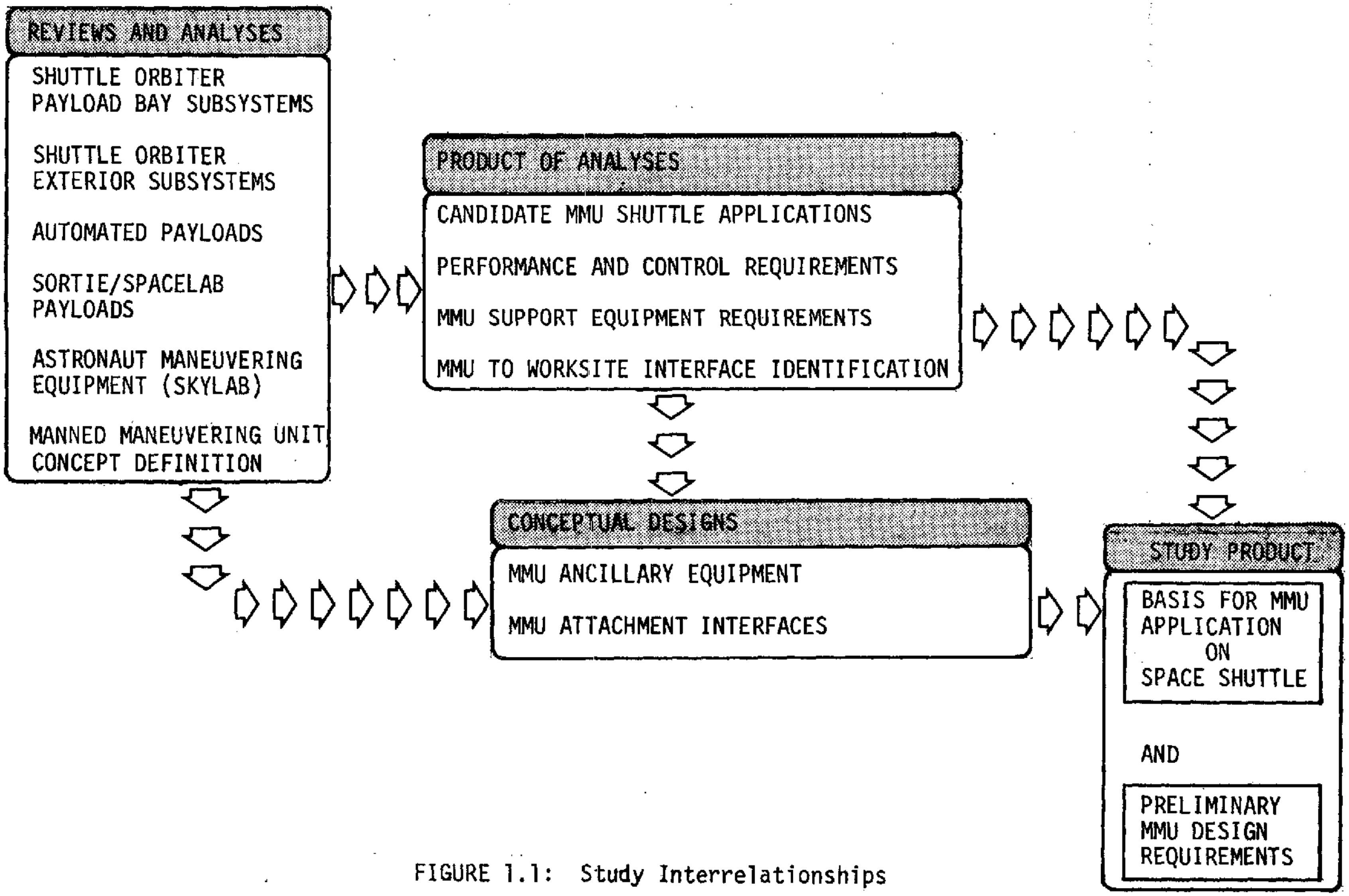


FIGURE 1.1: Study Interrelationships

systems and interfaces depicted in Figure 1.2. Interfacing the MMU to the Shuttle

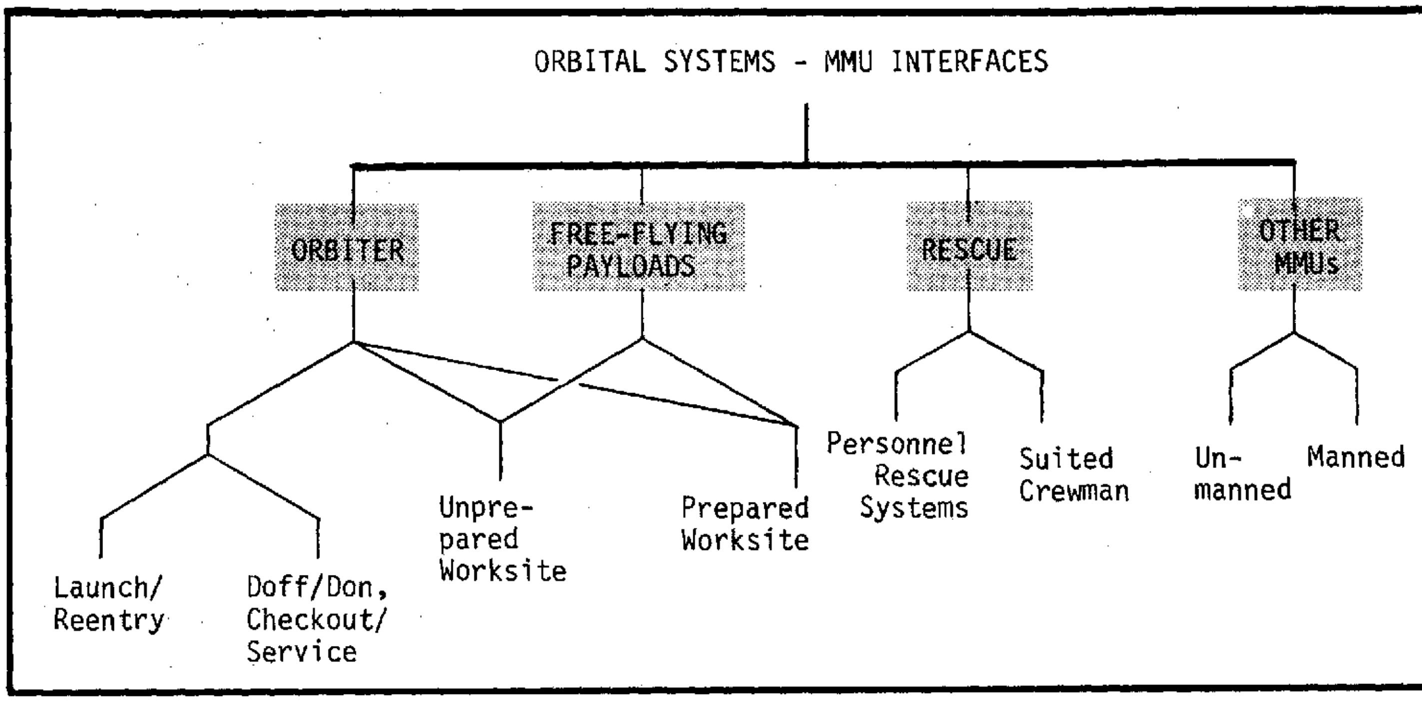


FIGURE 1.2: MMU-to-Orbital Systems Interface Requirements

Orbiter for launch, on-orbit servicing and reentry was addressed in addition to prepared and unprepared worksites. As shown in the figure, the MMU interface requirements for prepared and unprepared worksites on the Orbiter are similar to those of free-flying payloads. Various structural configurations should be available at the unprepared worksites for MMU-crewman support equipment attachment/stabilization. Prepared worksites will be configured (prior to launch) to accept MMU-crewman equipment.

Conceptual designs of equipment for interfacing the MMU-crewman to personnel in a rescue situation was a viable requirement derived from the potential MMU applications analyses. The MMU would require an attachment arrangement with the Shuttle personnel rescue systems (PRS) and space suited crewmen in a "free-space pickup" rescue mode. The MMU may also be utilized to transport rescue MMUs to a disabled Orbiter for rescue operations or to rescue another disabled MMU-crewman system.

1.4 ORBITAL SYSTEMS SUPPORT REQUIREMENTS

The orbital systems identified in the previous section require six major elements (see Figure 1.3) to effect EVA man-system functions on-orbit. The crewman (EVA astronaut), his protection (space suit), and life support systems are obviously mandatory for manned operations outside the spacecraft. Of major concern to this volume of the final report is the supporting equipment necessary for adequately provisioning the EVA crewman to conduct local and remote operations in space. Initially, the EVA crewman and supporting cargo must be provided with the capability to access the worksite (e.g., mobility aids) followed by a sufficient worksite restraining system(s). After worksite access, ancillary support subsystems may be required to perform specific tasks.

The shaded entries shown in Figure 1.3 are addressed in subsequent sections of this report with major emphasis on conceptual designs of ancillary add-on equipment to support free-flying MMU operations.

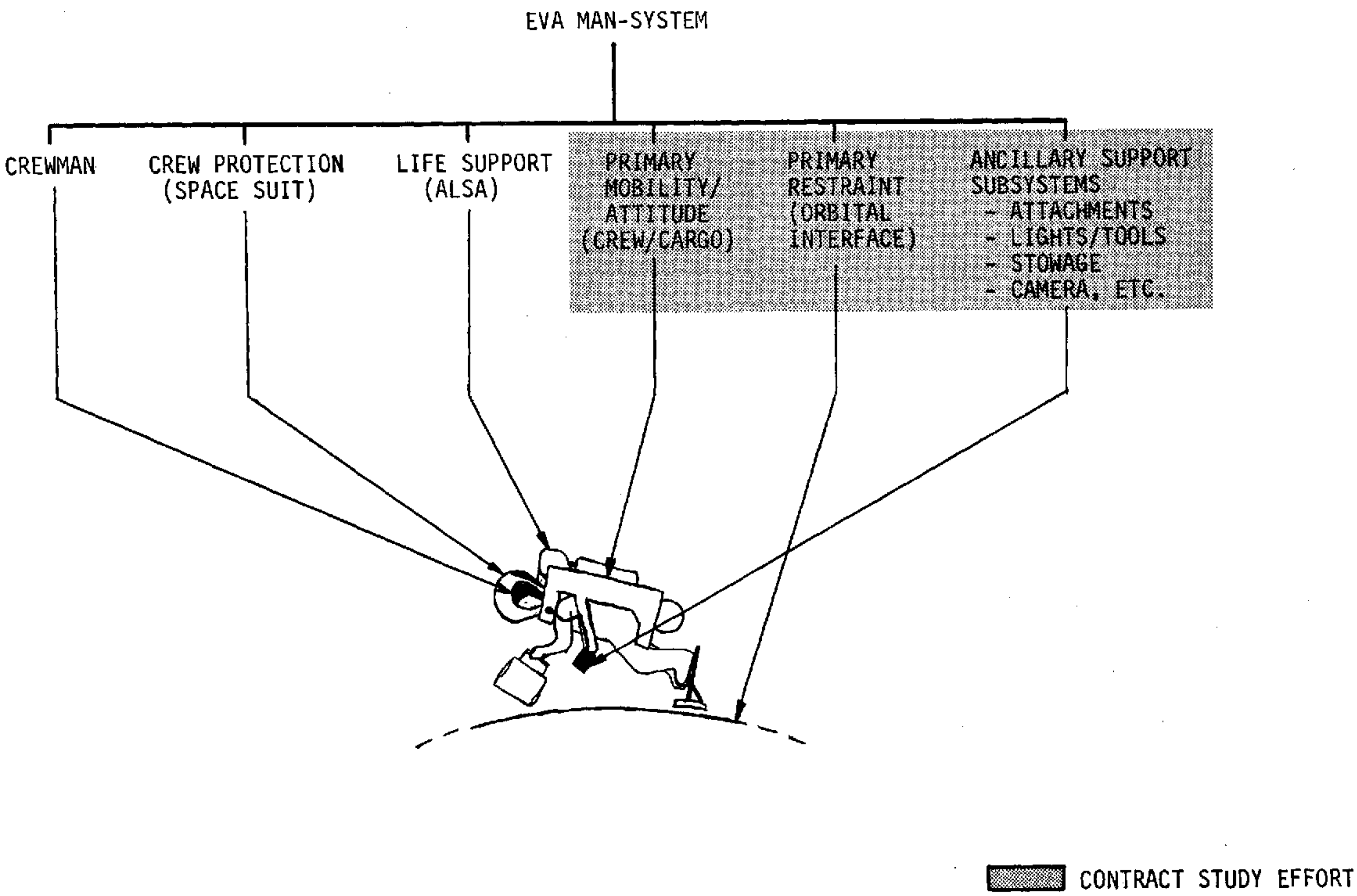


FIGURE 1.3: Major Elements/Requirements of EVA Man-System

2.0 MMU-EVA SHUTTLE CHARTER AND CONCEPT DEFINITION

The desired charter for the MMU-EVA crewman combination on the Space Shuttle consists of the following: (1) provide a capability to access and repair the Orbiter exterior to ensure reentry status, (2) serve as a personnel transporter in crewman rescue operations from a disabled Orbiter, (3) provide MMUs in a utility category to support/service free-flying satellites (berthed payloads also, if required), and (4) utilize the MMU capability to perform experiments and collect space related data (e.g., inspection, stand-off photography, deployment/retrieval, consumable resupply). Several credible Orbiter contingencies categorized as Class I criticality (i.e., loss of life or vehicle) 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 many tasks after all Orbiter-based support systems are operational. 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 the FFTS, are not presently defined. 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, inoperable experiment, etc. if the worksites cannot be accessed. A Shuttle rendezvous, capture, reentry and relaunch to acquire experiment data may be precluded by on-orbit repair of experiment equipment via EVA-MMU.

2.1 MMU ORBITAL REQUIREMENTS SUMMARY

Based on Astronaut Maneuvering Equipment performance from the in-flight Skylab M509 experiments and projected Space Shuttle MMU applications, the National Aeronautics and Space Administration has been responsible for developing preliminary MMU requirements for future space missions. Volume I of this study, "MMU Applications Analyses and Performance Requirements," reviewed the Orbiter vehicle exterior subsystem and all mid-1974 proposed payloads for required and candidate MMU applications. The major (preliminary) MMU performance requirements and desirable characteristics/capabilities are:

Desirable Characteristics/Capabilities

- Versatile design to serve as a manned utility vehicle for numerous space applications
- Noncontaminating system for sensitive payload servicing and maintenance
- Precision maneuvering and station-keeping capability for unrestrained tasks
- Quick turnaround time between MMU-EVA missions for maximum versatility
- Satellite rendezvous and spin rate duplication for satellite capture and stabilization
- Cargo transportation capability between orbiting vehicles/satellites
- Rescue of free-floating equipment or personnel from a disabled vehicle

Interface Requirements (Excluding Orbiter Utilities)

- MMU to Shuttle payload bay for launch, on-orbit and reentry
- MMU to Astronaut Life Support Assembly (ALSA)
- MMU to Personnel Rescue System (PRS)
- MMU to space suited astronaut
- MMU to another MMU
- MMU/crewman to prepared worksites (Orbiter, payloads and satellites)
- MMU/crewman to unprepared worksites (Orbiter, payloads and satellites)
- Ancillary equipment and supporting hardware (fixed and portable) to the MMU

Operational Considerations

- Fail-safe operation
- Mission duration of 6 hours
- One-man retrieval, stowage, service and don/doff on-orbit

- Self-contained system (utilizing the ALSA)
- Reasonable range capability from Orbiter
- Optional safety tether operation
- Spacecraft piloting logic
- Provisions for optional hot gas module (for additional delta V capability)

System Requirements

- Six degree-of-freedom control authority
- Automatic attitude hold using rate gyros
  - Rate: ±2 deg/sec
  - Displacement: ±2 deg
  - Drift: ±0.05 deg/sec
- Manual attitude hold (backup)
- Translational acceleration
  - .09 ±0.015 m/sec^2 (0.3 ±0.05 ft/sec^2) } NASA-recommended
  - .15 ±0.01 m/sec^2 (0.5 ±0.05 ft/sec^2) } Contractor-recommended (maximum for rescue)
- Rotational acceleration
  - 10 ±3 deg/sec^2
- Rotational velocity
  - 26.4 deg/sec } Contractor-recommended (satellite capture)
- Gaseous nitrogen (GN_2) propulsion
- Attitude rate command via acceleration command
- Delta velocity (ΔV) capability
  - 16 m/sec (52 ft/sec) NASA-recommended
  - 20 m/sec (65 ft/sec) Contractor-recommended (from applications analysis)

2.2 MANEUVERING UNIT CONFIGURATION CONCEPTS

Numerous maneuvering device concepts have been studied during the U.S. space programs ranging from simple handheld maneuvering units to integrated maneuvering life support systems. The most successful systems were the back mounted units--the type being considered for the Shuttle Program. An overview of the Gemini and Skylab (M509) units and configuration concepts being considered by the Air Force and NASA are contained in subsequent paragraphs of this section. URS/Matrix concepts are included in Section 2.2.3.

2.2.1 Existing MMU Units and Concepts

Astronaut Maneuvering Unit (AMU)

The Astronaut Maneuvering Unit (AMU) flown on the Gemini Program (Figure 2.1) was a backpack system consisting of a basic structure and six major subsystems: propulsion, flight control, oxygen supply, power supply, system status and communications. The unit was designed to allow the EVA crewman to maneuver in space completely independent of spacecraft systems. The AMU was flown on Gemini IX under Air Force experiment D012; however, the unit was not evaluated on-orbit due to inadequate crewman restraints. (The planned AMU test on Gemini XII was cancelled to allow more time to be devoted to restraint design evaluation.) The AMU contained an integrated crewman oxygen supply subsystem which supplemented the EVA life support system and provided for approximately one hour of operation. The total unit weighed 76.3 kg. (168 lbs.) and contained approximately 10.9 kg. (24 lbs.) of hydrogen peroxide propellant.

Automatically Stabilized Maneuvering Unit (ASMU)

The ASMU (Figure 2.2) was a back-mounted unit designed to evaluate direct, rate gyro, and control moment gyro (CMG) control modes for maneuvering equipment on Skylab experiment M509. The major components of the system were: structural, propellant, attitude control, electrical, telemetry, and control and displays. The maneuvering unit dimensions were 1.2 x 1.1 x .69 m. (48.0 x 41.5 x 27.0 in.) in the deployed configuration, and the unit weighed 116.3 kg. (256.5 lbs.). Each rechargeable propellant subsystem provided approximately 5.0 kg. (11 lbs.) of

FIGURE 2.1: Gemini Astronaut Maneuvering Unit

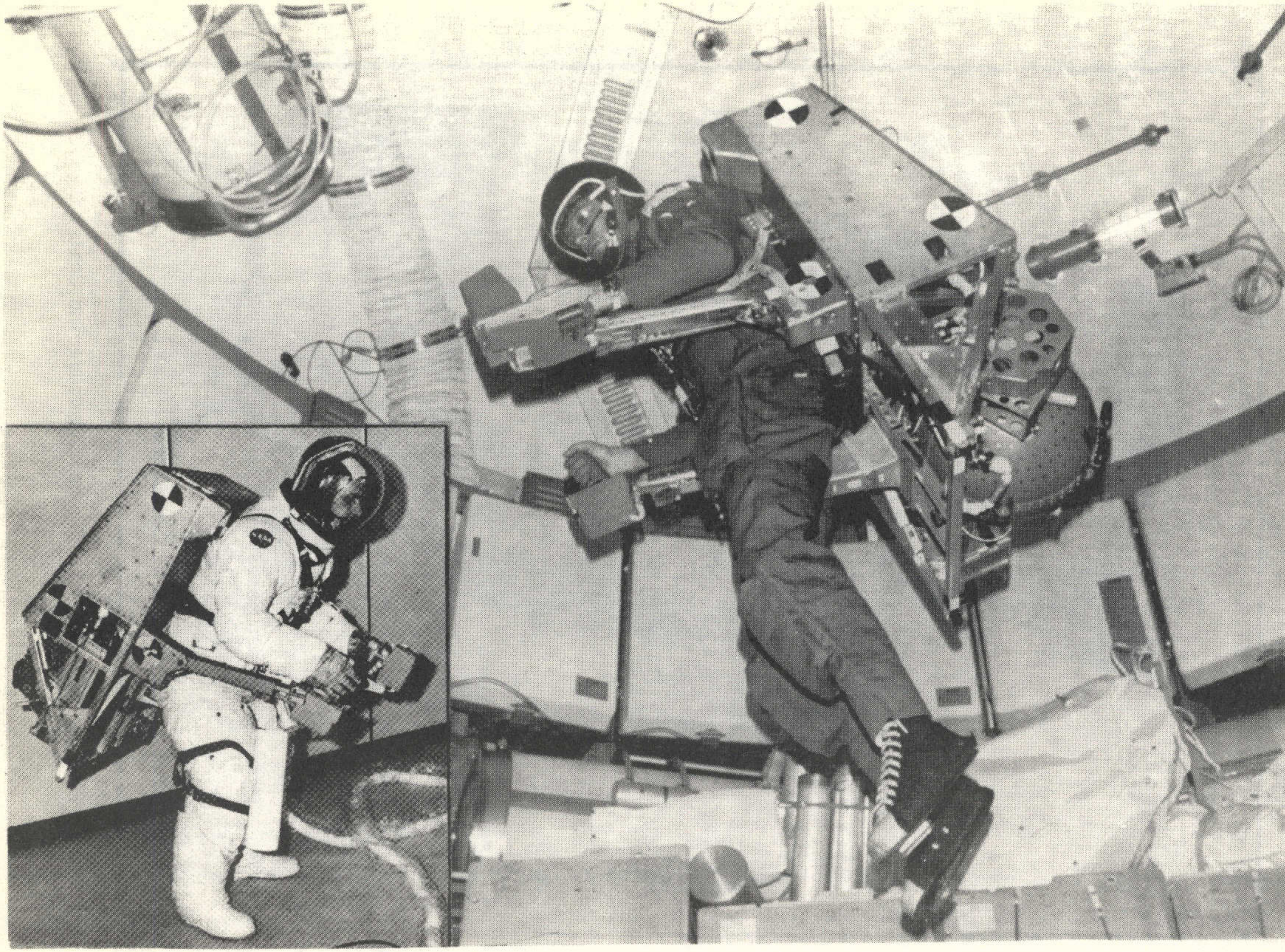


FIGURE 2.2: Skylab Automatically Stabilized Maneuvering Unit (ASMU)

GN_2 for 30 minutes operational time. The ASMU and a handheld maneuvering unit were evaluated on the Skylab Program inside the Orbital Workshop (OWS).

Space Shuttle Maneuvering Unit Concepts

Several preliminary artist concepts of Space Shuttle Manned Maneuvering Unit external configurations have been prepared by NASA. Figure 2.3 depicts a concept which would interface with existing portable life support systems and the Skylab A-7L-B spacesuit. Since the exact configuration of the spacesuits and life support systems for the Shuttle Program are undefined, the MMU configuration may remain relatively fluid until these interfaces are better defined. The concepts make no attempt to provide structural or operational features of the proposed MMU. Figure 2.4 pictorially describes a hot gas unit for use in conjunction with the concept shown in Figure 2.3.

The preliminary concept shown in Figure 2.5 depicts an MMU configuration to interface with an integrated extravehicular mobility unit (EMU) concept. The integrated EMU concept is in the study phase only as are the Manned Maneuvering Units.

2.2.2 Crew/MMU Reach and Visibility Analysis

A "paper" analysis was conducted to determine the crewman reach and visibility envelope based on the MMU configuration shown in Figure 2.6. A static mockup was fabricated, using estimated life support systems and spacesuit dimensional data (Shuttle concepts), to conduct the preliminary shirtsleeve reach and visibility study (see Figures 2.7 - 2.9). The shirtsleeve analysis was conducted using subjects with considerable spacesuit experience. The results of the analysis is shown in Figures 2.10 - 2.15.

The shaded area in Figure 2.16 shows the areas available for installing ancillary equipment to the MMU. The areas can be reached by the crewman for performing manipulative operations to secure, adjust or release operational devices. The crewman's reach to the MMU structural member appears limited;

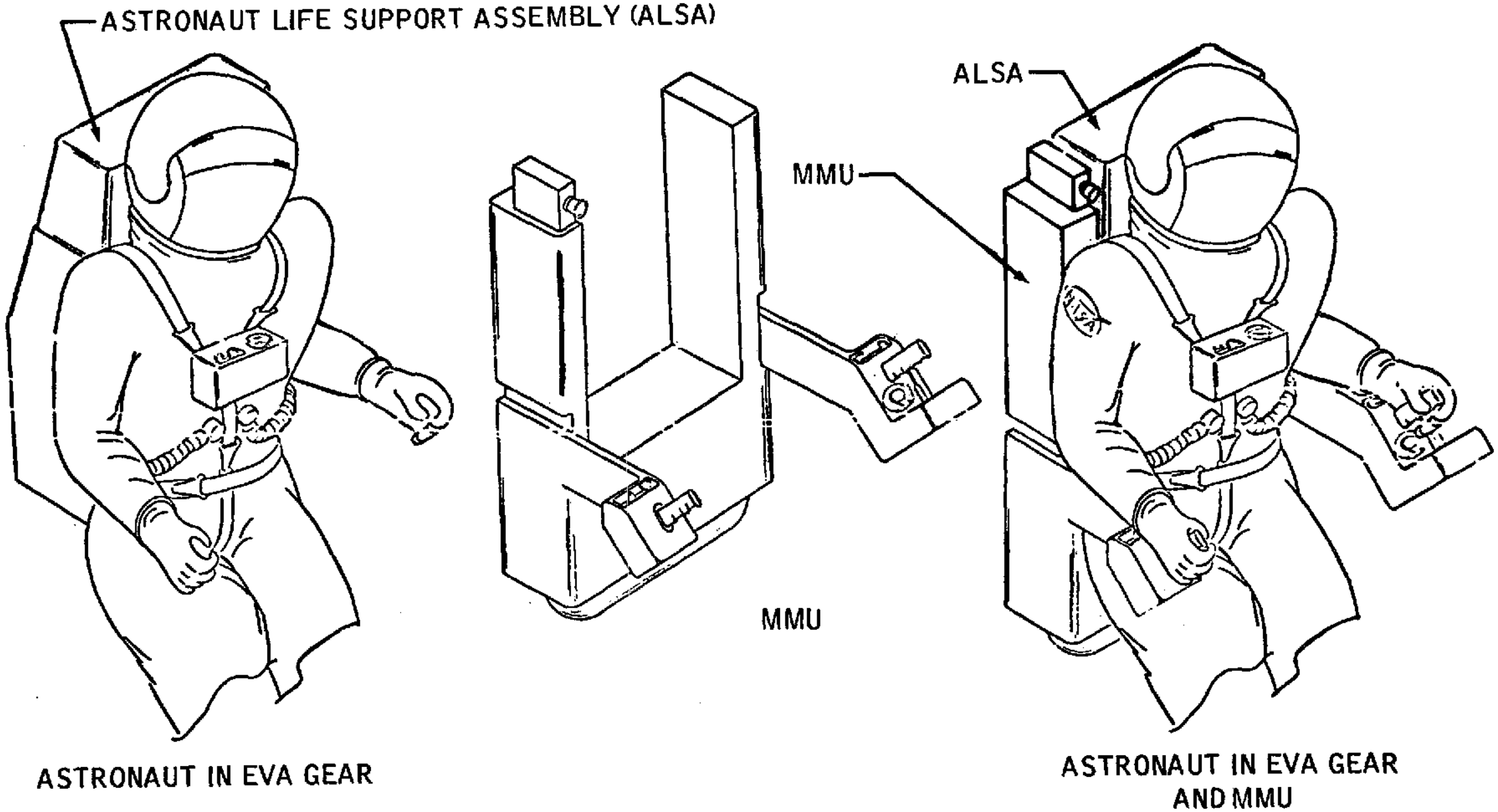


FIGURE 2.3: NASA MMU Configuration Concept

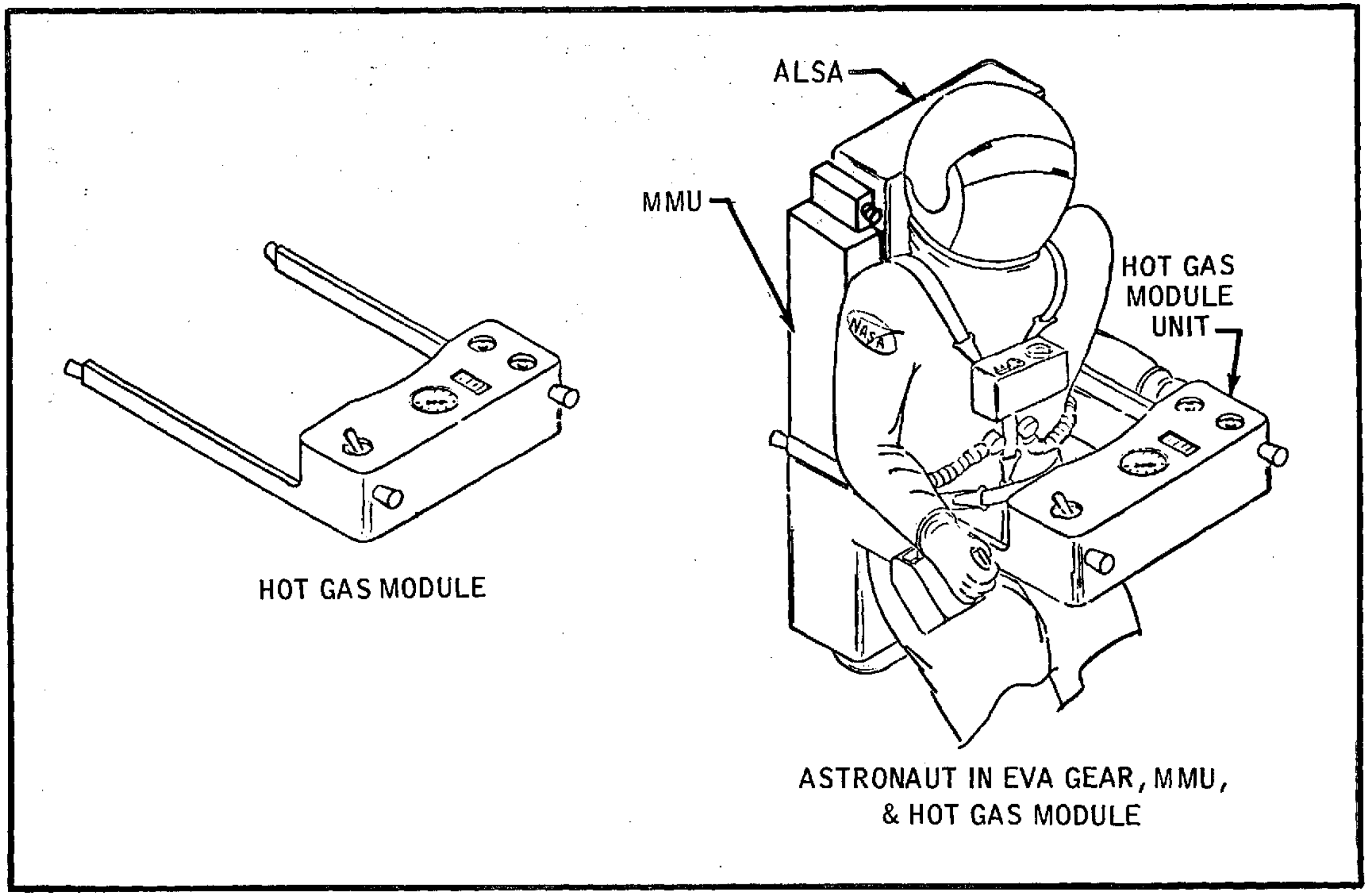


FIGURE 2.4: Hot Gas Module for MMU Concept

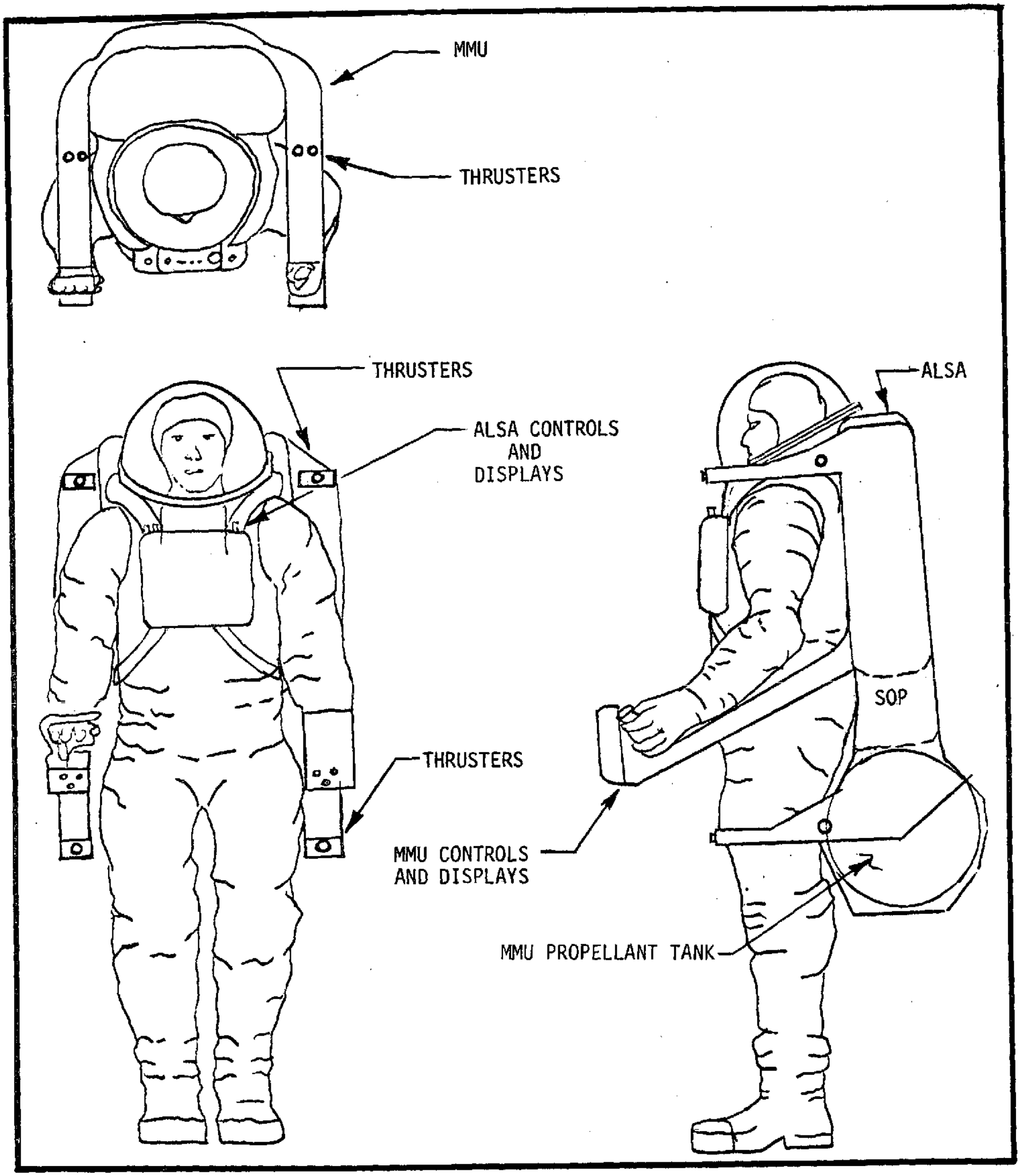


FIGURE 2.5: MMU With Integrated EMU (Preliminary Concepts)

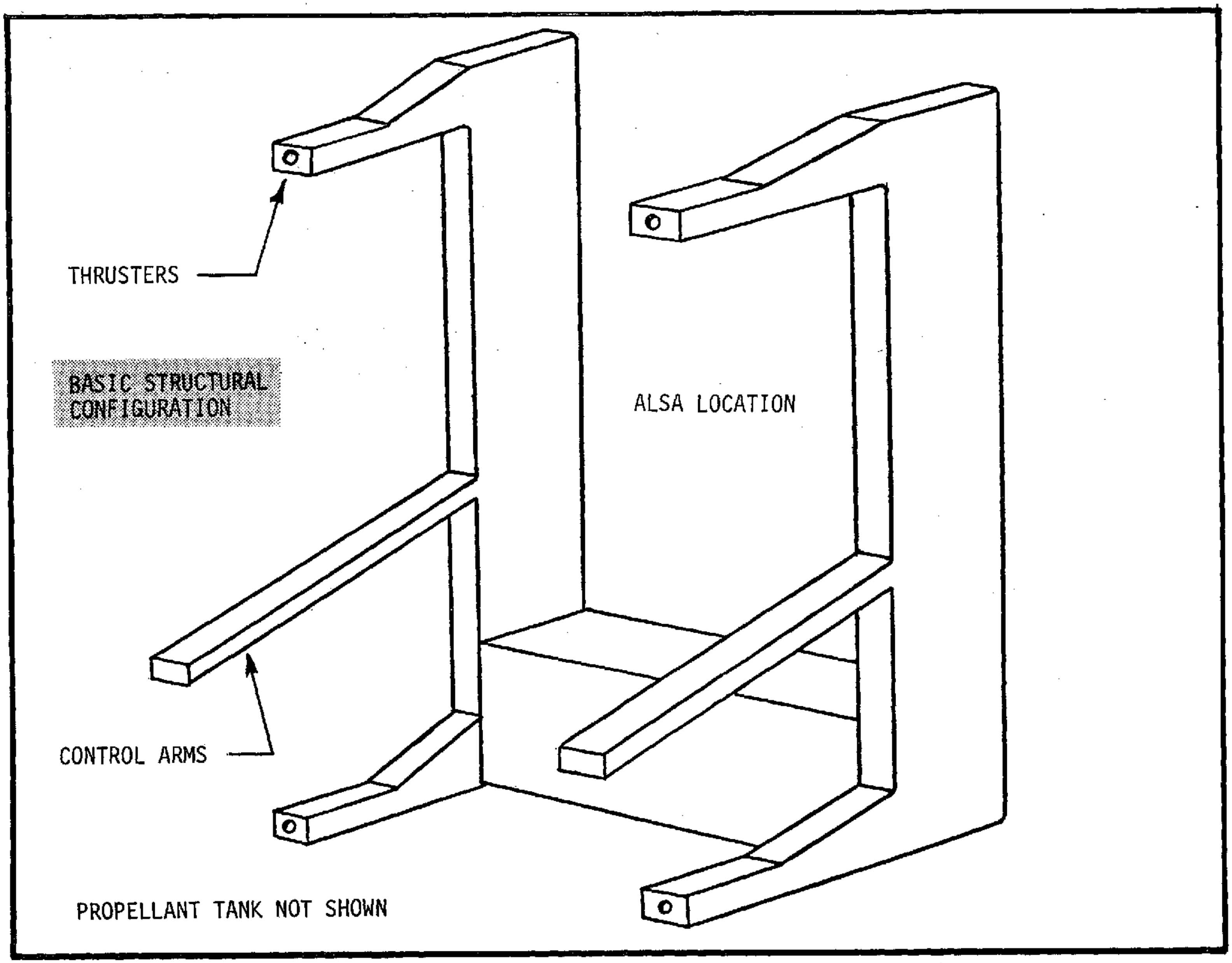


FIGURE 2.6: Basic MMU Configuration for Study Analysis

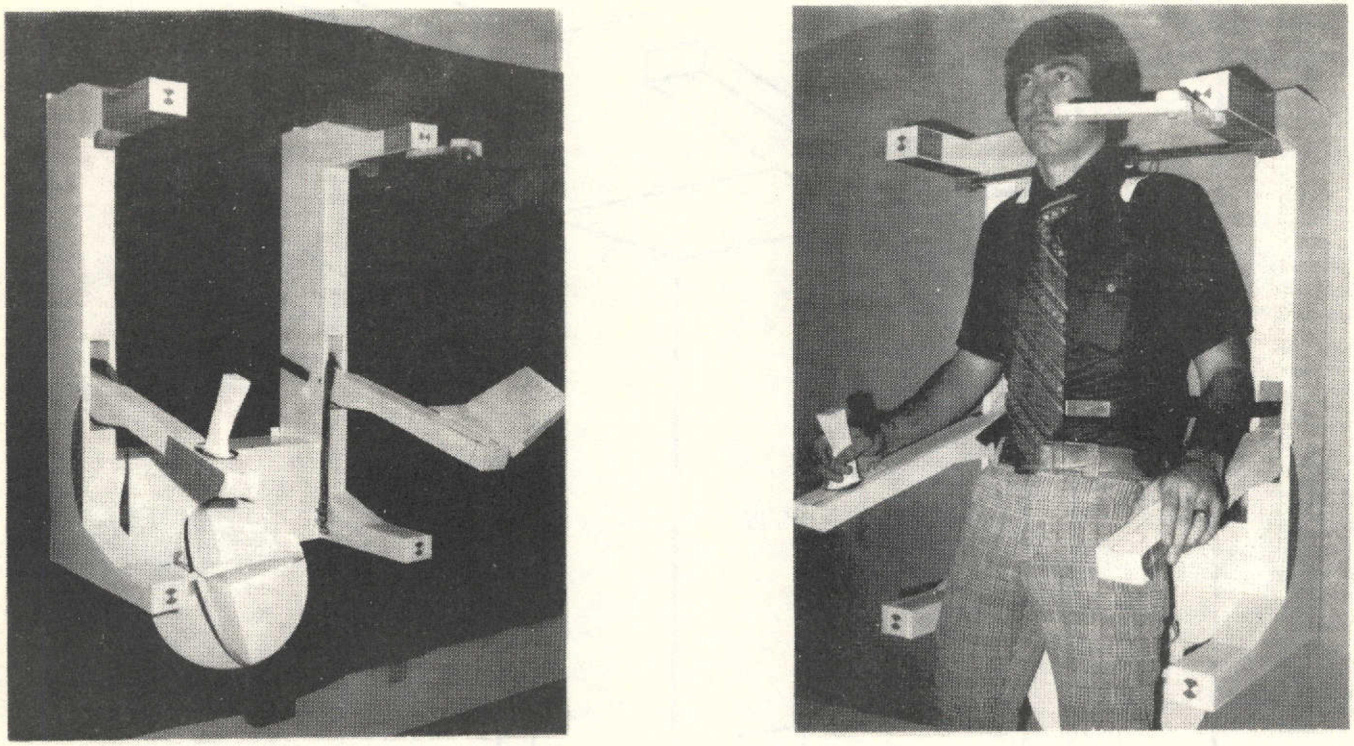


FIGURE 2.7: MMU Soft Mockup--Used for Reach and Visibility Studies

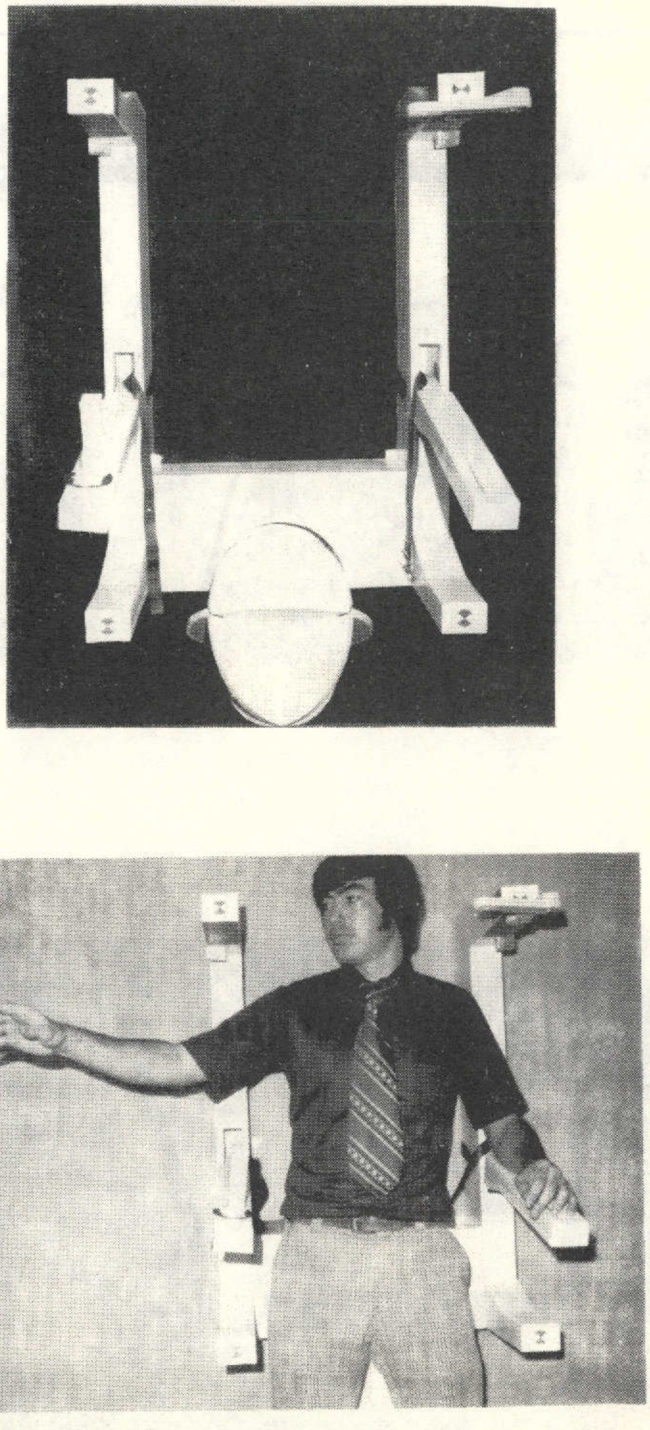


FIGURE 2.8: MMU Soft Mockup--Front Views

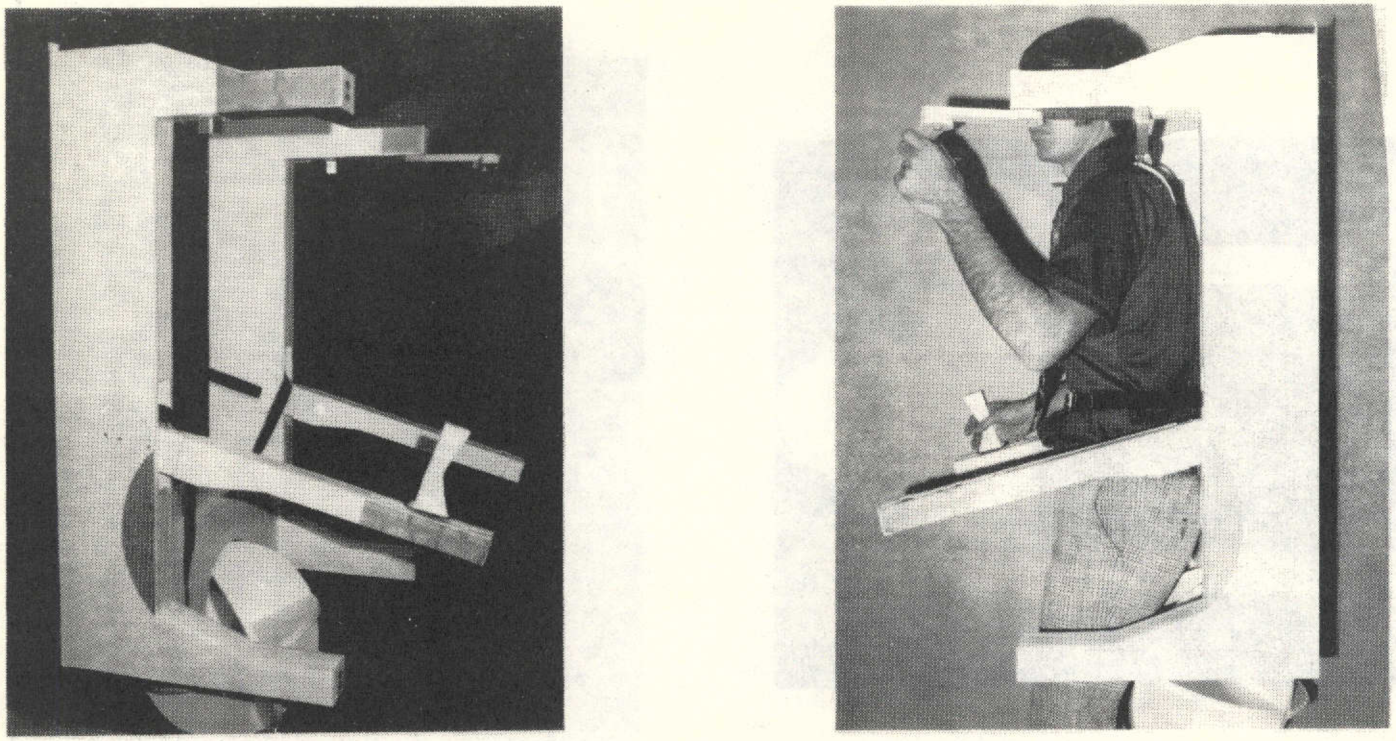
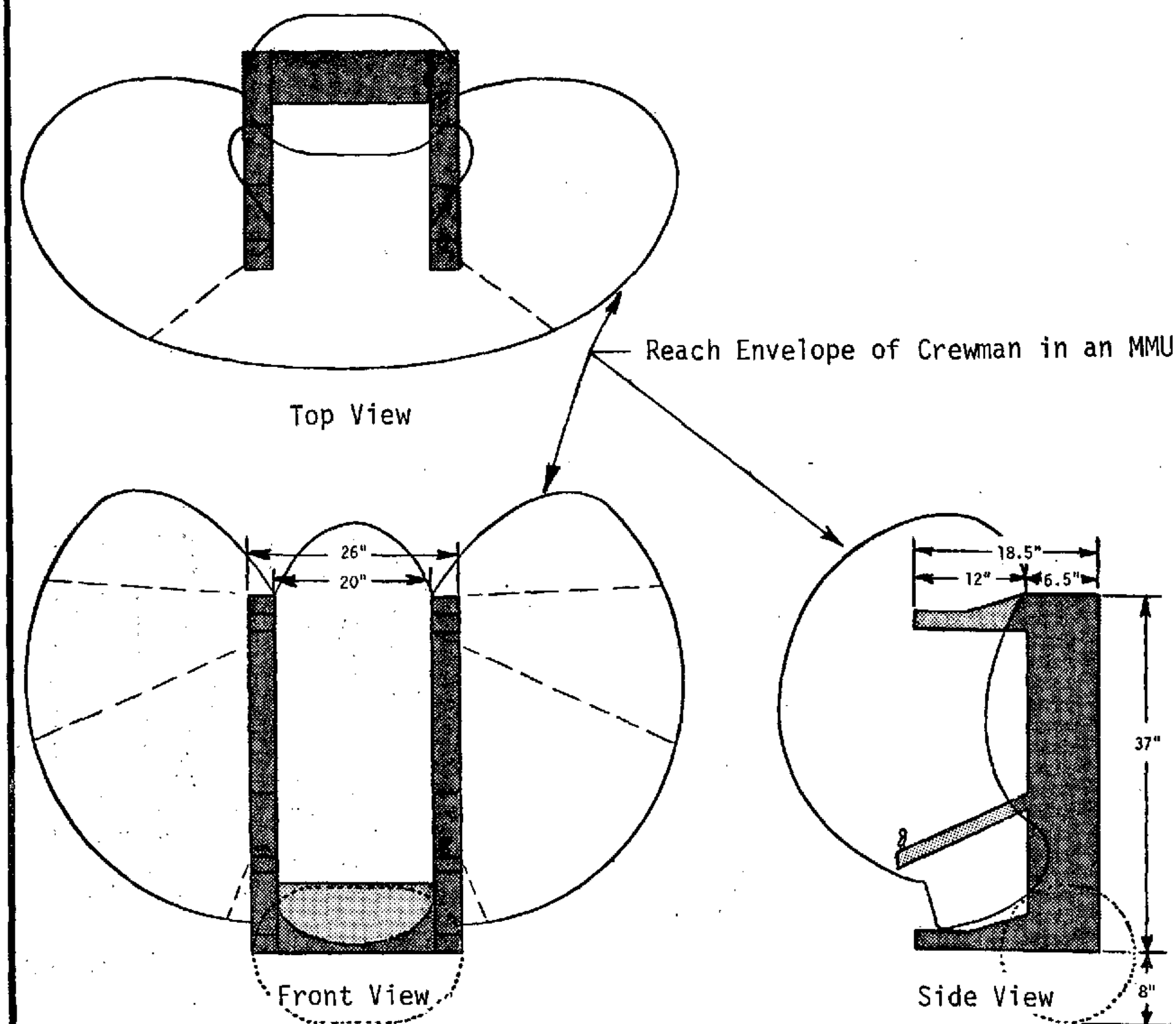
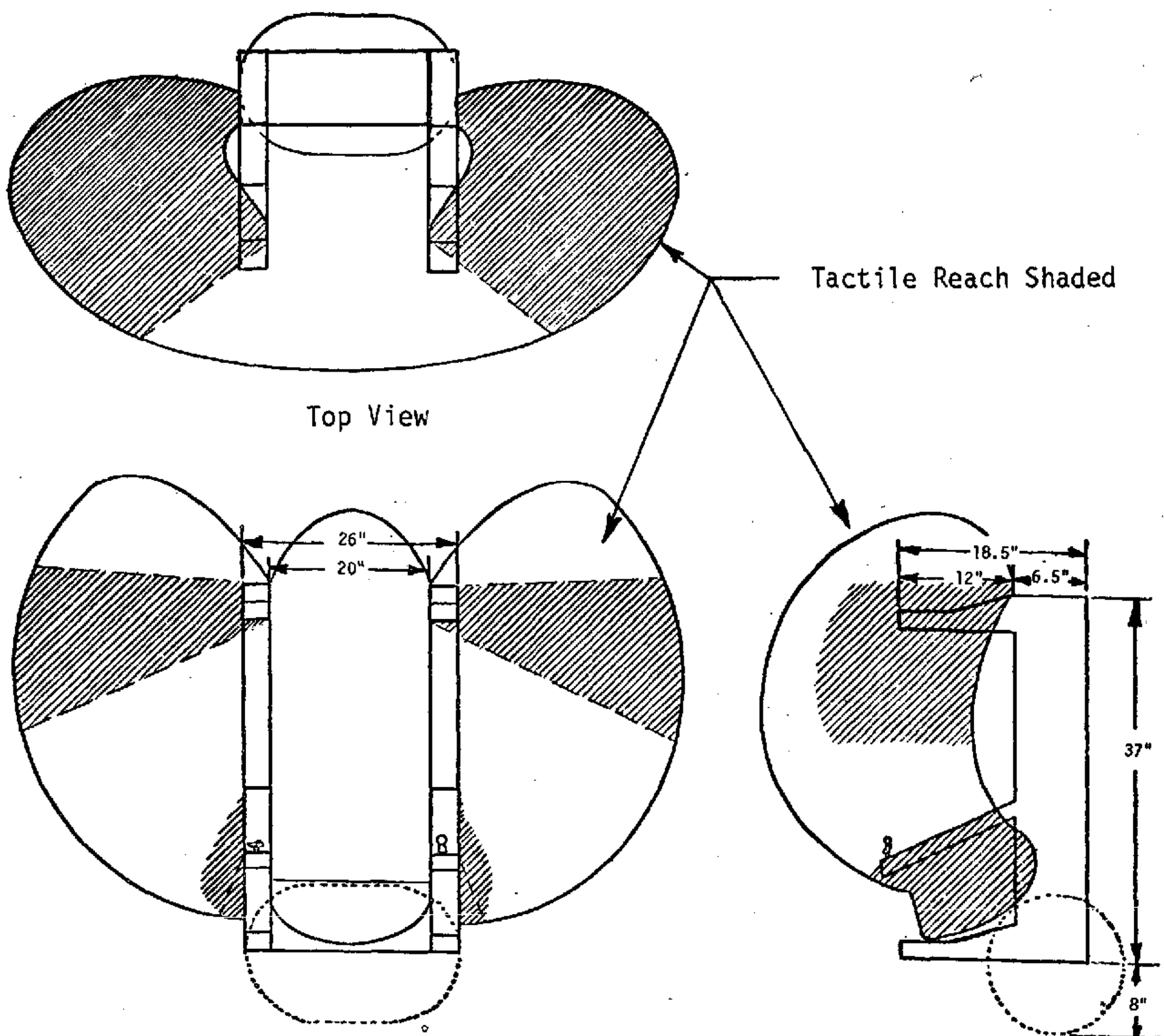


FIGURE 2.9: MMU Soft Mockup--Side Views



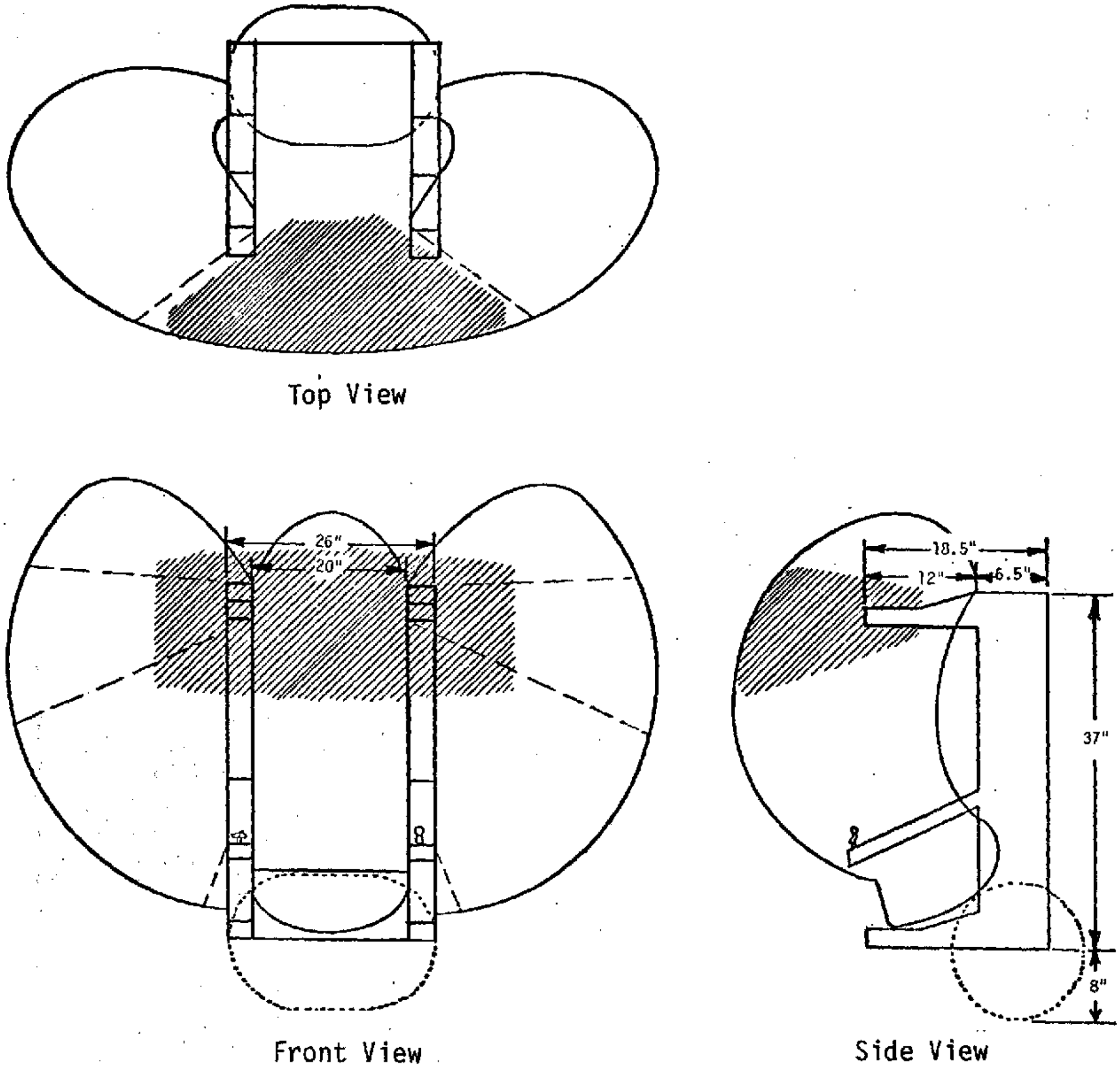
The above sketch illustrates the reach envelope determined from preliminary shirtsleeve studies using spacesuit-experienced subjects and representative mockups. With limited MMU configuration information, it was not possible to determine exact quantitative reach envelope data. However, the "relative" reach information was considered sufficient to determine general locations for attaching controls, ancillary equipment and MMU stowage/restraint devices. The envelope shown represents the maximum reach to perform useful hand operations.

FIGURE 2.10: Crewman-MMU Preliminary Reach Envelope



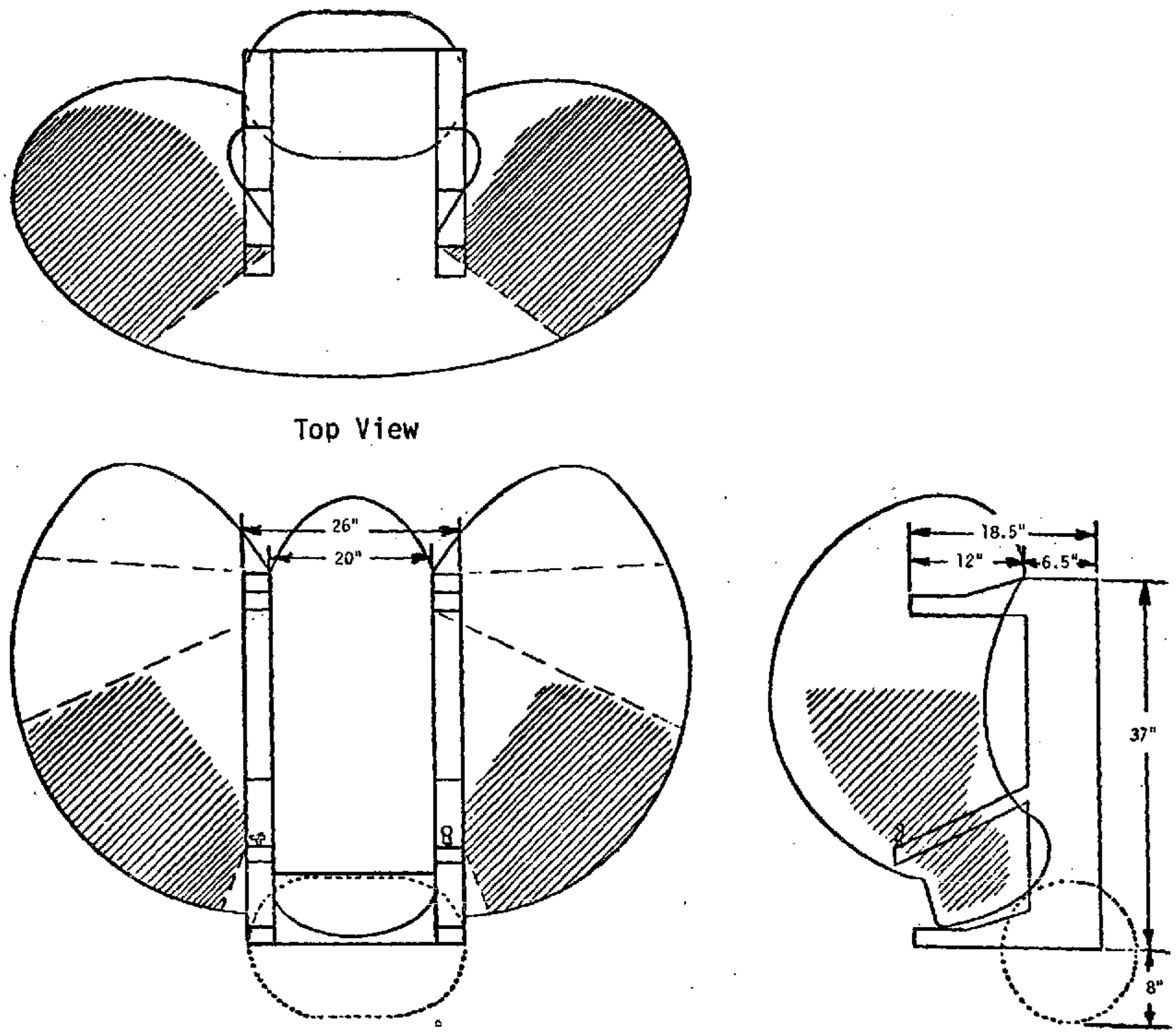
The shaded areas on the sketch depict the "blind spots" within the crewman's reach envelope using the quasi MMU mockup. The mechanisms located within these areas should be designed to be operated using tactile cues or indirect (mirror) visual aids only. The unitized mounting arrangement between the MMU structure and the crewman provides no relative motion for improving access. The envelope shown represents the maximum reach required to perform useful functions using the tactile sense only.

FIGURE 2.11: Crewman-MMU Tactile Reach Envelope



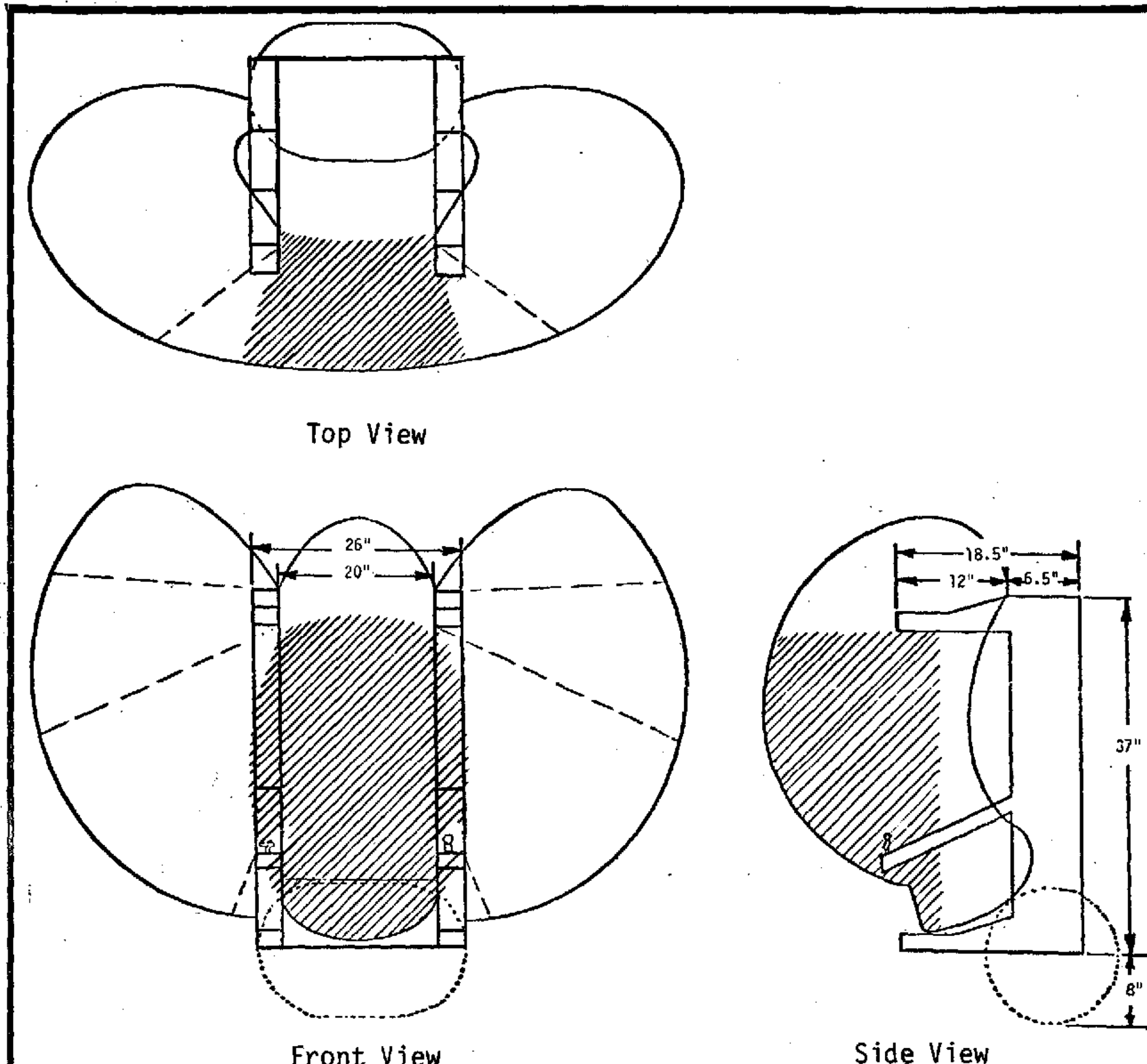
The shaded areas in the sketch above depict locations recommended for mounting support hardware requiring a direct (eye-to-hardware) visual interface (e.g., cameras, navigation equipment). The support hardware should either be located within the shaded areas or designed to be manipulated into the areas as required. Visual envelope recommendations for control and display locations are shown in the subsequent sketch.

FIGURE 2.12: Crewman-MMU Direct Visual Equipment Recommended Locations



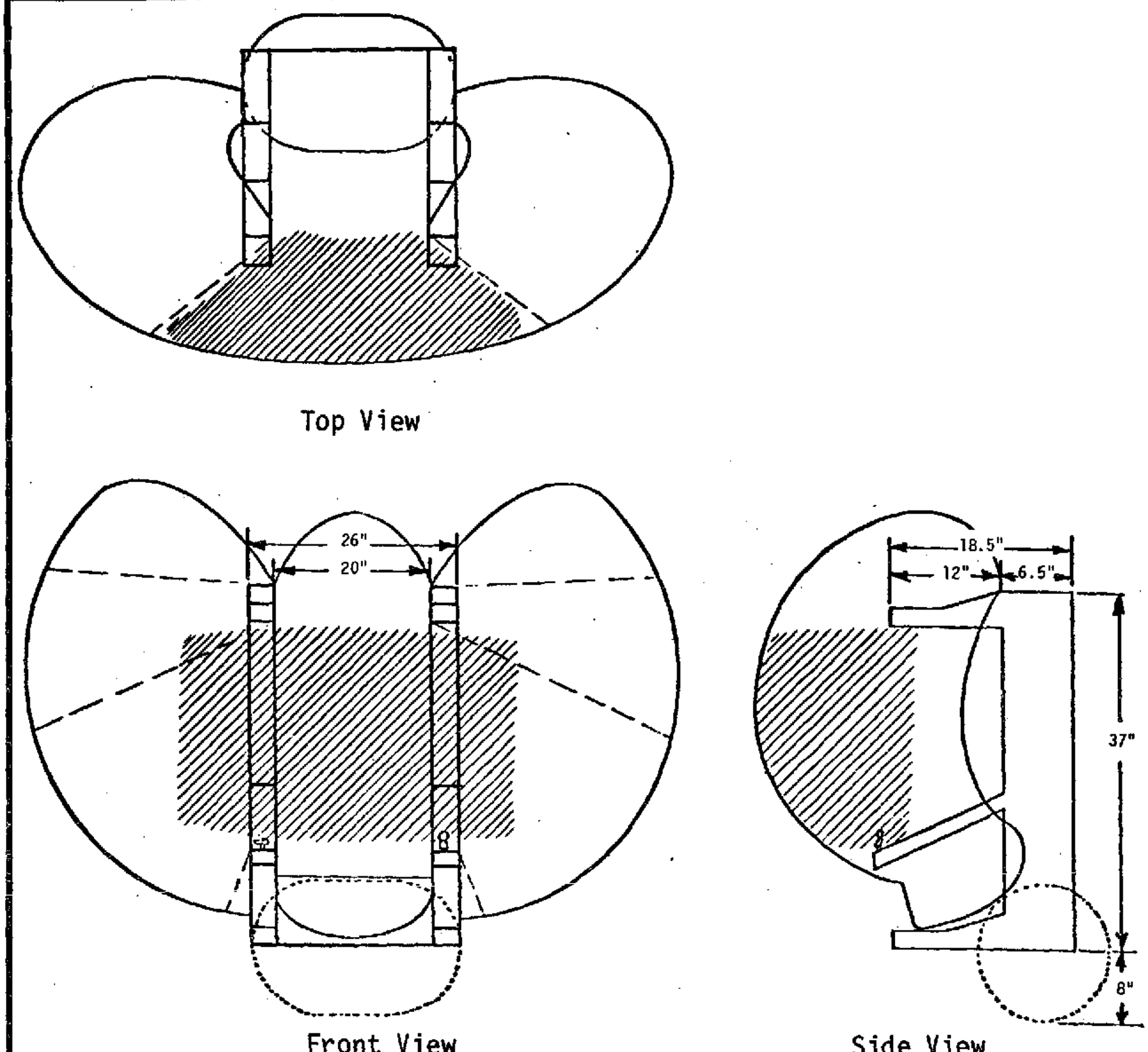
The shaded portion of the accompanying sketch illustrates the suggested areas for locating maneuvering unit control and display (C/D) panels and worksite support hardware. The C/D panel will require the crewman's visual capability and manipulative skills during MMU maneuvers. Location of support hardware in these areas allows optimum crewman access to the work area both visually and for manipulative operations. Small cargo items (e.g., portable restraints, repair kits, lights) should be located in these areas to prevent interference with the MMU thrusters and allows unrestricted crewman access.

FIGURE 2.13: Recommended Locations for MMU C/D Panels and Support Hardware



Cargo items such as small free-flying subsatellites, personnel rescue systems and payload replacement modules may be transported by the MMU. Attachment devices for transporting this category of equipment should be located forward of the crewman to position the cargo near the center of gravity and below the crewman's forward line-of-sight. This location will allow two-handed operations by the crewman. Positioning or stabilizing large payloads when the line-of-sight is blocked may best be accomplished by MMU and crewman facing the payload and "backing" the payload by use of mirrors. (Additional study is required in this area.)

FIGURE 2.14: Recommended Location for MMU Cargo Attachment



When the MMU is stationkeeping or restrained at a worksite, the area directly in front and slightly to each side of the unit are obviously the optimum area for performing manipulative tasks. At worksites requiring the MMU to be structurally attached to the site, the workpiece should be located in the shaded area as shown above. When the MMU-crewman combination is stabilized by EVA foot restraints at the worksite, torso movement allows access to a greater area.

FIGURE 2.15: Recommended Locations for MMU Positioning Relative To Worksites

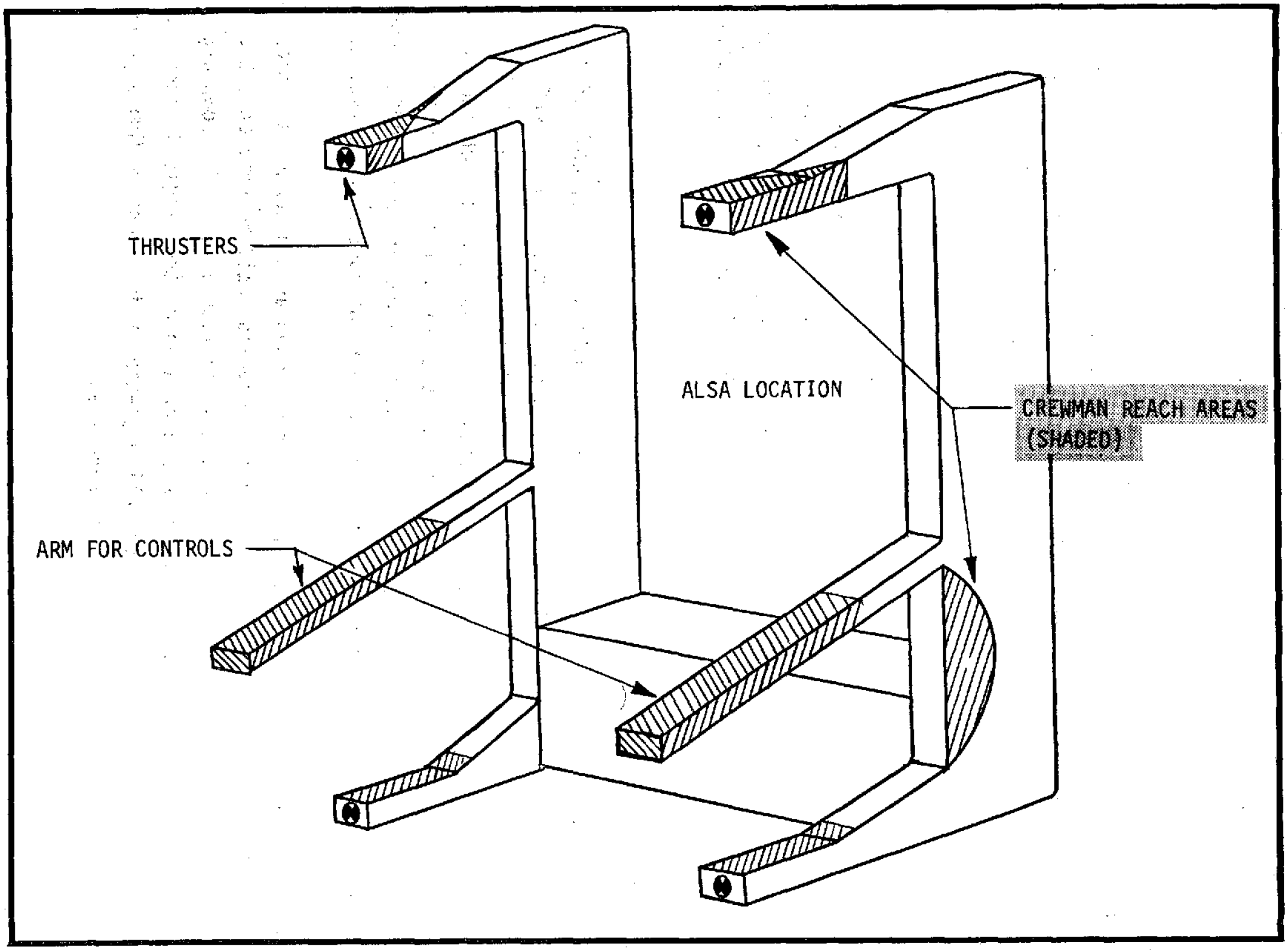


FIGURE 2.16: Crewman Reach and Visibility--Basic MMU Configuration

however, equipment may protrude into areas adjacent to the control arms. The adjacent areas can easily be reached by the crewman.

Visibility of the MMU structural areas that can be reached is limited. The areas below the control arm mounting points and the areas on the forward ends are completely out of view. Areas on the outside surfaces of the control arms and upper thruster housings are also out of view. Devices located in these areas will require designs based on identification by tactile sense only or provide indirect viewing.

2.2.3 Study Developed Concepts

Two basic MMU configuration concepts were considered in the study--unitary and modular. MMU configuration design was not a part of this study; however, to develop concepts for securing a unit in the payload bay and attaching ancillary equipment, the concepts shown in the following figures were used.

Unitary Designs

The concept shown in Figure 2.17 depicts a single structural unit with the exception of removable control arms for compact stowage. The concept incorporates external configuration features shown in the NASA artist sketches (see Figures 2.4 and 2.5). A control arm adjustment and removal technique is shown in Figure 2.18. The control arm telescopes to allow for crewman arm length variations, pivots about the attach point for lower arm positioning, and also pivots at the hand-controller interface for optimum control orientation.

The concept provided in Figure 2.19 features modular MMU controls integrated into the lower thruster housings. The control modules would be removable and designed with a "downward-swept" arm-hand access configuration. The downward-swept configuration would be limited to avoid crewman control logic disturbance. The configuration in Figure 2.19 would allow greater side access to MMU support equipment and front access to cargo and worksites.

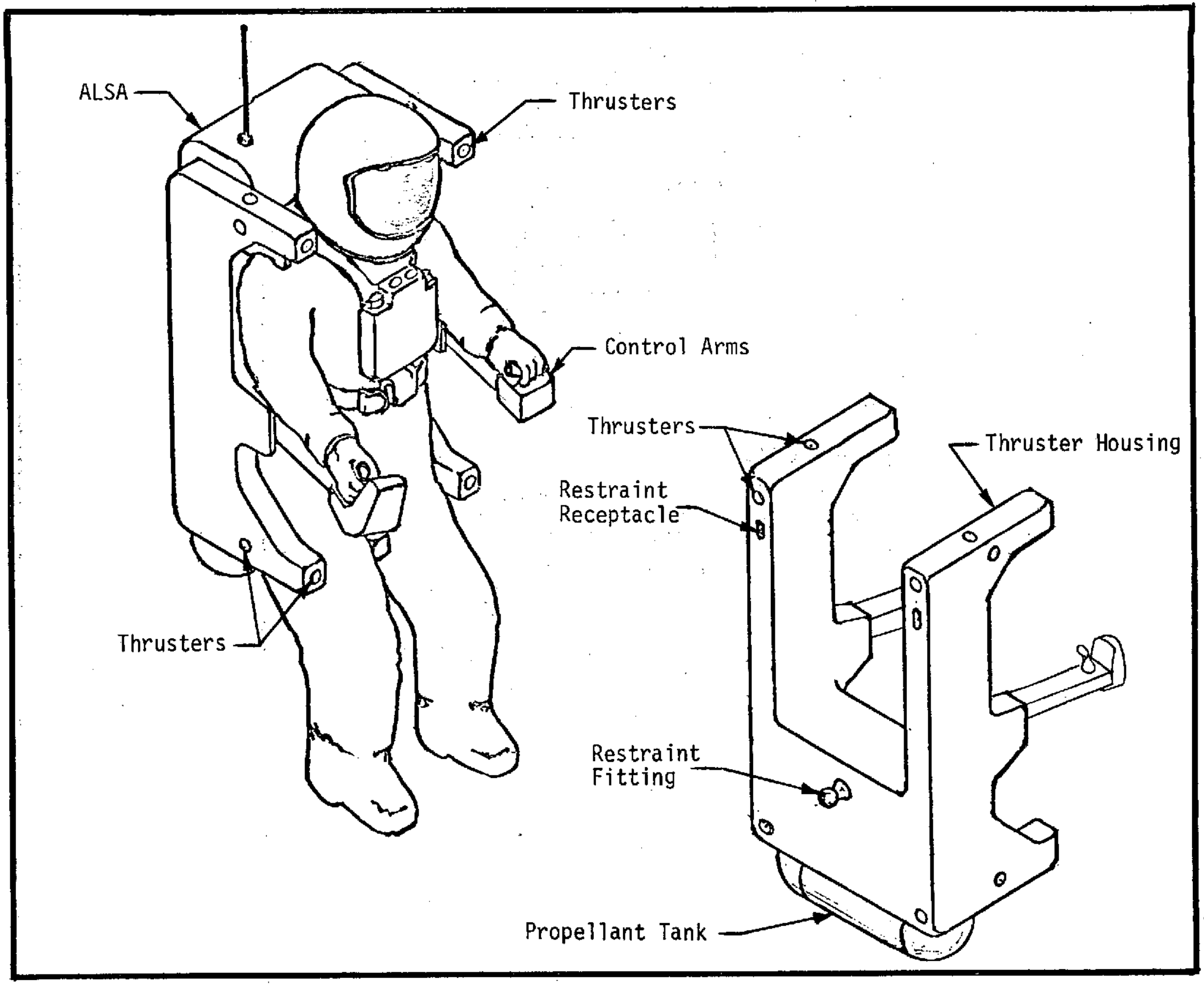


FIGURE 2.17: MMU Configuration Concept--Unitized Design
with Removable Control Arms

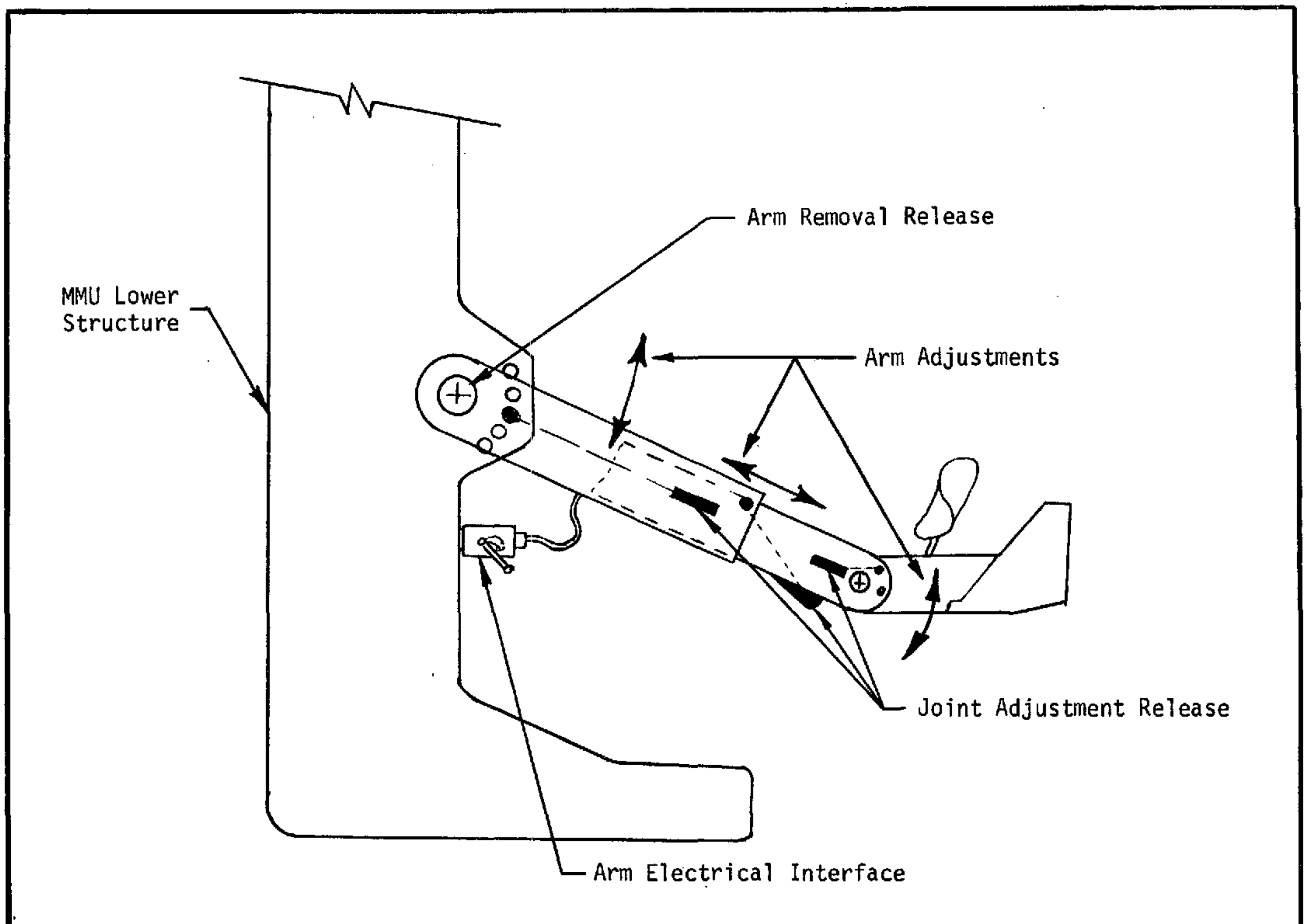


FIGURE 2.18: MMU Control Arm Adjustment Concept

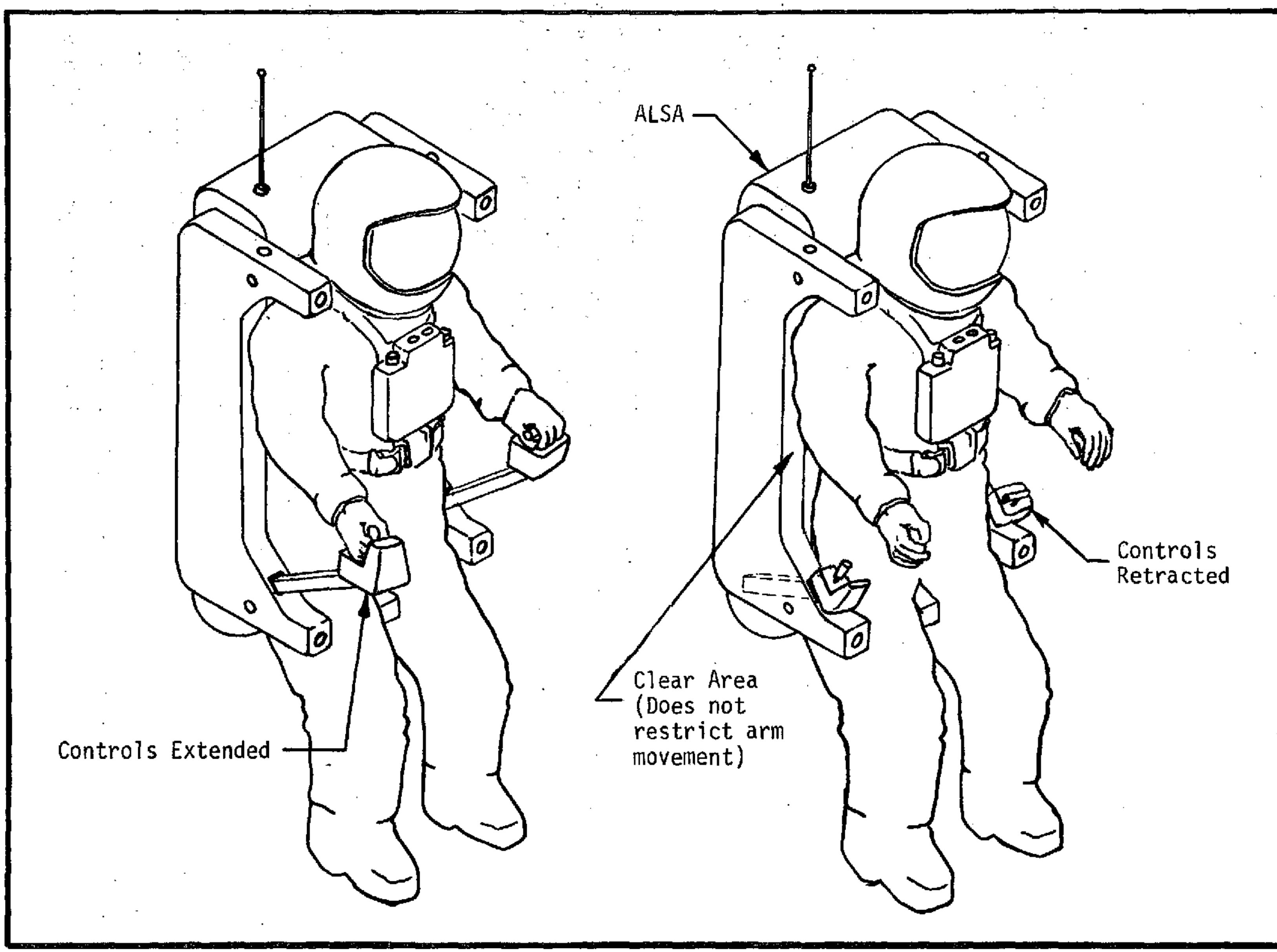


FIGURE 2.19: MMU Configuration Concept--Unitized Design With Integrated Controls

The units are secured to the crewman by a flexible strap system and supplementary restraints as shown in Figures 2.20 and 2.21 (assumes non-integrated EMU concepts). The concept shown in Figure 2.20 assists in restraining the crewman through inflatable contoured shoulder pads and a contoured seat arrangement. The seat provides major adjustments for different percentile crewmen by positioning the device prior to donning the MMU. The inflatable pads are activated by the crewman to the required force. The flexible strap system (perhaps a single strap) is attached to the MMU (see Figure 2.20) and the portable life support system connected to the MMU with mechanical fasteners (crewman releasable).

Figure 2.21 shows a passive supplementary crew restraint system. The passive elements in Figure 2.21 are shown as pneumatic or fluid filled units located at the shoulders. The contoured seat is adjusted by the crewman through a mechanical system to the desired tension. The flexible strap system as in the previous concept would be used.

The inflatable or passive bag units in the above concepts may be replaced with retractable/adjustable rigid units (concept not shown) or the MMU thruster structure in the shoulder area contoured and padded to interface with the space-suit. If an integrated EMU system is developed, the candidate MMU-to-crewman attachment may be a rigid mechanical system between the PLSS and the MMU.

Modular Design

An MMU conceptual modular design is shown in Figure 2.22. The unit features quick disconnects with backup locking characteristics on all removable components. The contoured seat folds for stowage. The control and display (C/D) panel is located on the left control arm and is removable. All units except the C/D panel and the propellant tank may stow in the life support system space during launch as shown in the Figure 2.22 inset. The forward thruster structures may be configured as a relatively simple insulated tube or designed to provide supplementary crew restraint as shown in earlier restraint concepts (Figures 2.20 and 2.21).

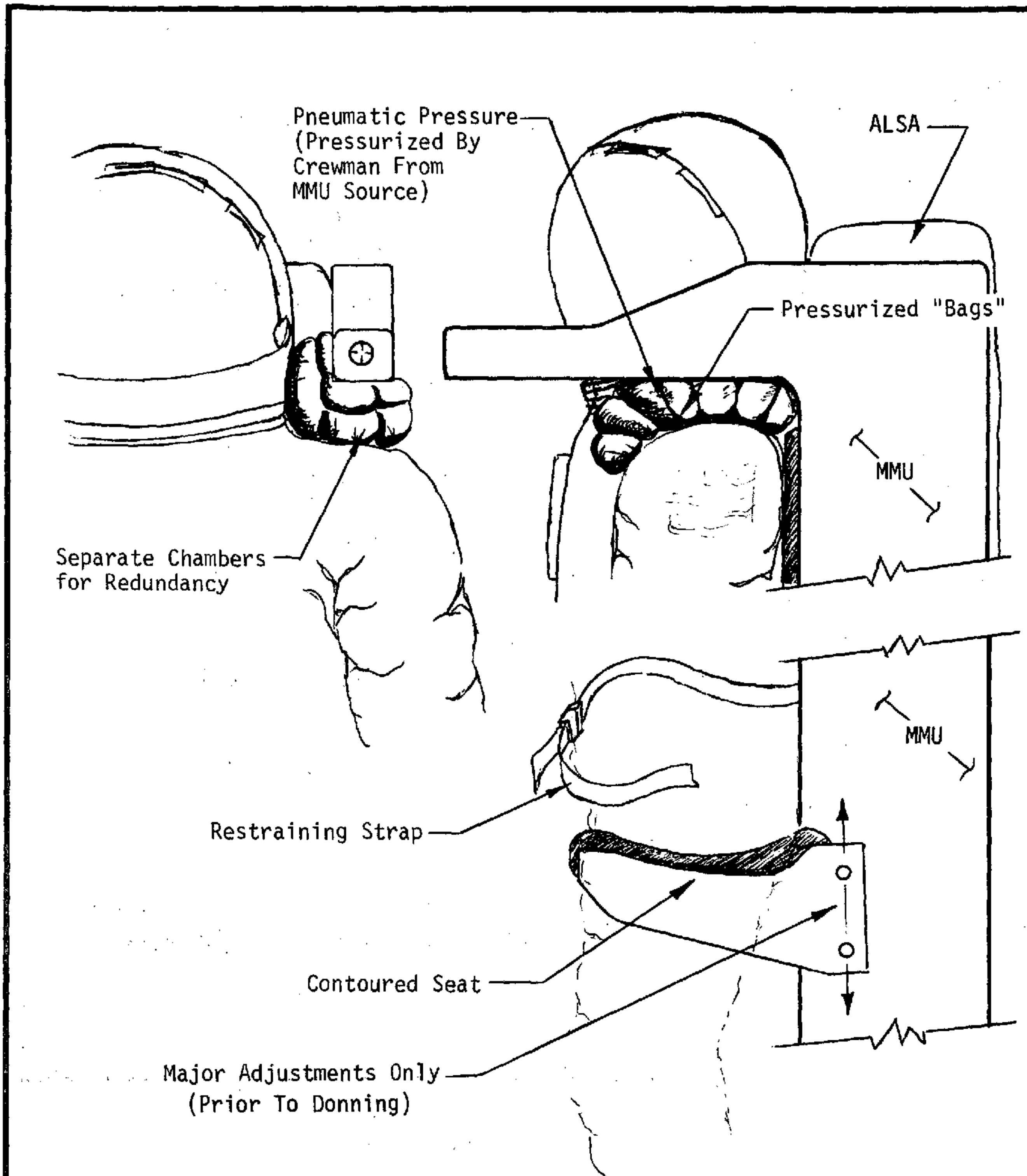


FIGURE 2.20: MMU Supplementary Crew Restraint--Concept 1

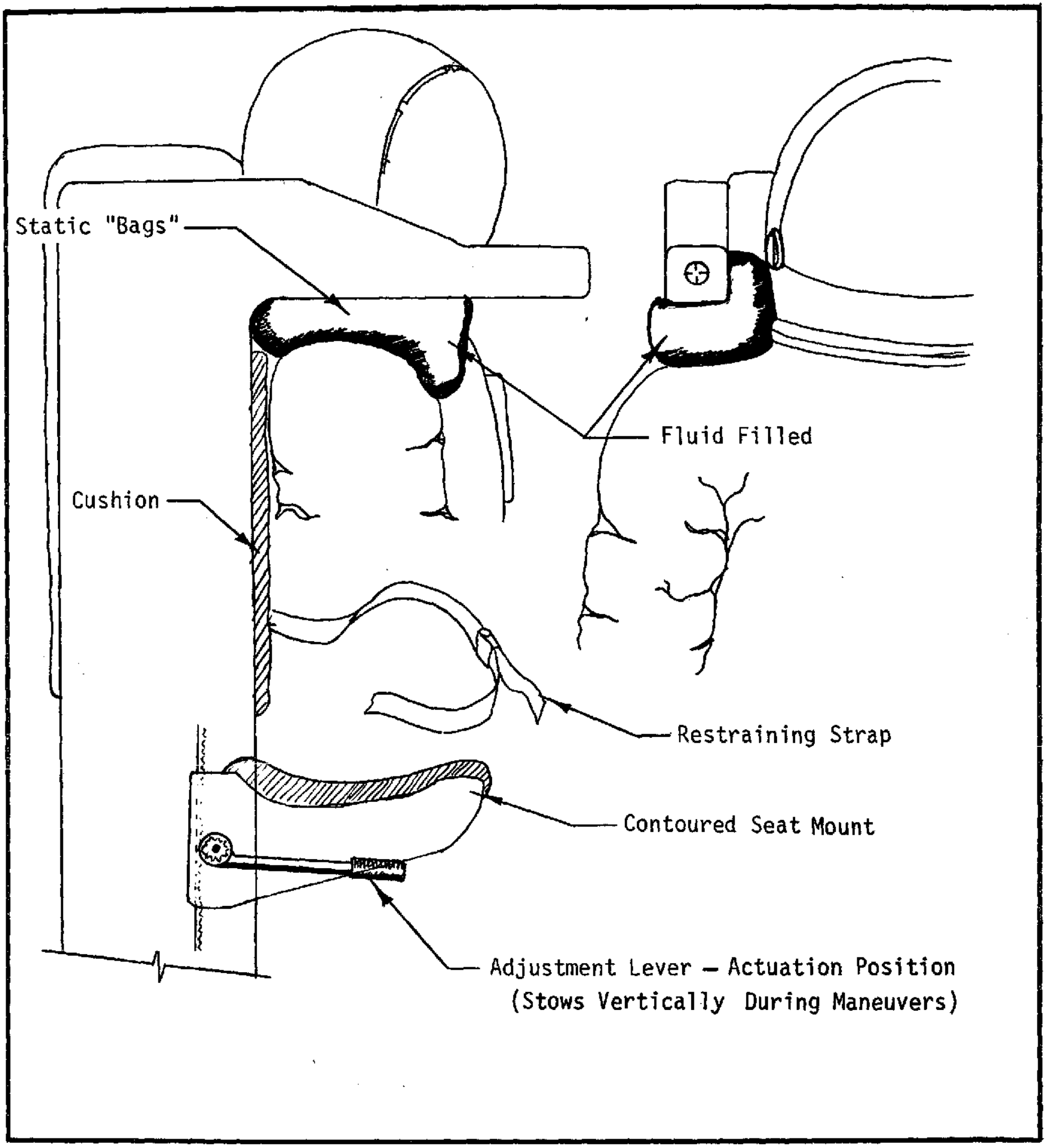


FIGURE 2.21: MMU Supplementary Crew Restraint--Concept 2

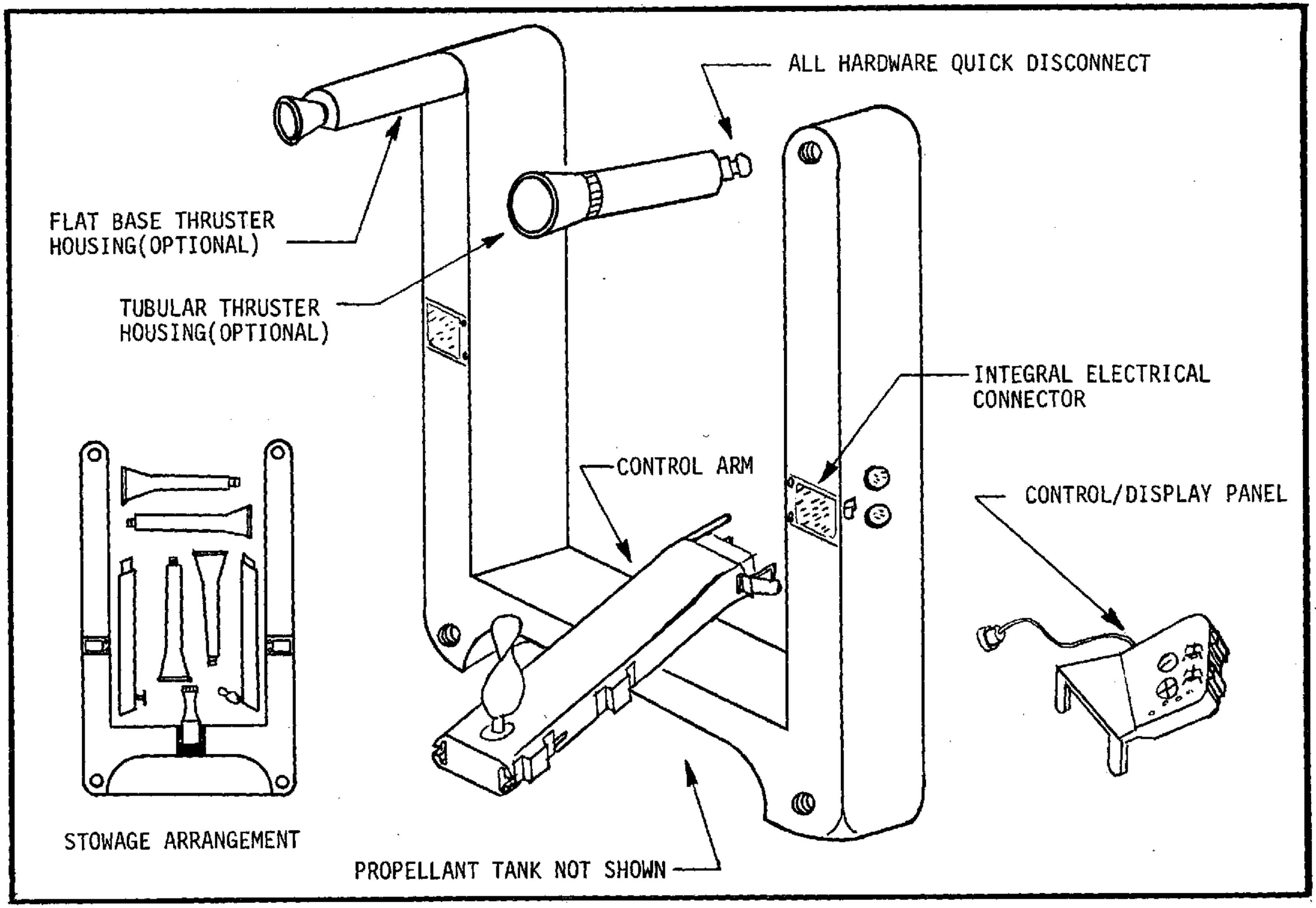


FIGURE 2.22: MMU Configuration Concept--Modular Design

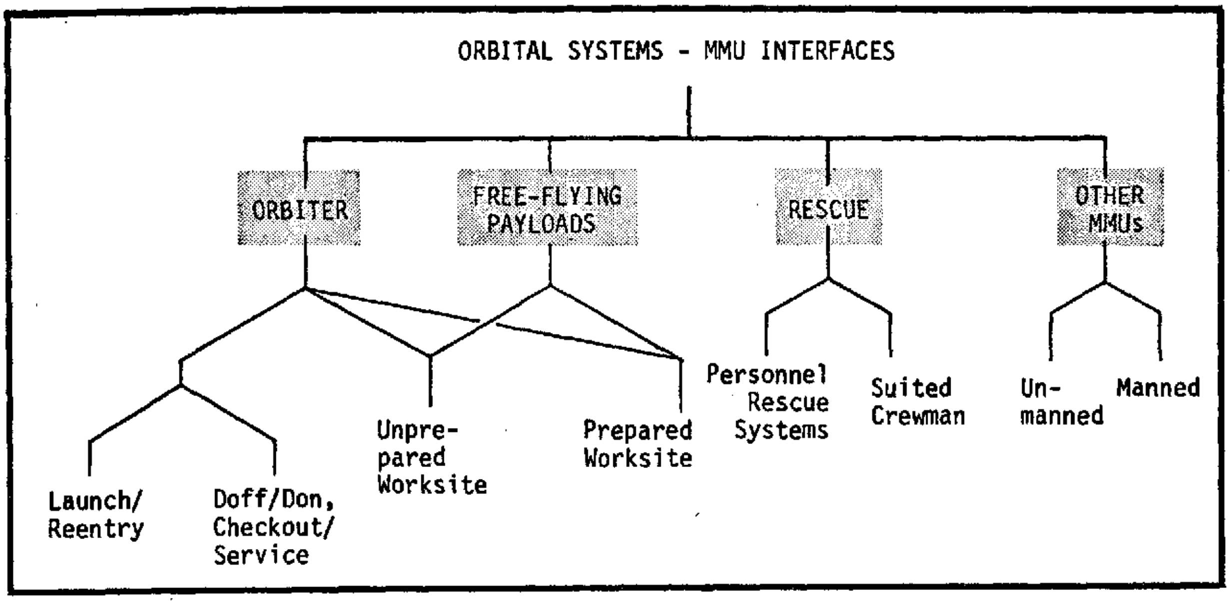
3.0 MMU ANCILLARY SUBSYSTEM CONCEPTS

Section 3.0 contains the MMU ancillary subsystem concepts developed as part of the Manned Maneuvering Unit Mission Definition Study. The attachment and stabilization of the MMU-crewman combination to various orbital systems will be the major factor in efficiently performing EVA tasks. Subsection 3.1 presents concepts for attaching and securing the MMU and the MMU-crewman combination to the vehicle and payload structural configurations. The interfaces addressed include the MMU to the Shuttle payload bay (launch, service, reentry); to prepared and unprepared worksites on the Orbiter and free-flying satellites; to the proposed personnel rescue system (PRS); to crewmen in EMU (Extravehicular Mobility Unit) gear; and to another MMU for on-orbit rescue support.

To provide a versatile MMU-EVA support system for the Shuttle Program, several items of ancillary support equipment attached directly to the MMU will be required. Supporting subsystems, such as module stowage provisions, lighting, cameras, tools, cargo, etc. will require attachments to the MMU to secure the hardware during translation and worksite operations. Subsection 3.2 presents modular, add-on ancillary equipment concepts for interfacing support hardware to the MMU.

3.1 ORBITAL SYSTEMS INTERFACES

Orbital systems that will require an interface with the MMU for performing candidate Shuttle support tasks were identified in the MMU applications analysis phase of this study. The interfaces are graphically illustrated in Figure 1.2 and reproduced on the following page. The chart categorizes the orbital systems into four basic interface areas: Shuttle Orbiter, payloads, rescue systems and another MMU. Since the MMU must be secured for transporting to and from orbit, attachment concepts for use during launch, servicing on-orbit and reentry are presented first--Section 3.1.1. Both fixed and portable MMU restraint concepts are presented.



The methods/techniques for temporarily attaching an MMU to the Orbiter or a free-flying payload for on-orbit servicing operations will be similar and require essentially identical types of attachment devices. The attachment equipment will vary, however, between prepared and unprepared worksites. Prepared worksites are configured prior to launch with interface provisions for accepting EVA support equipment, such as foot restraints, portable workstations, lights, module stowage, etc. Unprepared worksites have no structurally integral provisions for accepting EVA support equipment. The EVA equipment must be attached to the worksite basic structure when EVA is required. Subsection 3.1.2 is a compilation of the major concepts developed for interfacing an MMU-crewman to a worksite, including both prepared and unprepared worksites.

Subsection 3.1.3 presents the concepts developed for interfacing an MMU to personnel in a rescue configuration (e.g., PRS, spacesuit) and an MMU to another MMU for supporting rescue operations.

3.1.1 MMU Restraint Systems

This subsection provides concepts for restraining the MMU for launch, servicing, reentry and on-orbit donning/doffing activities. The concepts depict attachment fixtures that may either be fabricated integral to the Orbiter and payloads or designed as a "bolt-on" unit. The bolt-on MMU attachment fixture would be attached at a specified location prior to launch.

The first concept (Figure 3.1) satisfies MMU launch/reentry restraint requirements by using overcenter latching mechanisms, attached to each side of the MMU, and three fixed pins. The overcenter locking and alignment guides device serve to initially restrain the MMU to allow final alignment of the three primary load bearing pins. After alignment, the overcenter lock secures the MMU to the launch/reentry interface. A lock-lock device is incorporated into the overcenter locking system to ensure positive latching. Actuation of the overcenter latching mechanism is a pulling motion which aids in stabilizing the crewman during on-orbit MMU restowage. Pushing the overcenter latching device releases the locking mechanism and aids in departing the MMU stowage area when the unit is donned. Flexible guides assist the crewman in aligning the unit for doffing, and handrails provide the necessary aids for ingress/egress of the foot restraints. Both the handrails and foot restraints fold when not in use.

Figure 3.2 presents a concept similar to the overcenter latching arrangement for restraining the MMU during launch, servicing, reentry and don/doff activities. The concept utilizes a ball and socket system and two fixed pins. The ball unit and the fixed pins are load bearing members. The ball interface and the alignment guides temporarily restrain the MMU on initial contact. The MMU is firmly secured to the stowage location by actuating a latching handle. The active latching mechanisms depicted in Figures 3.1 and 3.2 are located on the MMU mounting interface. The MMU contains only the passive portion of the connecting mechanisms. Similar alignment and restraint ingress/egress provisions are included for the ball and socket attachment concept as shown in the previous illustration.

Figure 3.3 provides a concept in which the active latching mechanisms are integrated into the MMU structure. The passive side of the connectors are attached to the MMU stowage interface and the crewman's portable life support system.

The latching arrangement is designed to accommodate MMU stowage and also attachment to the crewman via the EMU system. The attachment mechanisms may

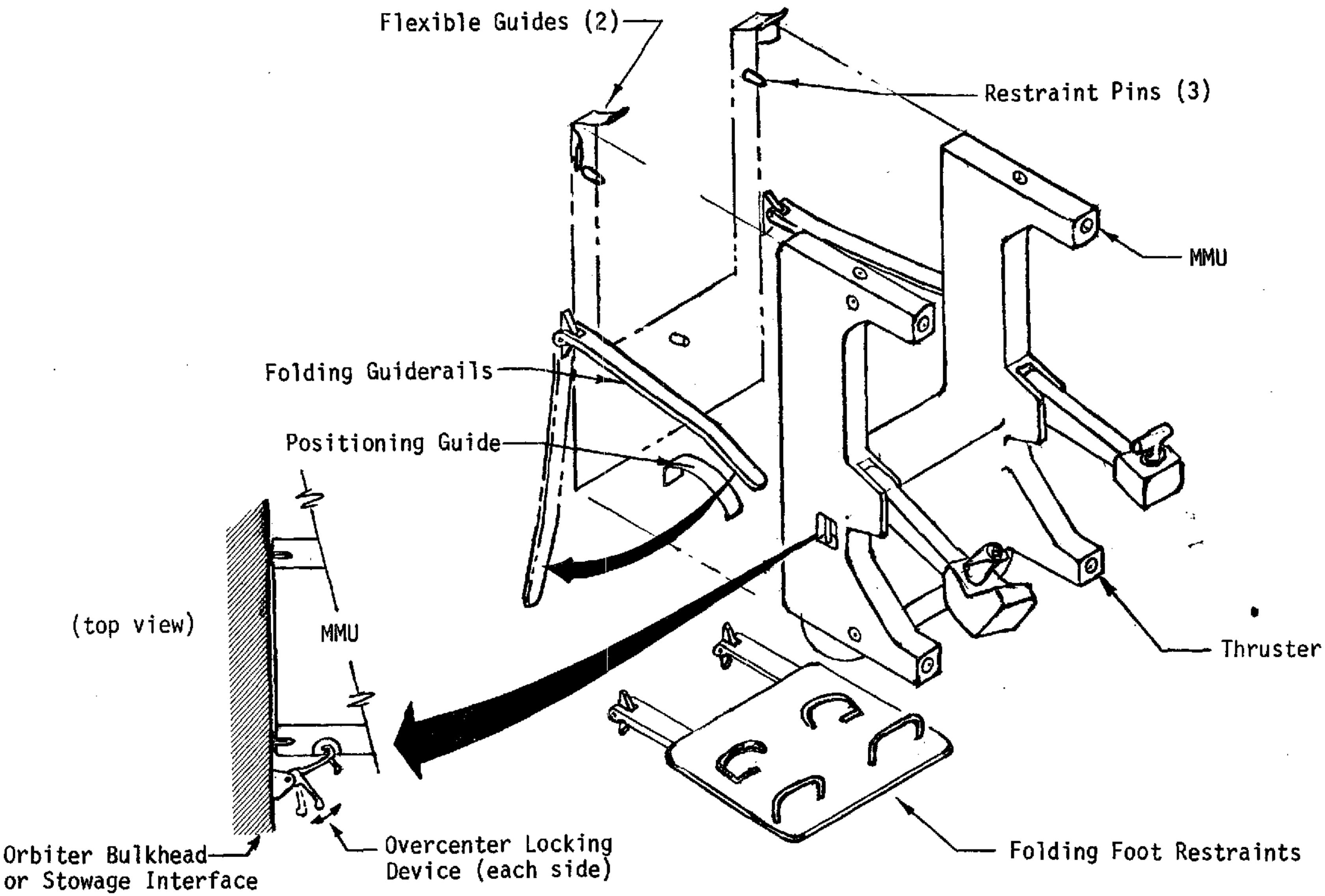


FIGURE 3.1: MMU-to-Orbiter Interface--Launch, Reentry and Servicing Restraint
(Overcenter Side Locks and Pins)

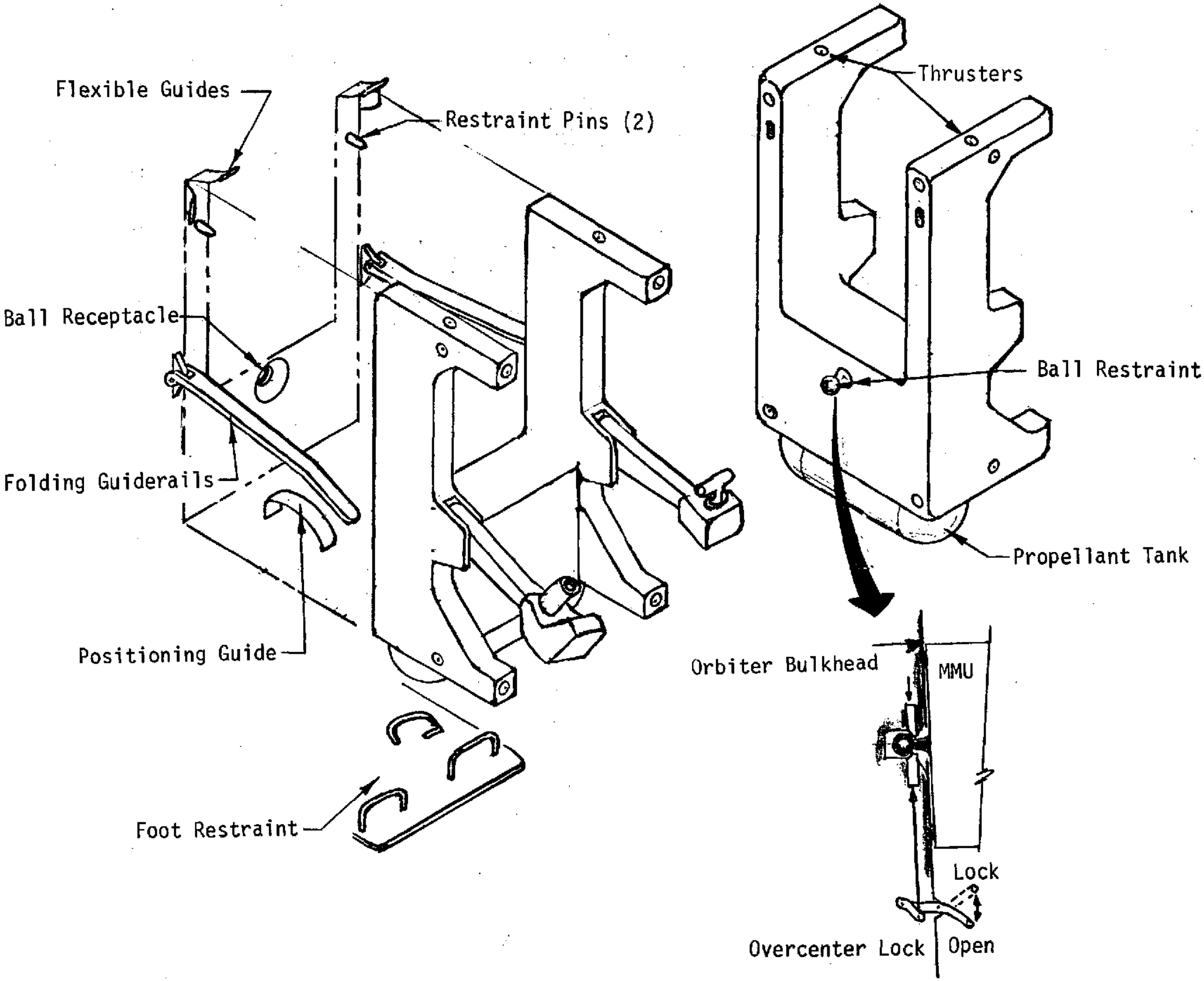


FIGURE 3.2: MMU-to-Orbiter Interface--Launch, Reentry and Servicing Restraint (Ball and Socket Plus Pins)

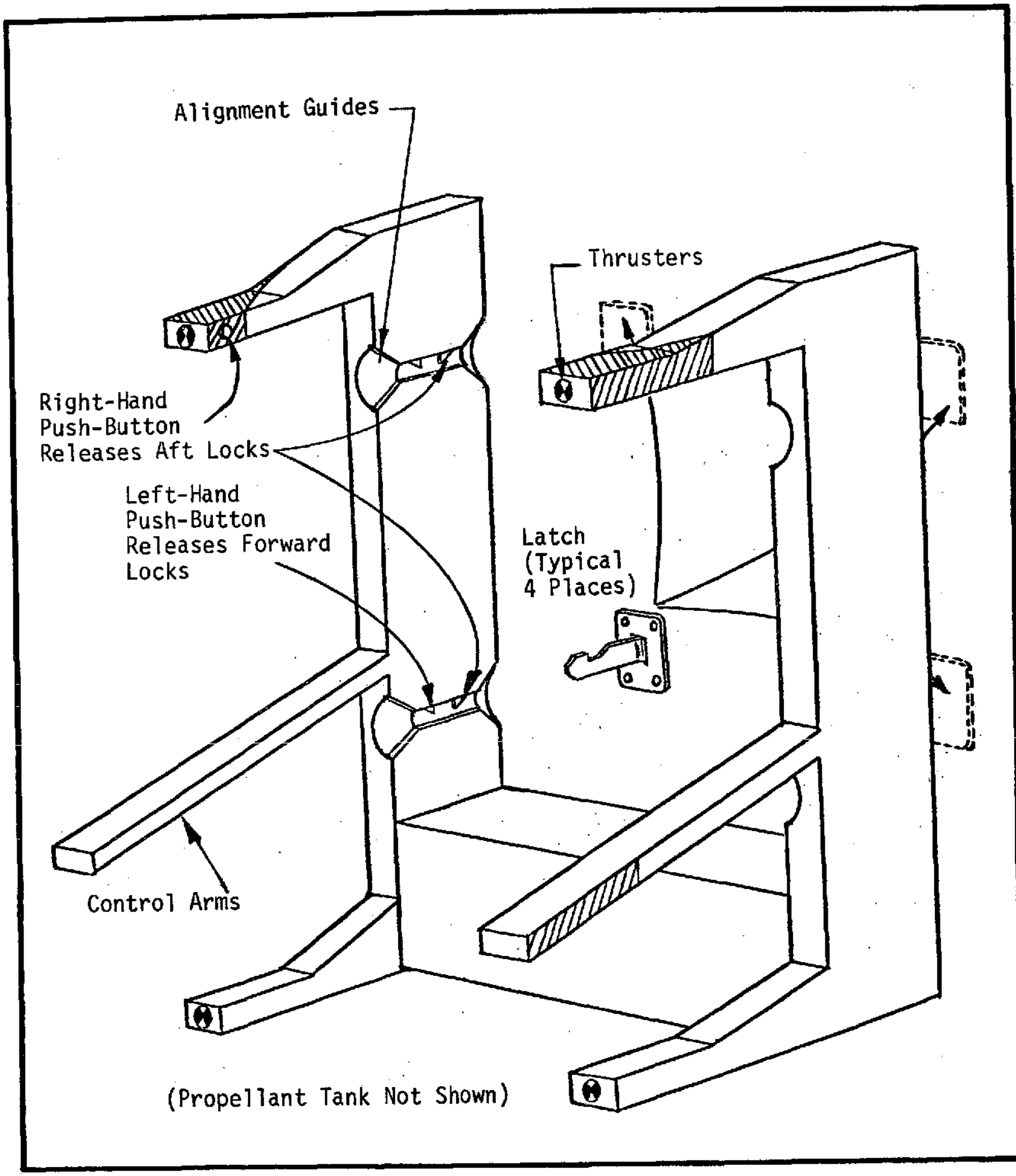


FIGURE 3.3: MMU-to-ALSA and Orbiter Restraint Attachment Concept (Slider-Type Interfaces)

be slider-type devices with a mechanical push-button or lever-linkage release system actuated by the crewman while in the unit. Solenoid actuated latching mechanisms with mechanical backup were also considered. The final alignment guides are integral to the MMU with gross alignment provided by handrails and foot restraints as shown in Figure 3.4. The handrails provide guides for the crewman when donning the MMU (crewman in EMU configuration) or restowing the MMU after an EVA mission. To don the MMU the crewman would back into the stowage station using the ingress aids (handrails) and ingress the foot restraints. Mirrors would be provided to aid final alignment for both MMU-to-crewman attachment and MMU stowing.

Depending on the final external configuration of the Space Shuttle MMU, numerous alignment aids of varying configuration can be provided to assist in donning and stowing the MMU on-orbit. The concepts shown in Figures 3.1 and 3.2 indicate flexible (semi-rigid) guides for alignment of the upper portion of the MMU and a ramp to contact the propellant tank for "tactile" assistance. All MMU ingress and stowage aids shown in the concepts fold or retract when not in use.

The numerous payload/experiment arrangements in the Orbiter payload may necessitate affixing the MMU at various locations on the Orbiter or payloads. Figure 3.5 depicts a bolt-on MMU interface fixture concept. The fixture may be attached at any desired location that provides sufficient structural support for MMU launch and reentry.

The preceding concepts have combined MMU restraint systems for launch and reentry with those used in servicing and donning the units while in orbit. It may be desirable to provide separate systems for these functions. The temporary on-orbit restraints shown in Figures 3.6 and 3.7 would be used to secure the MMU during servicing and initial checkout operations. Such temporary restraint devices may also be used in conjunction with MMU launch/reentry restraints. The primary launch/reentry restraint system may best be designed such that the release mechanisms are operated prior to donning the MMU. The temporary MMU restraints would then be used during MMU donning and doffing operations. The

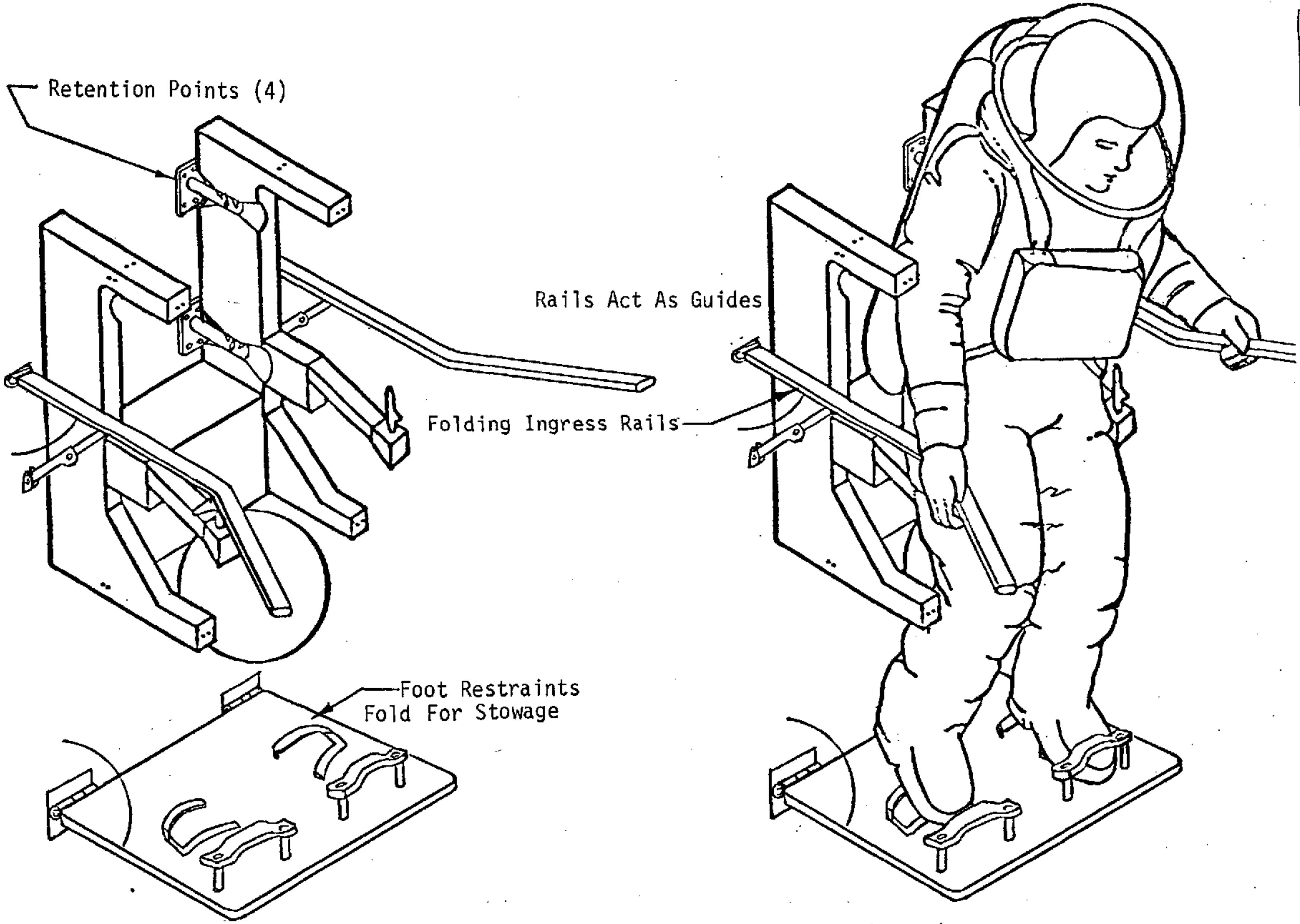
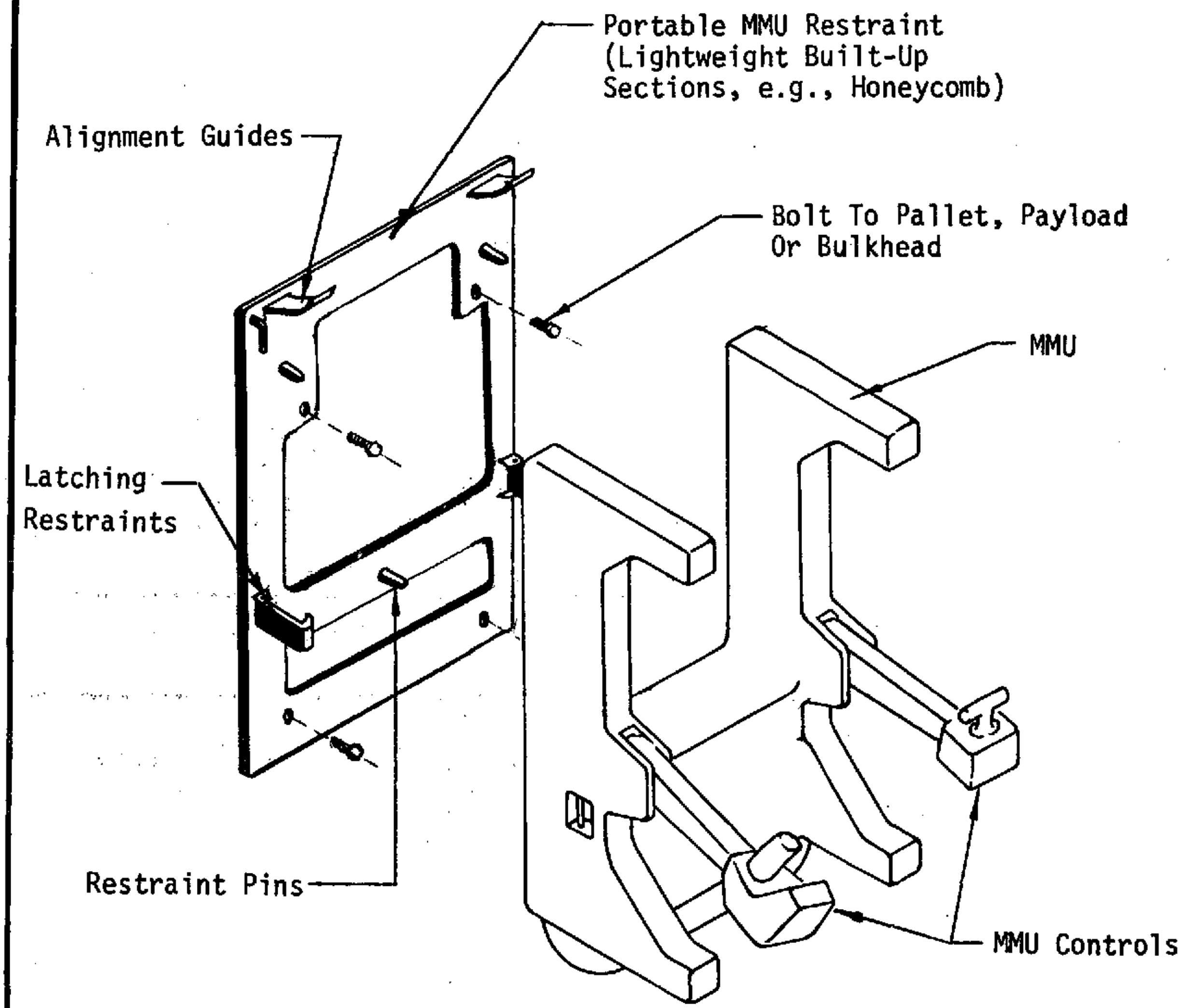


FIGURE 3.4: MMU Donning Station Concept (Fixed)



Note: MMU restraint designed to attach to various Shuttle Orbital elements

FIGURE 3.5: Removable Launch/Reentry MMU Attachment Concept

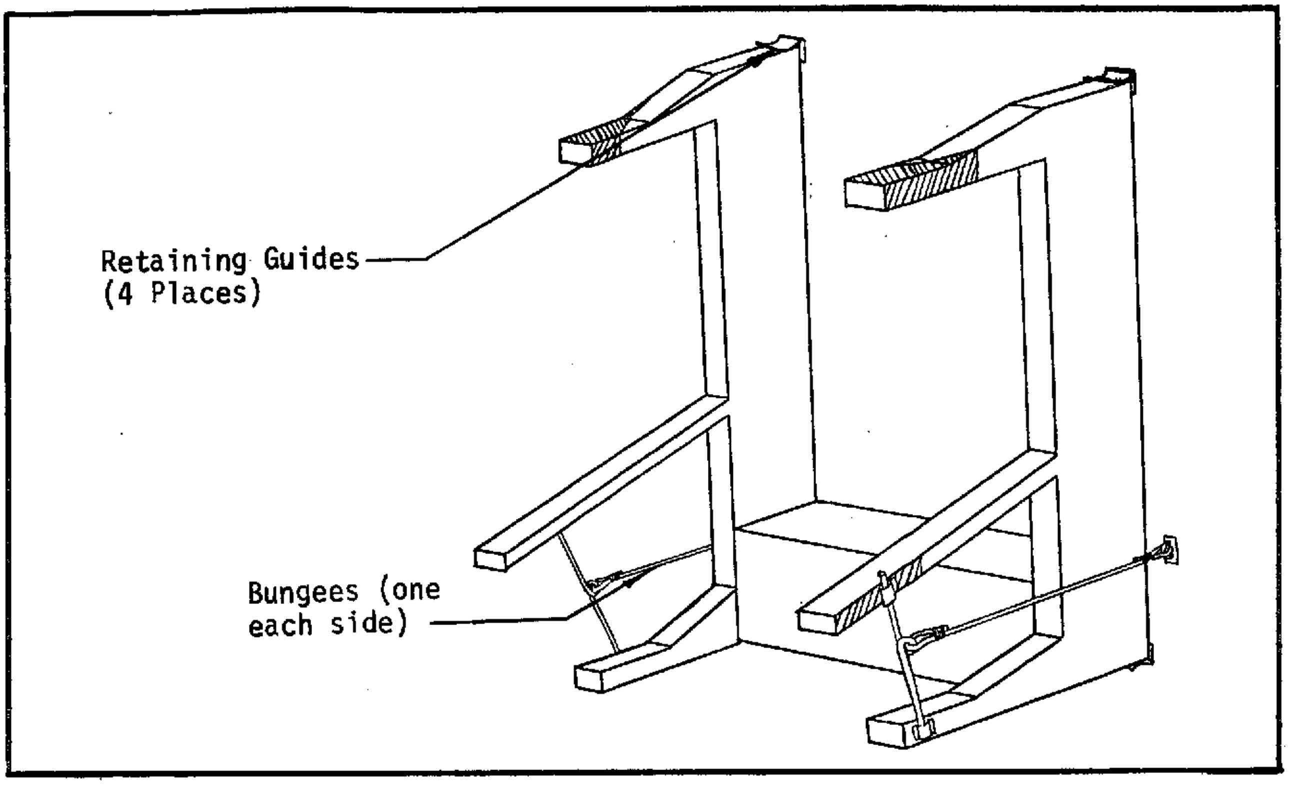


FIGURE 3.6: Bungee Restraint for MMU Donning/Checkout Concept

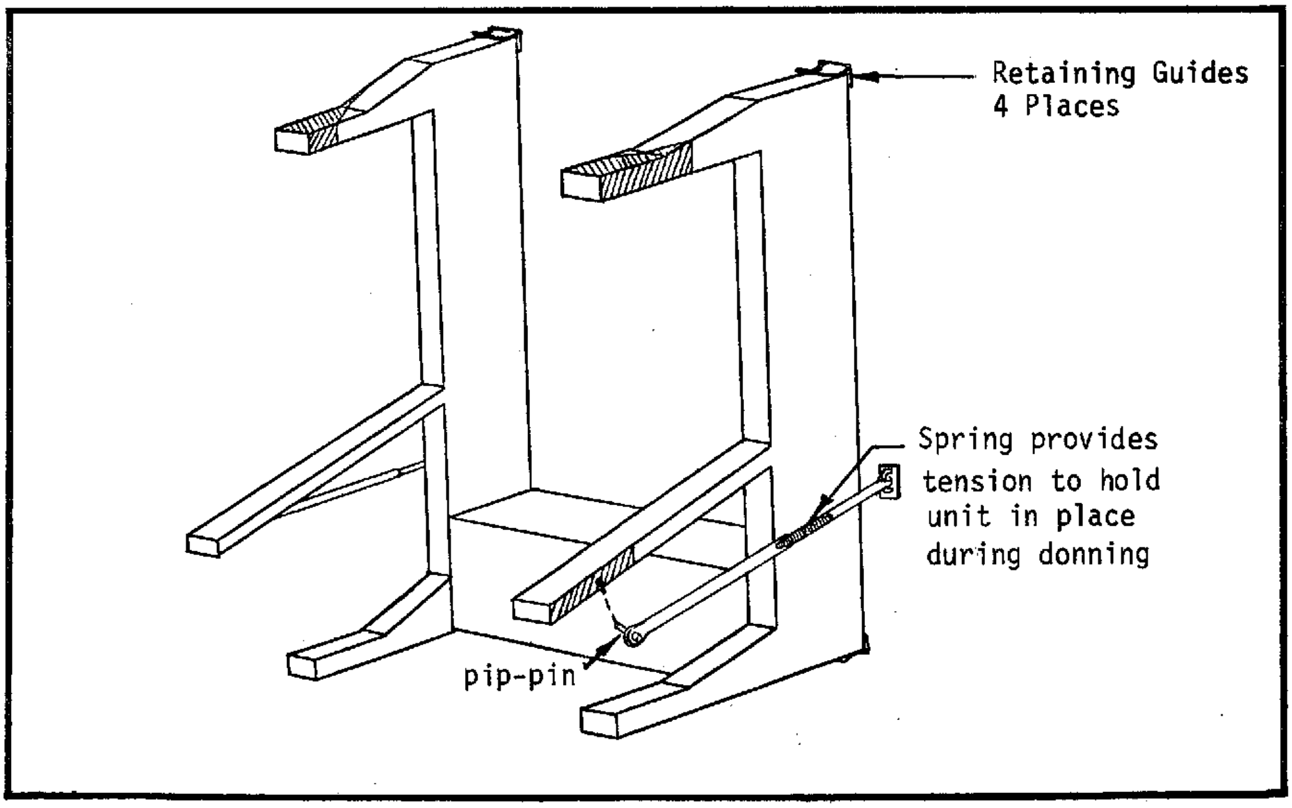


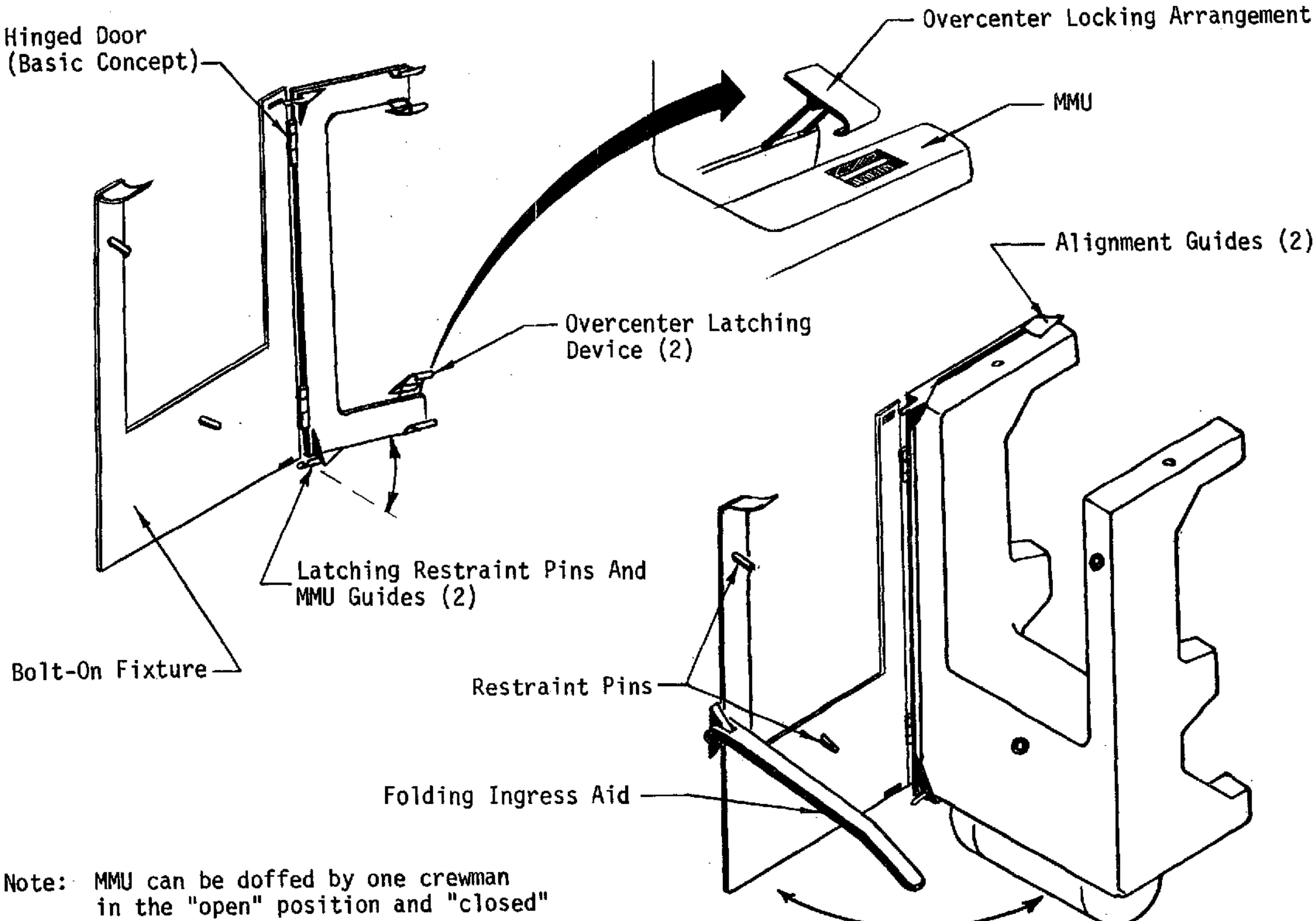
FIGURE 3.7: Tension Bar Restraint for MMU Donning/Checkout Concept

relatively simple temporary MMU restraint concepts (Figures 3.6 and 3.7) assure the crewman the capability to release himself from the donning station. Depending on the final MMU configuration, access to the aft areas of the unit for on-orbit servicing may be required. Figure 3.8 describes a "swing-out" fixture that may be designed to provide the following:

- Access to all areas of the MMU for on-orbit servicing
- Access (direct reach and visibility while in the unit) to the latching mechanisms for retrieving and stowing the unit on-orbit
- Launch and reentry restraint when positioned and secured to the Orbiter payload bay or payload structure

For launch/reentry the MMU servicing support fixture (Figure 3.8) would secure the MMU with mechanical fasteners similar to previously shown concepts. For servicing, the mechanical fasteners would be released, allowing the unit to swing away or extend from the mounting surface. The MMU may be released or restowed while in the extended configuration by one crewman with adequate visibility and reach, and without the need for extensive guides and visual aids (e.g., mirrors, tactile aids).

On-orbit contingency situations are feasible in which an MMU would be required for servicing operations outside the Shuttle Orbiter when the payload bay doors cannot be opened. Since the current stowage location is outside the Orbiter cabin, the MMU would be transferred from the payload bay, through the cabin, and out the Orbiter side hatch. The side hatch may not accommodate the MMU-crewman combination (MMU configuration dependent). Under this condition, the MMU would be donned from a special fixture deployed from the cabin through the side hatch. The concept shown in Figure 3.9 depicts a fixture that would be attached to the side hatch prior to crewman egress. Depending on the MMU size and configuration, the MMU and fixture may be deployed through the hatch as a unit. The EVA crewman would egress the cabin using mobility aids provided on the fixture and ingress the foot restraints and MMU. The foot restraints pivot to allow the crewman to rotate into the proper orientation for MMU donning and doffing. The reverse procedure would be employed for



Note: MMU can be doffed by one crewman in the "open" position and "closed" for stowage

FIGURE 3.8: MMU "Swing-Out" Servicing Attachment Concept

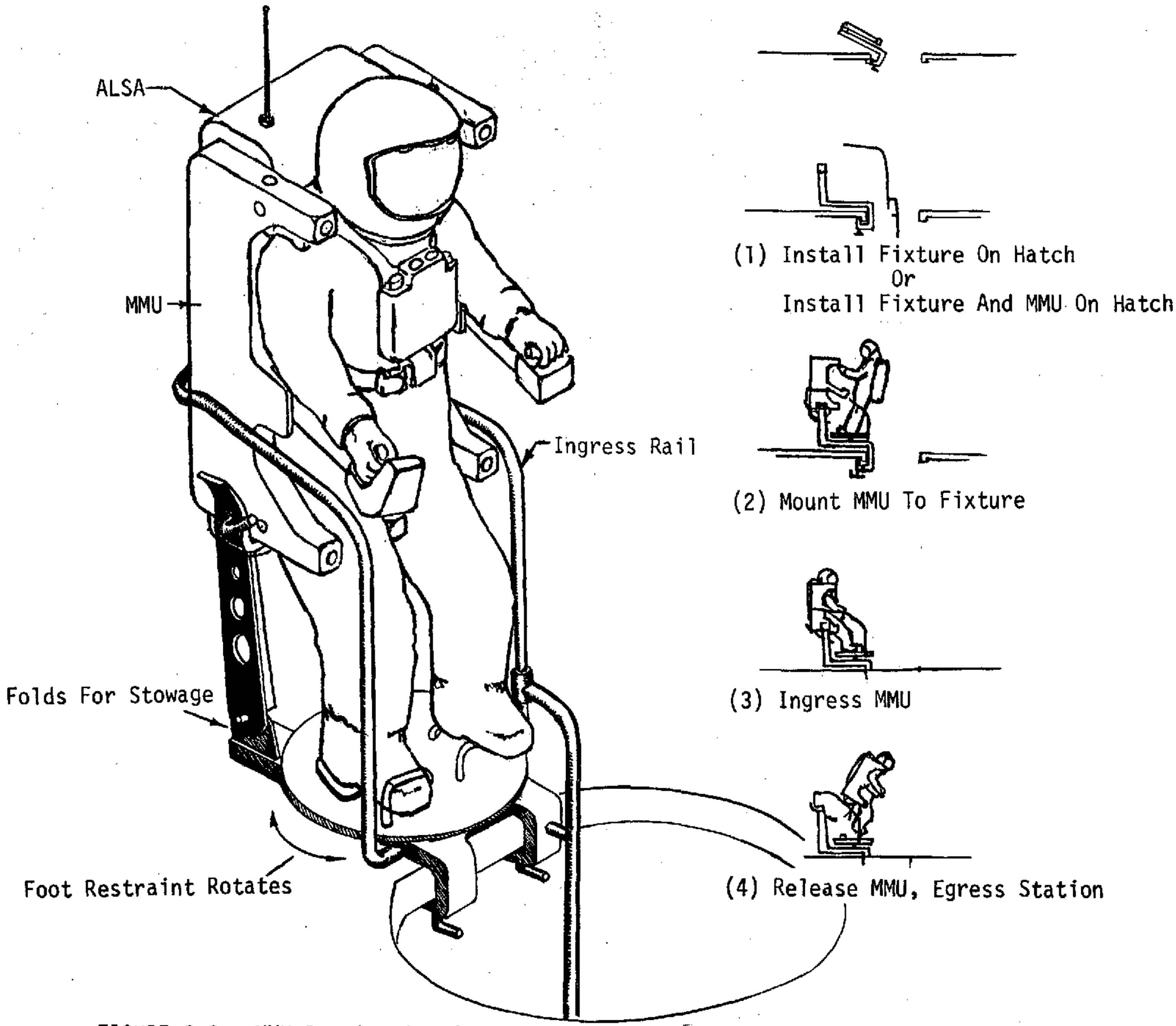


FIGURE 3.9: MMU Donning Station Concept--Interface with Orbiter Side Hatch

stowing the MMU following an EVA mission. The fixture shown in Figure 3.9 would be designed to fold into a compact package for stowage inside the Orbiter cabin or the payload bay. Figure 3.10 provides a modular fixture concept for deploying the MMU from the side hatch. The modular fixture is disassembled for stowage when not in use and incorporates only the minimum requirements for an MMU side hatch don/doff station:

- MMU restraint to don/doff station
- MMU don/doff station to Orbiter vehicle
- Crewman ingress and stabilization aids
- Crewman foot restraints

The fixture would be deployed with the MMU attached. The EVA crewman would translate along the fixture and deploy the ingress aids and foot restraint system.

The preceding concepts were primarily concerned with techniques for attaching the MMU to the carrier vehicle for launch, on-orbit servicing and reentry. Provisions for donning and doffing the unit from the nominal stowage interface and from the side hatch were considered. The following section addresses attaching the MMU to prepared and unprepared worksites on the Orbiter and payloads.

3.1.2 MMU-to-Worksite Interface (Orbiter and Payloads)

Potential applications of the MMU to orbital systems are limited only by the imaginative proficiency of mission, vehicle and payload planners and designers. Figures 3.11 through 3.13 illustrate potential MMU applications to advanced payloads--Volume I of this report considers MMU applications to the Orbiter and across all payloads currently being studied for flights through 1990. As proven in the early Gemini EVA Program and verified on all subsequent orbital/transearth EVAs, the crewman must be adequately restrained in order to perform manipulative (force application) tasks in the space environment. Either the MMU or the EVA crewman (perhaps the MMU-crewman combination

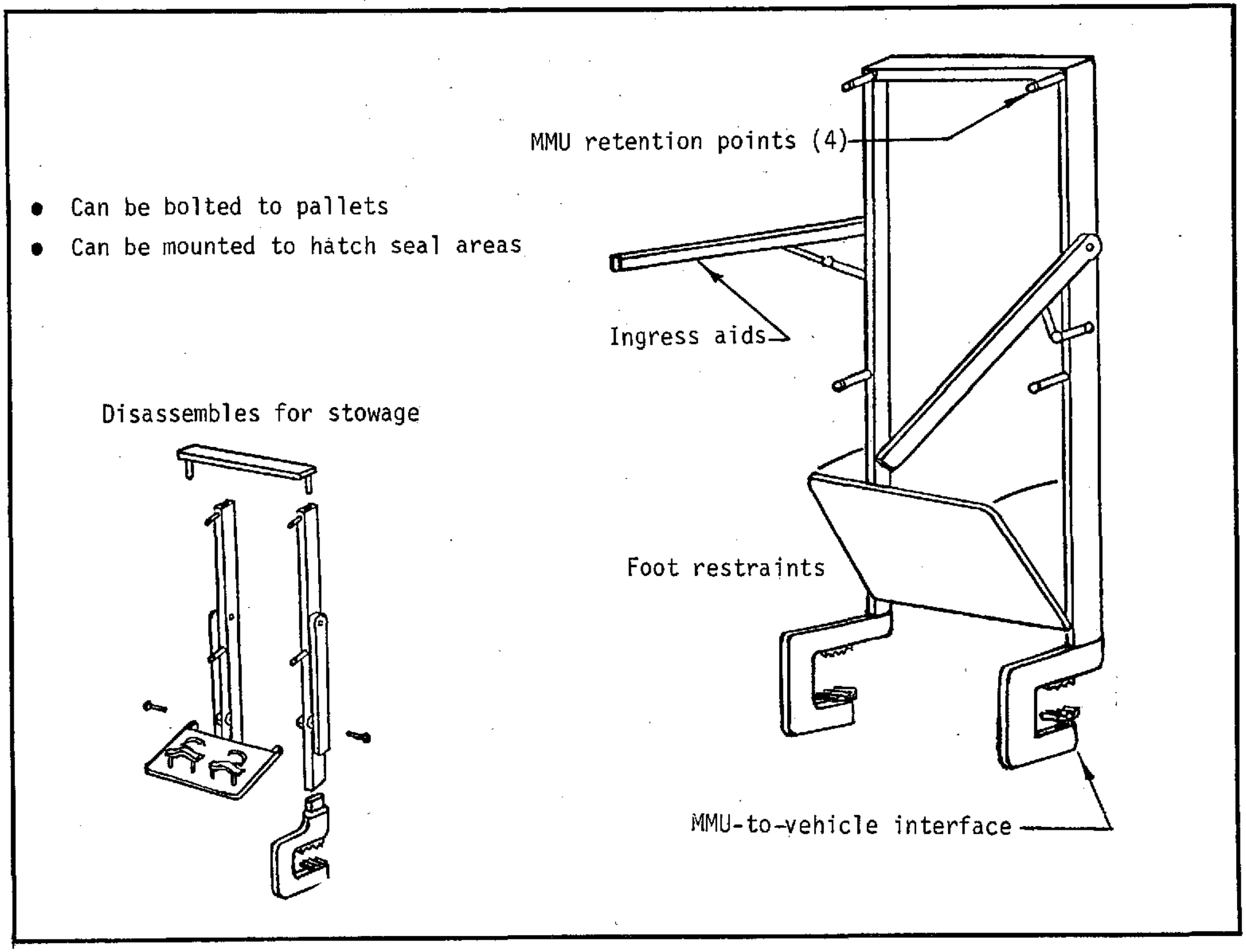


FIGURE 3.10: Modular MMU Donning Station Concept

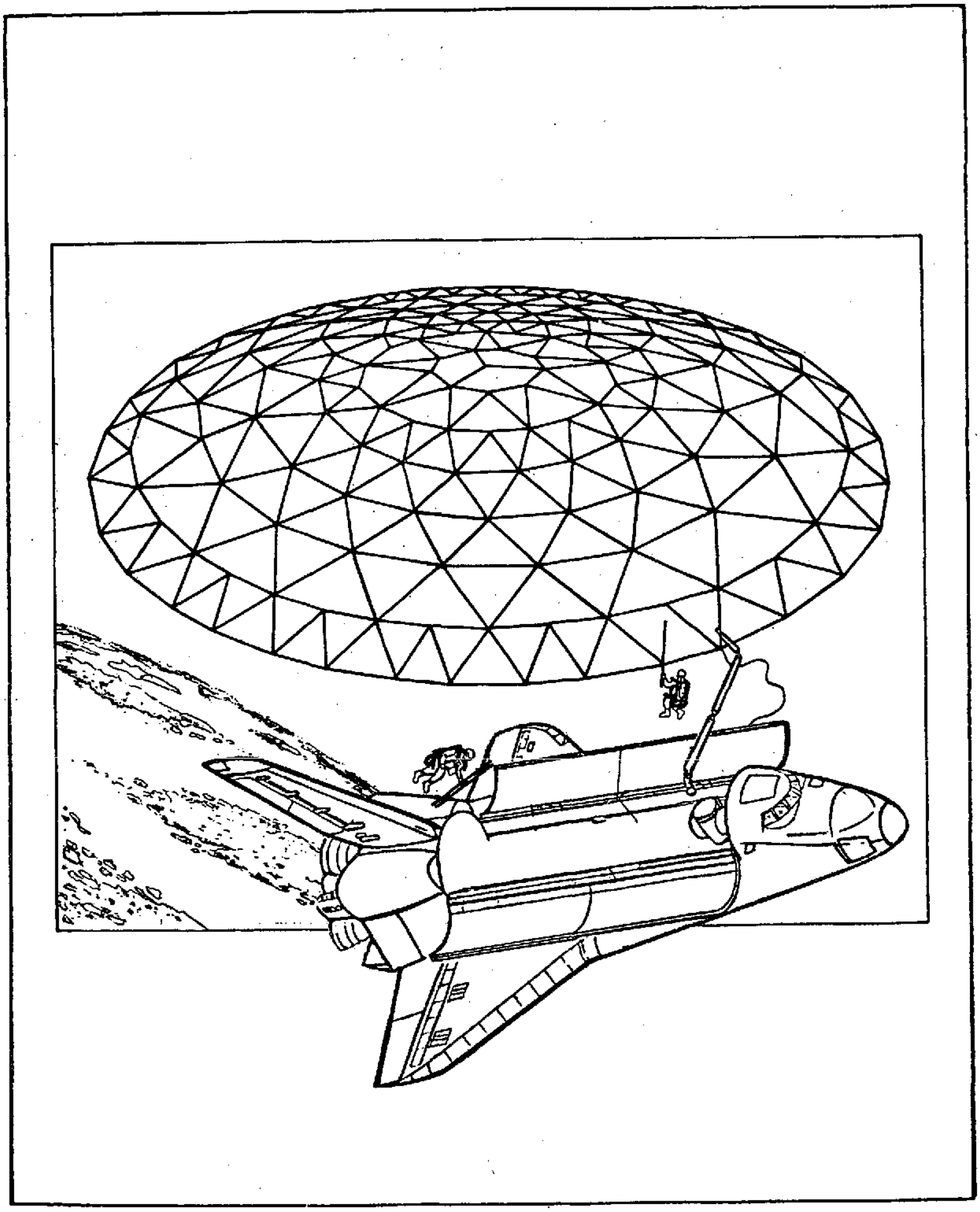


FIGURE 3.11: MMU Application to Large Geodetic Space Structure Assembly

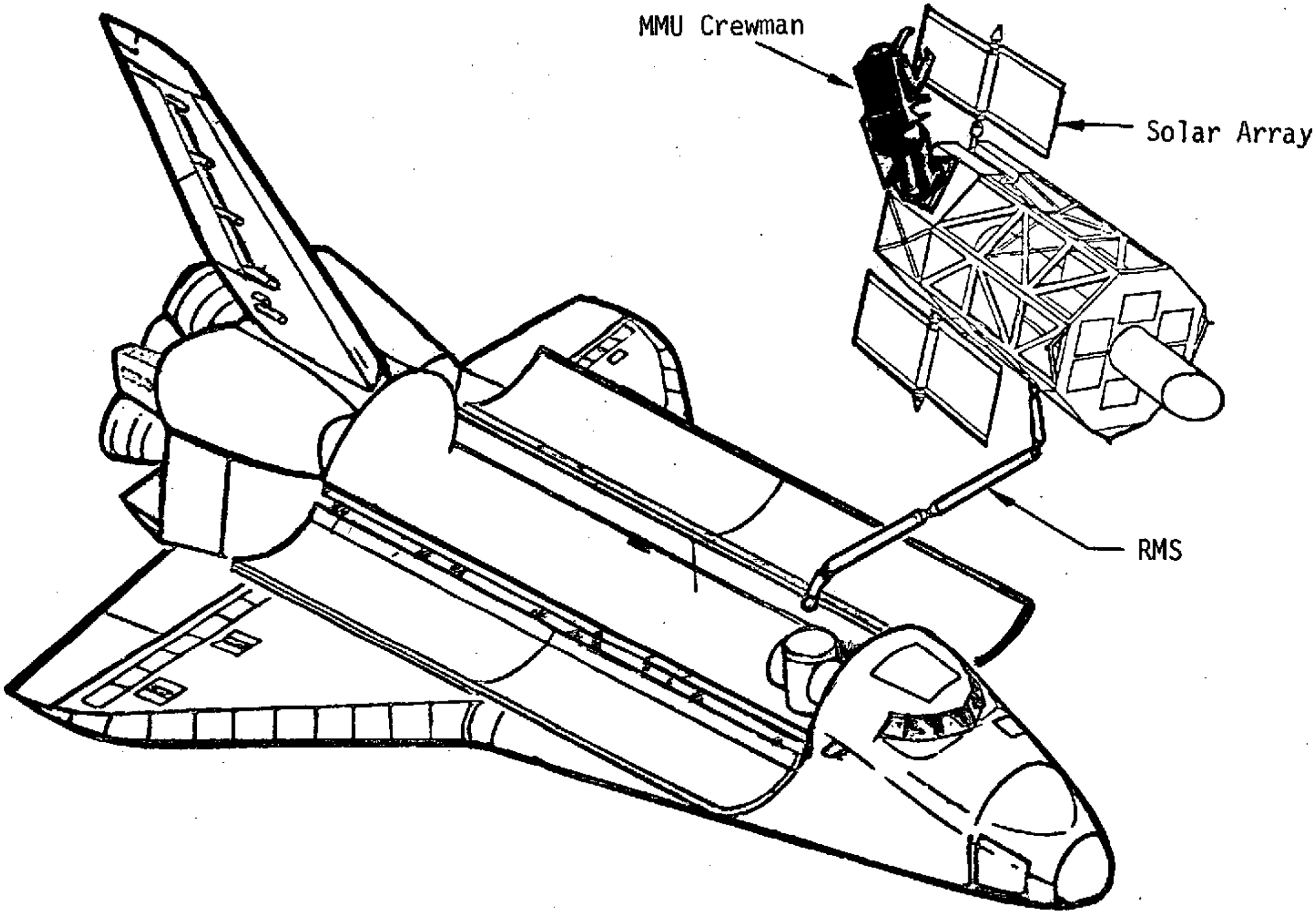


FIGURE 3.12: MMU Application to Automated Payload--Repair at Prepared Worksite

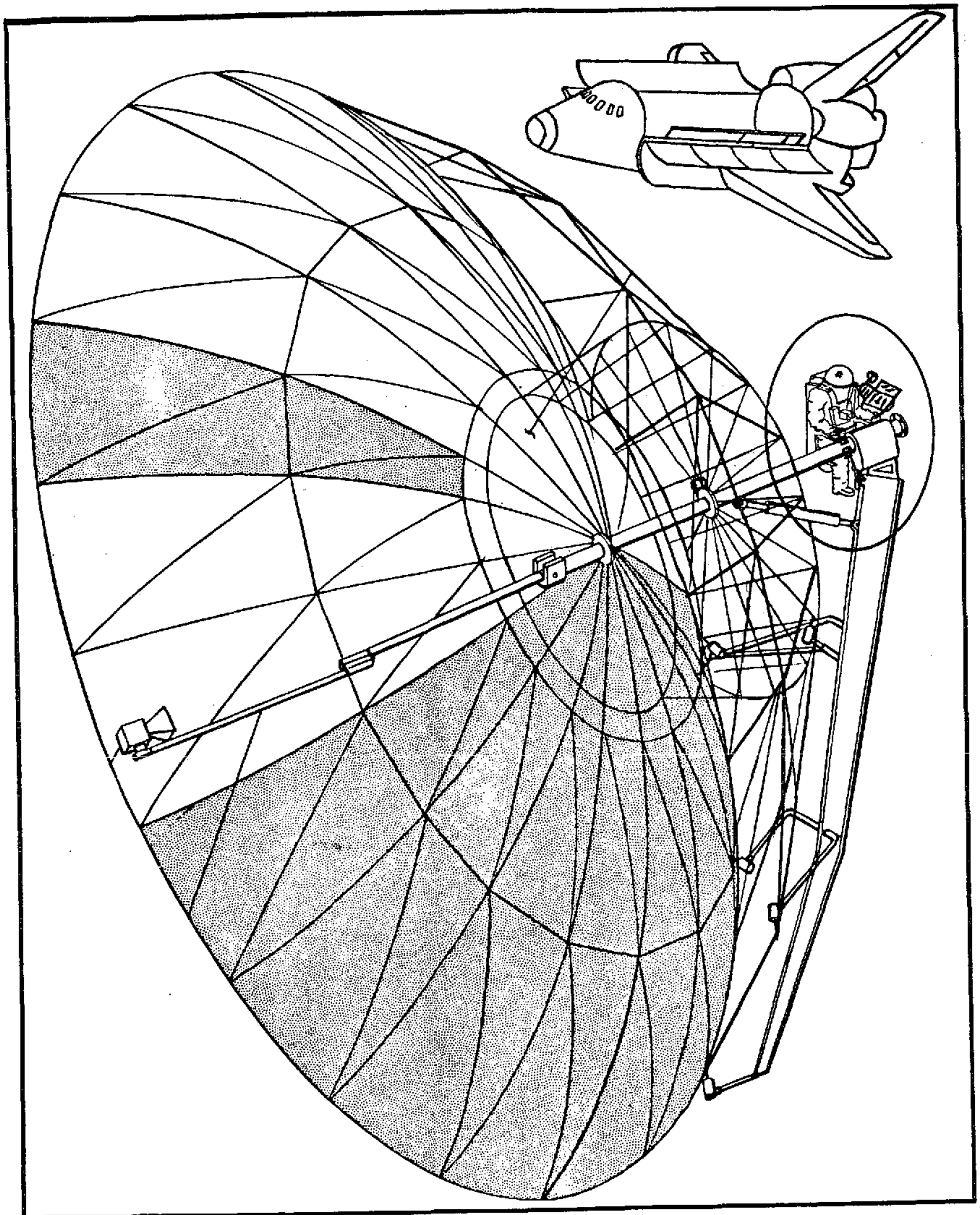


FIGURE 3.13: MMU Application to Large Antenna System--Repair at Unprepared Worksite

for special application) must be restrained at the worksite. Restraining the MMU-crewman system will involve attachment to either a prepared or unprepared site on the Shuttle Orbiter and payloads.

Prepared worksites are defined as interfaces provided prior to vehicle launch to support planned EVA functions. Such worksites contain adequate provisions for attaching the required EVA support hardware. An unprepared worksite contains no provisions for EVA functions, and the crewman must transport and attach the required restraint equipment to the orbiting structural interface. The restraint design criteria apply equally to the payloads and Shuttle Orbiter for both prepared and unprepared worksites. Therefore, the MMU/EVA crewman-to-worksite interface concepts presented in the following paragraph are applicable to all orbital systems.

Prepared Worksites

The concepts illustrated in Figures 3.14 through 3.19 are for temporarily attaching the MMU, EVA crewman, and the MMU-crewman combination to a prepared worksite. Figure 3.14 provides a concept in which the MMU is mechanically attached to the worksite through pip-pins, astro-pins, ball and sockets or various clamp-on devices. Depending on the capacity of the worksite interface to support the passive element of the attachment device, several space-qualified restraint mechanisms can be modified/redesigned for MMU application. The active restraint elements in Figure 3.14 are shown connected to the MMU at the control arms to provide a two-point restraint system. Flexible tethers could be used in conjunction with the two-point restraint to improve stabilization. The restraints could also be attached to other structural members of the MMU (e.g., forward thruster housings, seat restraint) with additional adapters to provide a rigid three-point attachment. The active restraints and supporting adapters could be installed prior to donning the MMU and would remain through the EVA mission. The active restraint elements would contain a jettisoning capability at the MMU interface for contingency situations. The restraint elements could also be stowed on the MMU and installed at the worksite, as required.

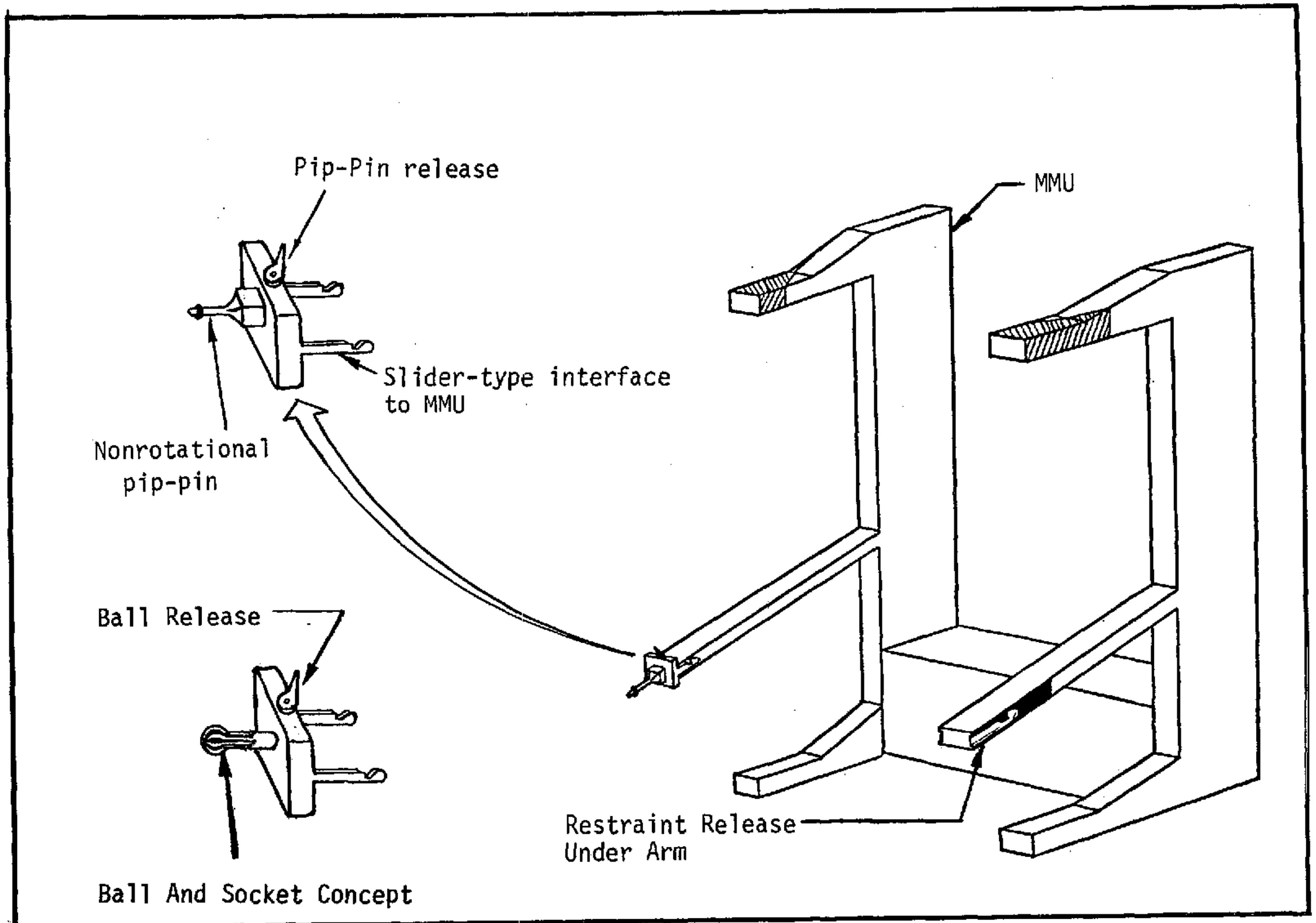


FIGURE 3.14: Concept for MMU Attachment to Prepared Site

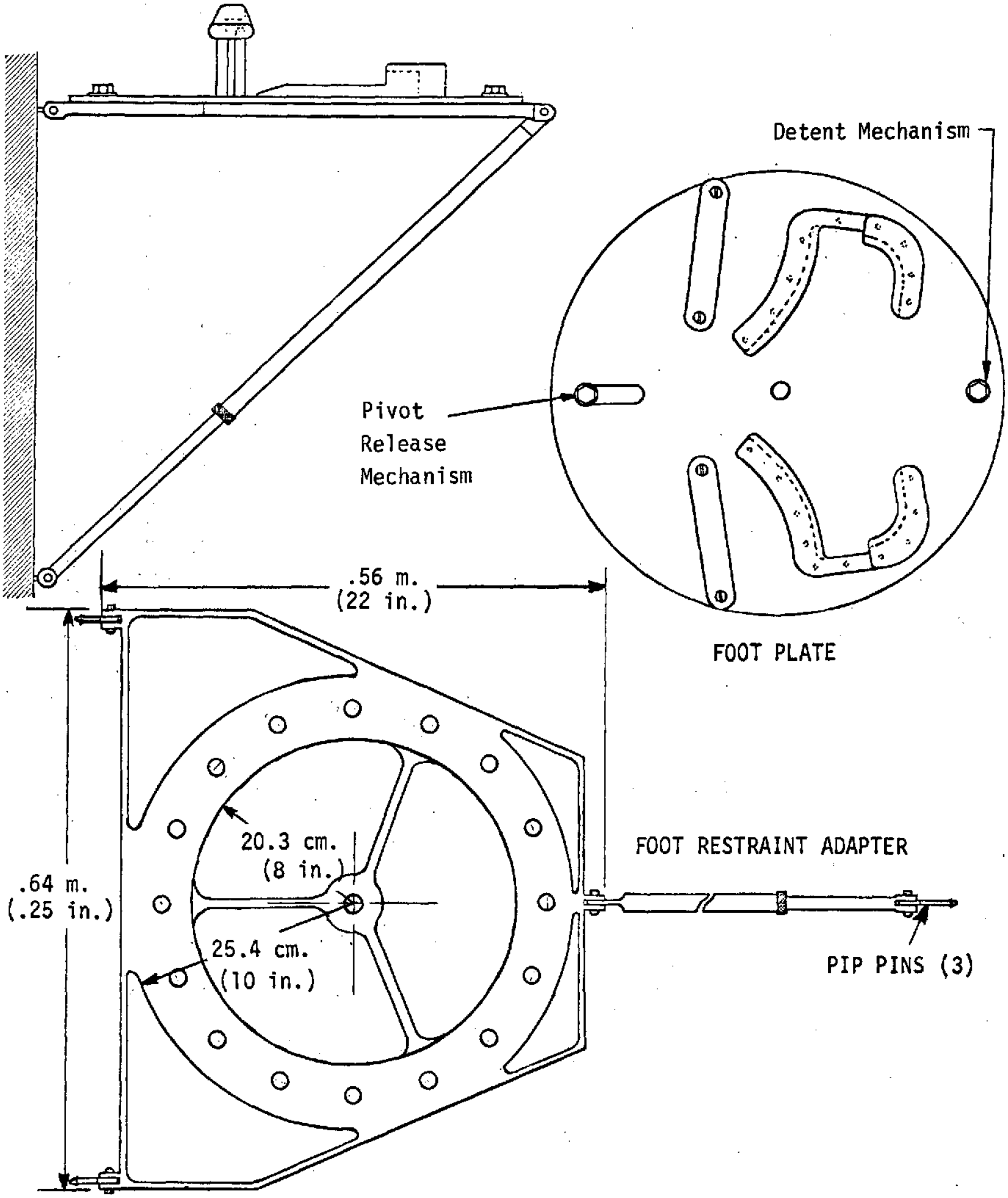


FIGURE 3.15: Tripod Foot Restraint Concept

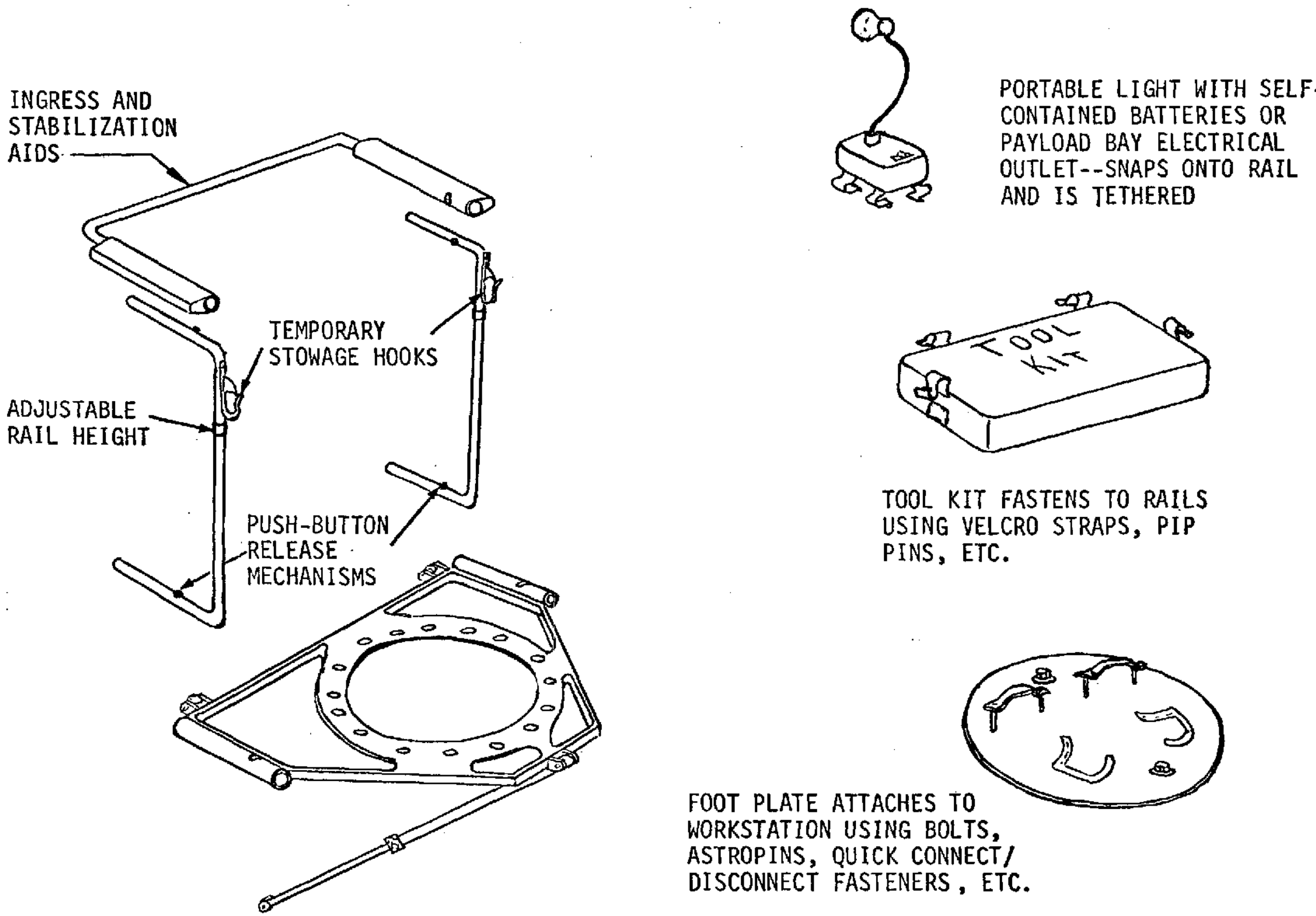
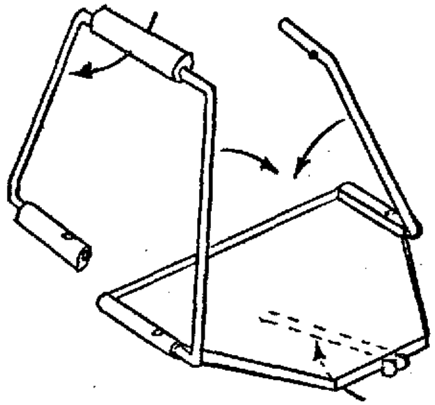
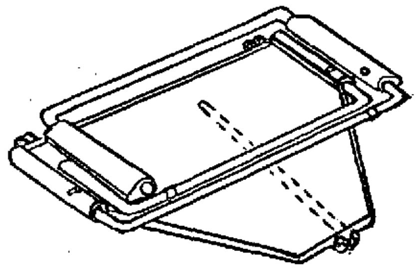


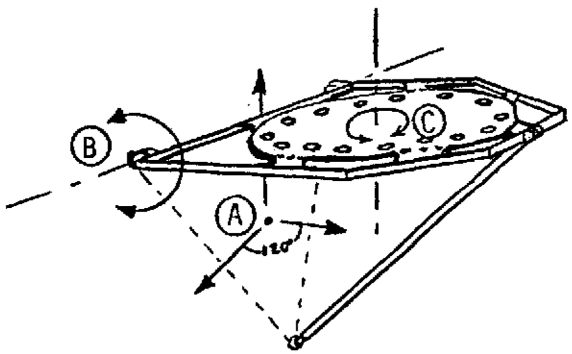
FIGURE 3.16: Tripod Workstation Concept--Modular Equipment



FOLDING SEQUENCE (RAILS MAY ALSO BE REMOVED)



STOWED CONFIGURATION



(A) EQUIDISTANT HOLES ON MOUNTING SURFACE ALLOW 3 WORKSTATION ORIENTATIONS 120° APART

(B) REAR SUPPORT MEMBER ALLOWS WORKSTATION ADJUSTMENT IN PITCH

(C) CIRCULAR HOLE PATTERN ALLOWS DISCRETE YAW POSITIONING OF WORKSTATION

FIGURE 3.17: Tripod Workstation Folding Sequence and Positioning

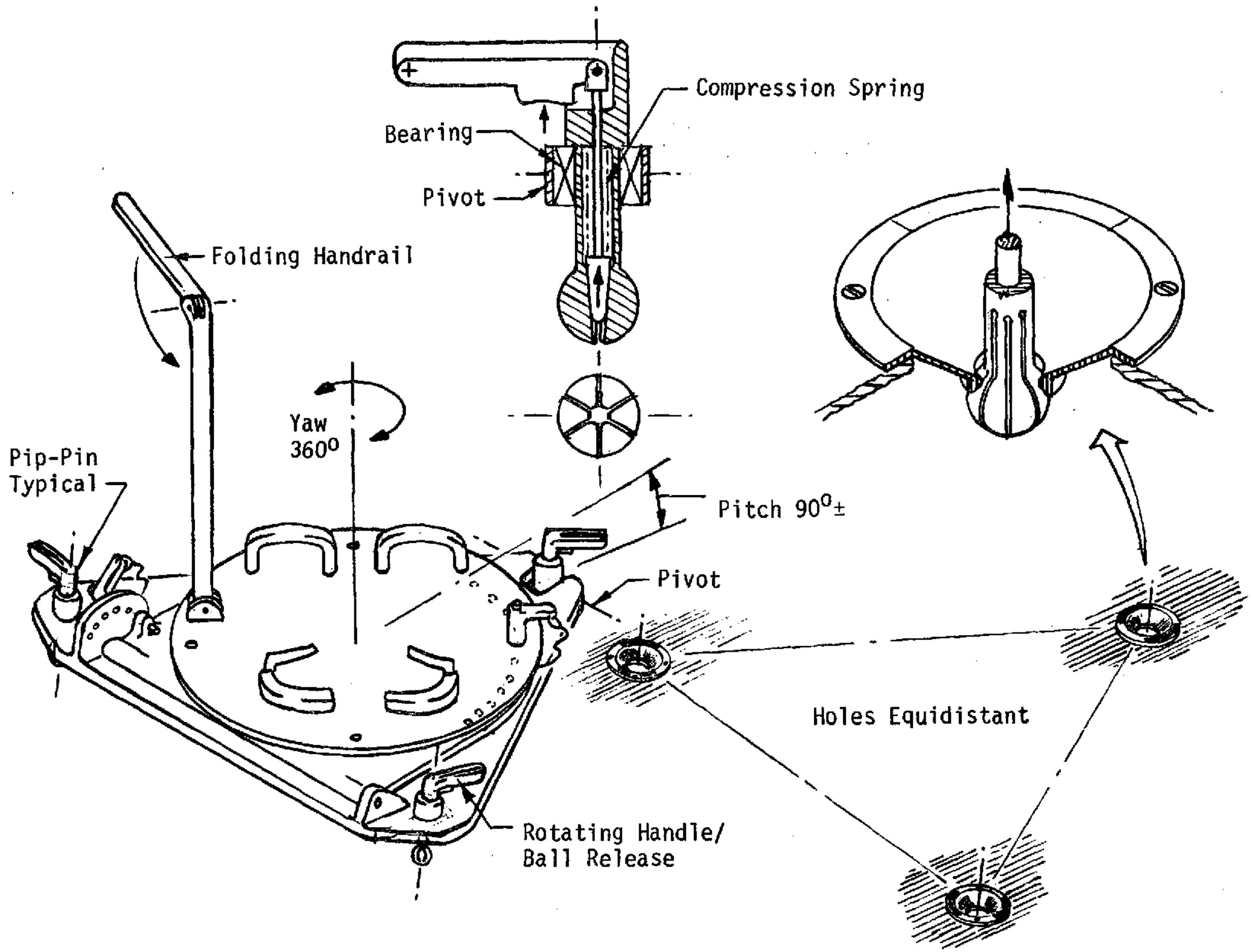


FIGURE 3.18: Foot Restraint Attachment Concept--Prepared Worksite
(Ball and Sockets)

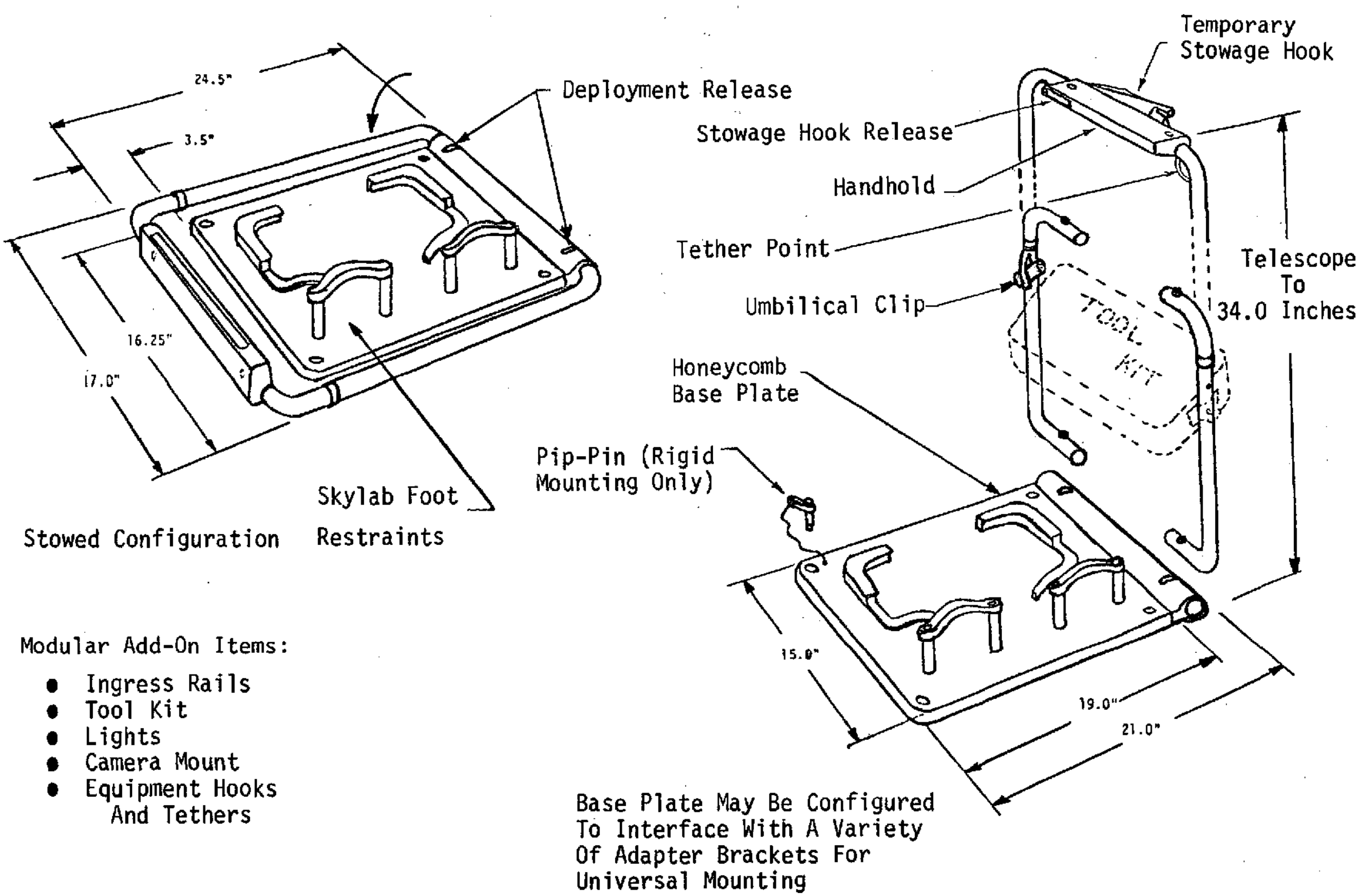


FIGURE 3.19: Portable Workstation Concept--Modular Equipment

Figures 3.15 through 3.18 depict concepts for restraining the MMU crewman to a prepared worksite. The portable workstation concept shown in Figures 3.15 through 3.17 would be mounted at the worksite using three holes in an equilateral-triangular pattern. The workstation concept would provide adjustments in the roll, pitch, and yaw axes and is a modular design to range from a simple foot restraint unit to a completely equipped workstation. The workstation concept is designed to accept only those modular elements required for a specific task(s) and folds for transporting and compact stowage (Figure 3.17).

Figure 3.18 provides an alternate restraint concept for attaching to a three-hole proposed interface. The attachment interface would be equipped with alignment/retaining inserts for accepting a ball-type releasable probe. The restraint provides a folding crewman ingress aid and may be easily transported by the MMU to remote sites. Figure 3.19 depicts a previously developed concept of a modular-portable workstation. The workstation may be secured to a prepared worksite prior to launch by bolts, pip-pins, etc. or transported to the worksite on-orbit. The workstation may also be attached to unprepared worksites by utilizing attachment concepts developed in subsequent sections of this report.

Unprepared Worksites

Several typical attachment devices used on the Skylab Program to interface with various structural members are illustrated in Figure 3.20. Similar interfaces and attachment techniques are applicable to the Space Shuttle for attaching the MMU to unprepared worksites. However, unique attachment devices for each candidate interface are undesirable for orbital application. Figure 3.21 provides a concept capable of interfacing with a variety of structural shapes. The "C" clamp attachment device would incorporate adjustable and/or removable inserts to provide the "universal" interface. Mounting interfaces would be provided on the MMU structure and portable workstations to accept the "C" clamp.

An application of the "C" clamp concept is shown in Figure 3.22 in which an MMU-crewman combination is attached to a structural member at an unprepared

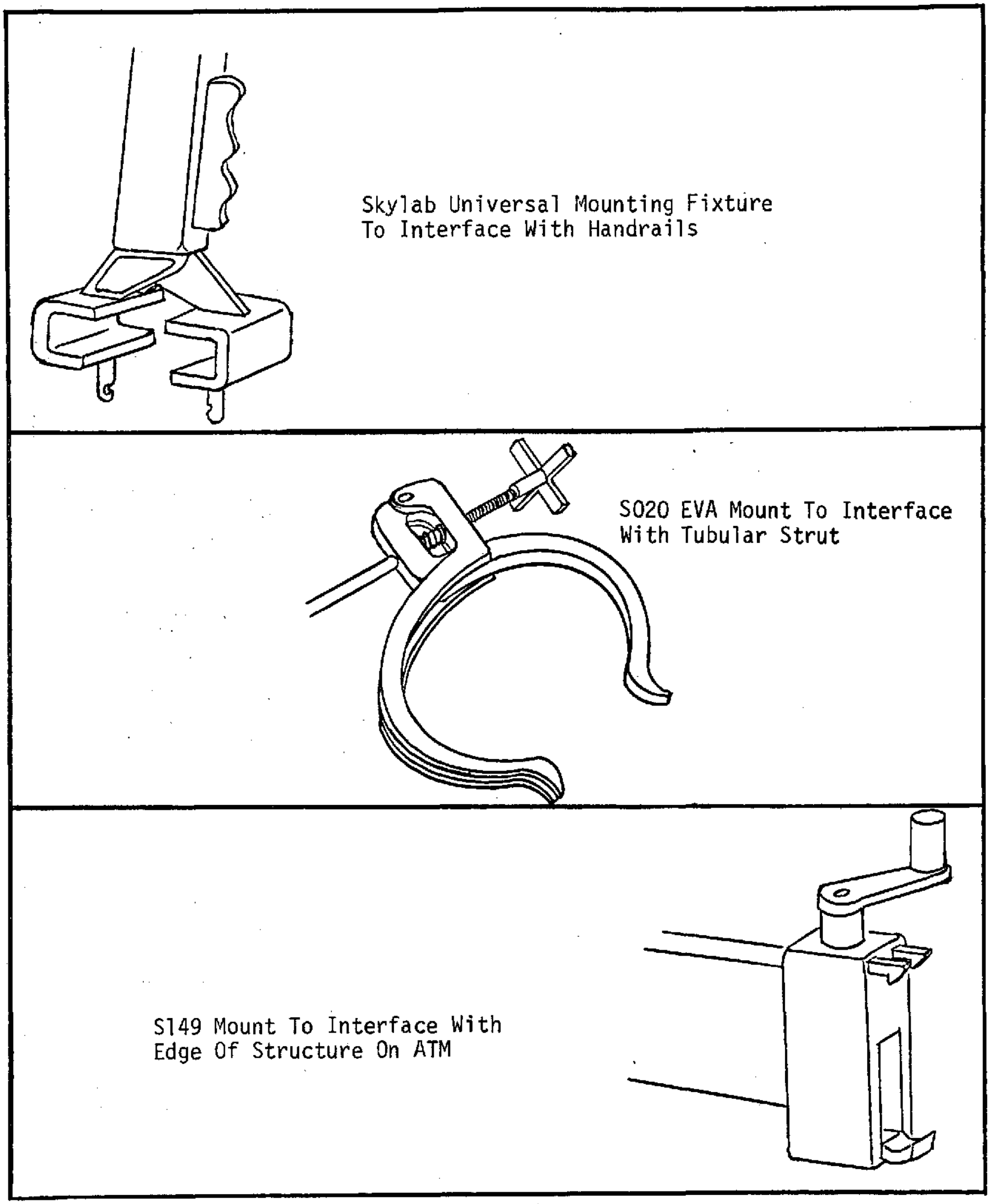


FIGURE 3.20: Typical Attachment Brackets from Previous Space Programs

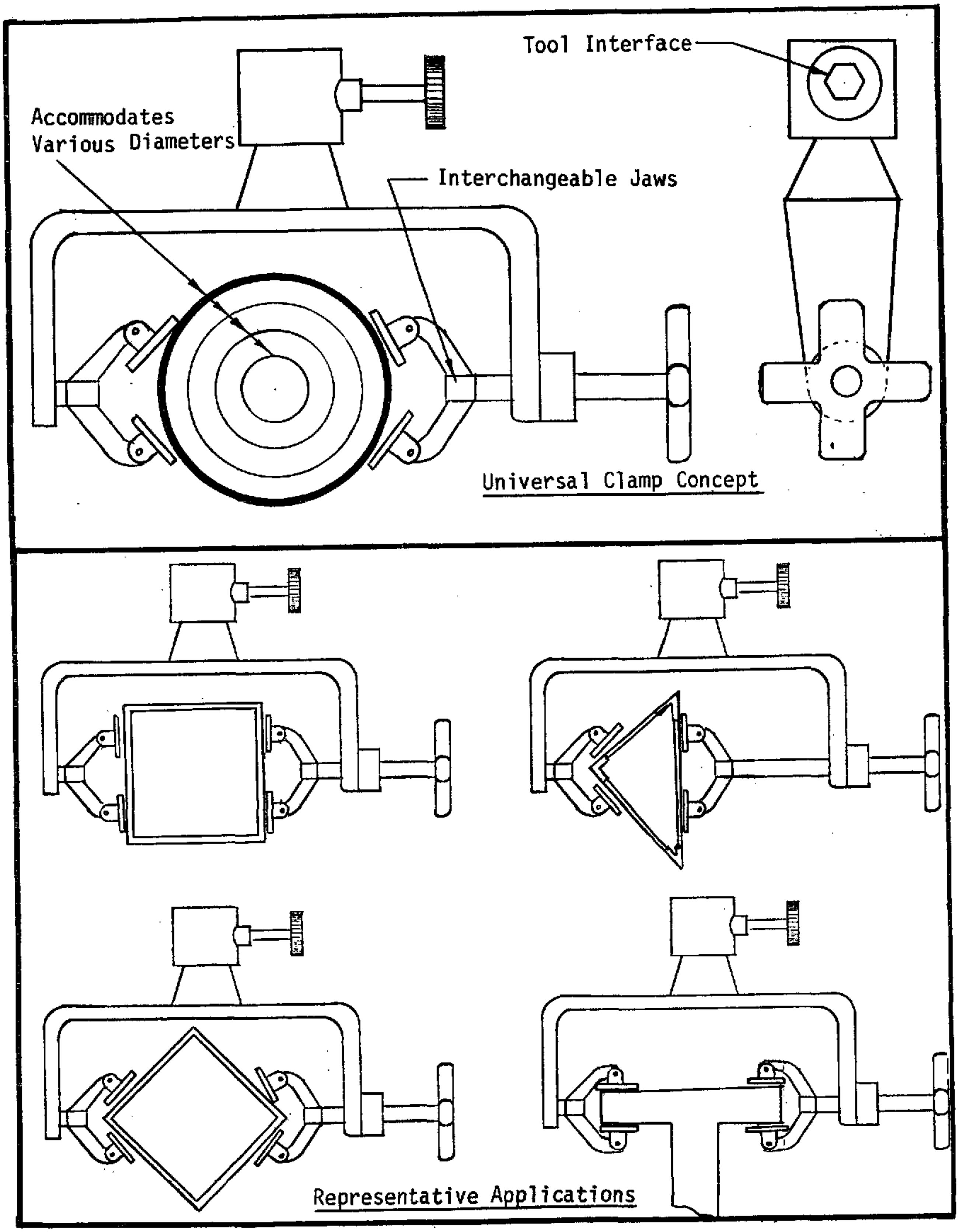


FIGURE 3.21: Universal "C" Clamp Attachment Device Concept

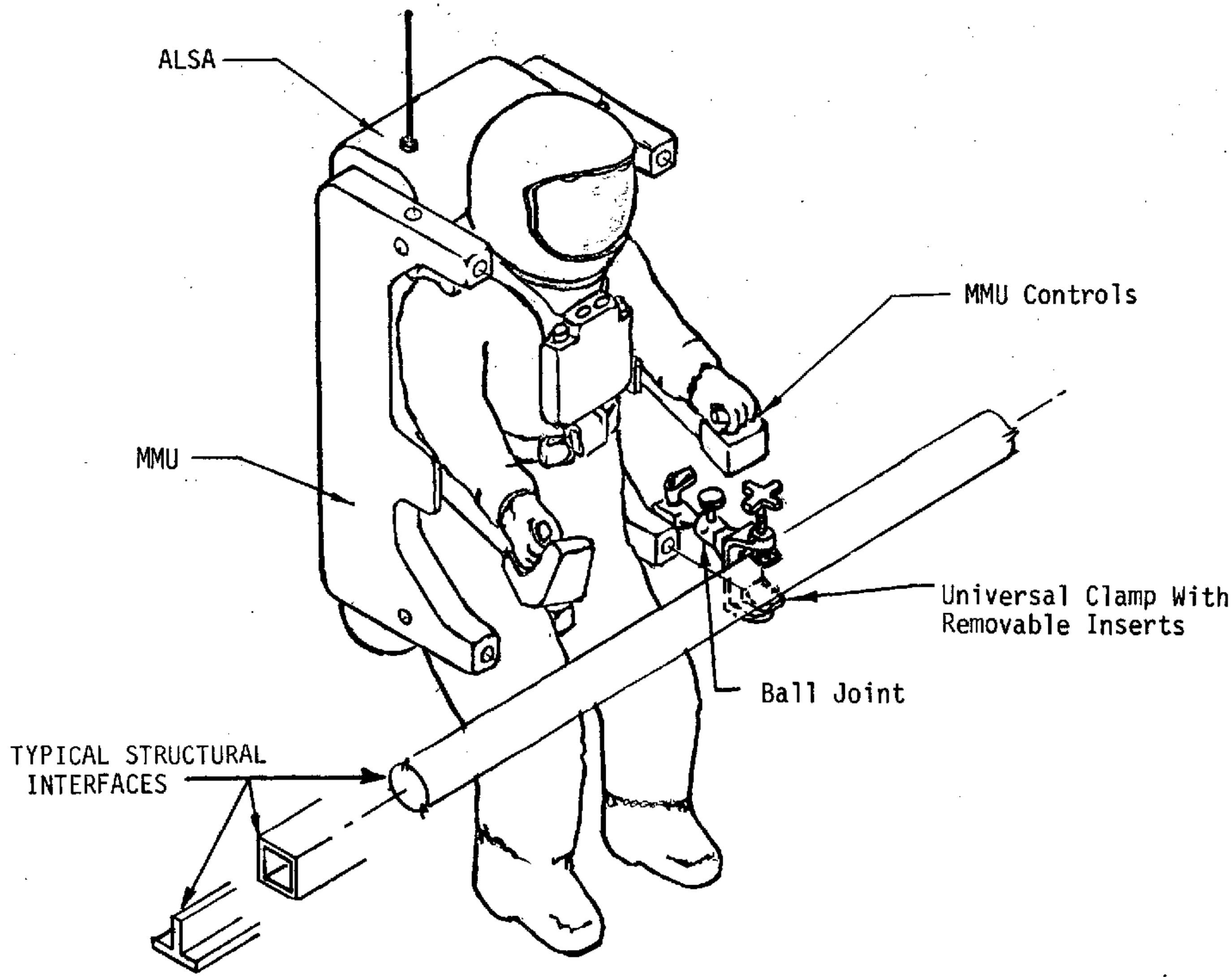


FIGURE 3.22: Universal Clamp Concept for MMU Restraint--Unprepared Worksite

worksite. Figure 3.23 provides additional details for attaching the "C" clamp concept to an MMU. Since the MMU contains various pneumatic components for thruster operation, the pneumatic system may feasibly be utilized to actuate MMU attachment devices. One such concept is shown in Figure 3.24. Figures 3.25 and 3.26 illustrate optional concepts that may be designed for either mechanical or pneumatic operations at the MMU-to-worksite interface. Optional end effectors would be provided for grasping structural configurations. The end effector would be spring-loaded to automatically actuate on contact and include a manual backup locking/release mechanism. The specific type of end effector would be connected to the MMU prior to egressing the MMU stowage locations or be one of a selection of end effectors stowed on the MMU. The MMU structural interface would be mechanical with a push-button release mechanism integral to the MMU structure. The end effector linkage is designed for contingency removal by the crewman for releasing the MMU from an orbital interface. Figure 3.26 depicts a concept for remotely operating an adjustable restraint mechanism to attach beyond the crewman's reach.

Figure 3.27 provides a concept for attaching the previous "C" clamp restraint device (Figure 3.21) to a portable foot restraint or modular workstation. A concept for attaching a portable workstation to the edge of a flat plate, leg of a structural angle, etc. for applying relatively large forces or torques is shown in Figure 3.28. The short "spikes" (approximately .08 cm. (.030 in.)) would form detents in the structural member to prevent slippage. The unit would be hand-tightened by the EVA crewman and secured by standard hand tools prior to workstation ingress. Each of the concepts above (Figures 3.27 and 3.28) provides a capability to restrain the crewman at an unplanned worksite in lieu of attaching the MMU. Restraining the crewman allows more latitude at the worksite for task performance.

The concepts provided in the remainder of this subsection address attaching MMU and crewman restraint systems to relatively flat, unprepared surfaces on the Orbiter or payload exteriors. Repair of the Orbiter Thermal Protection System (TPS) appears to be a strong MMU application; however, the TPS is restricted to .6 kg/cm^2 (8 lb/in^2) surface loading. Adhesive restraint surfaces which

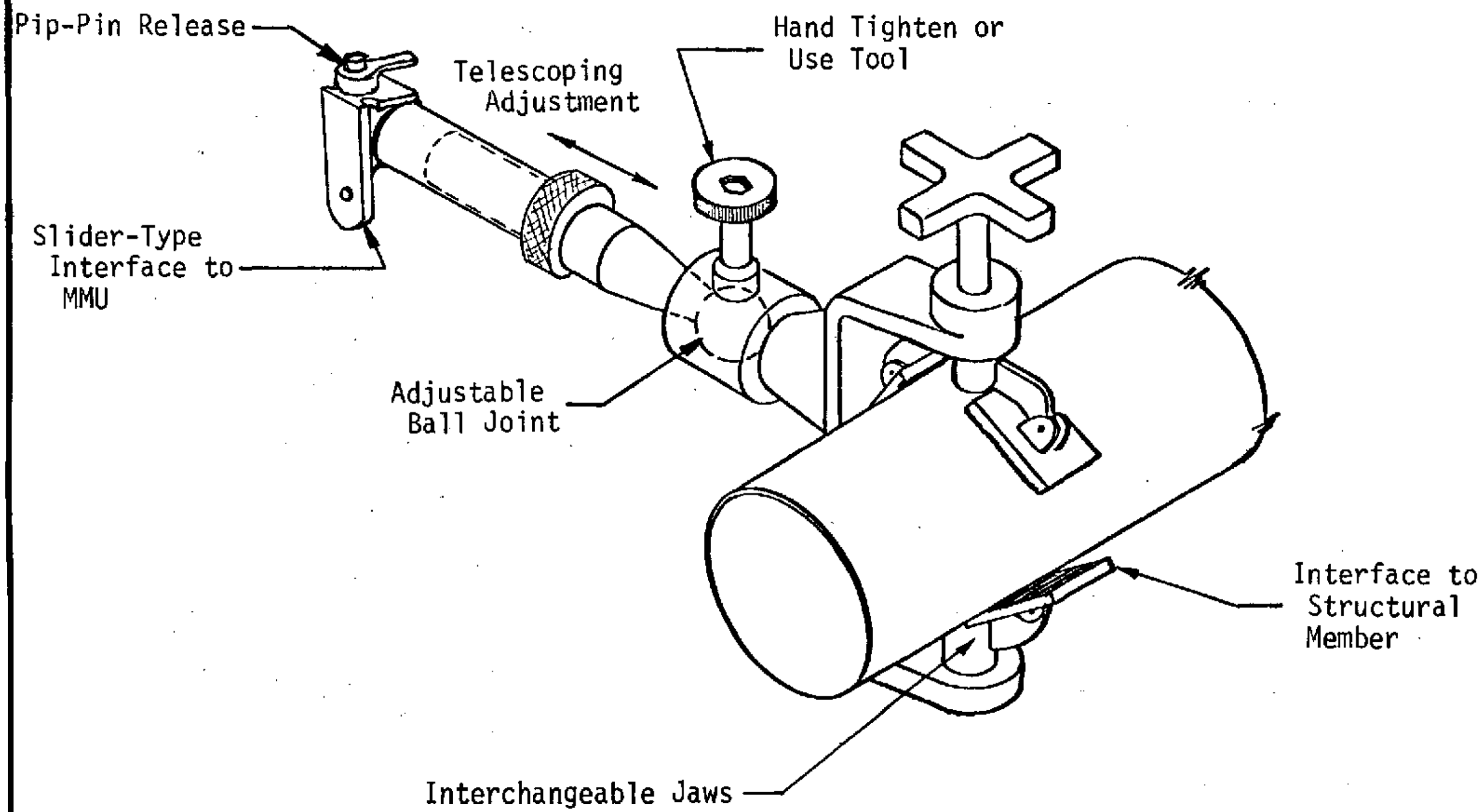


FIGURE 3.23: Universal MMU Clamp Details

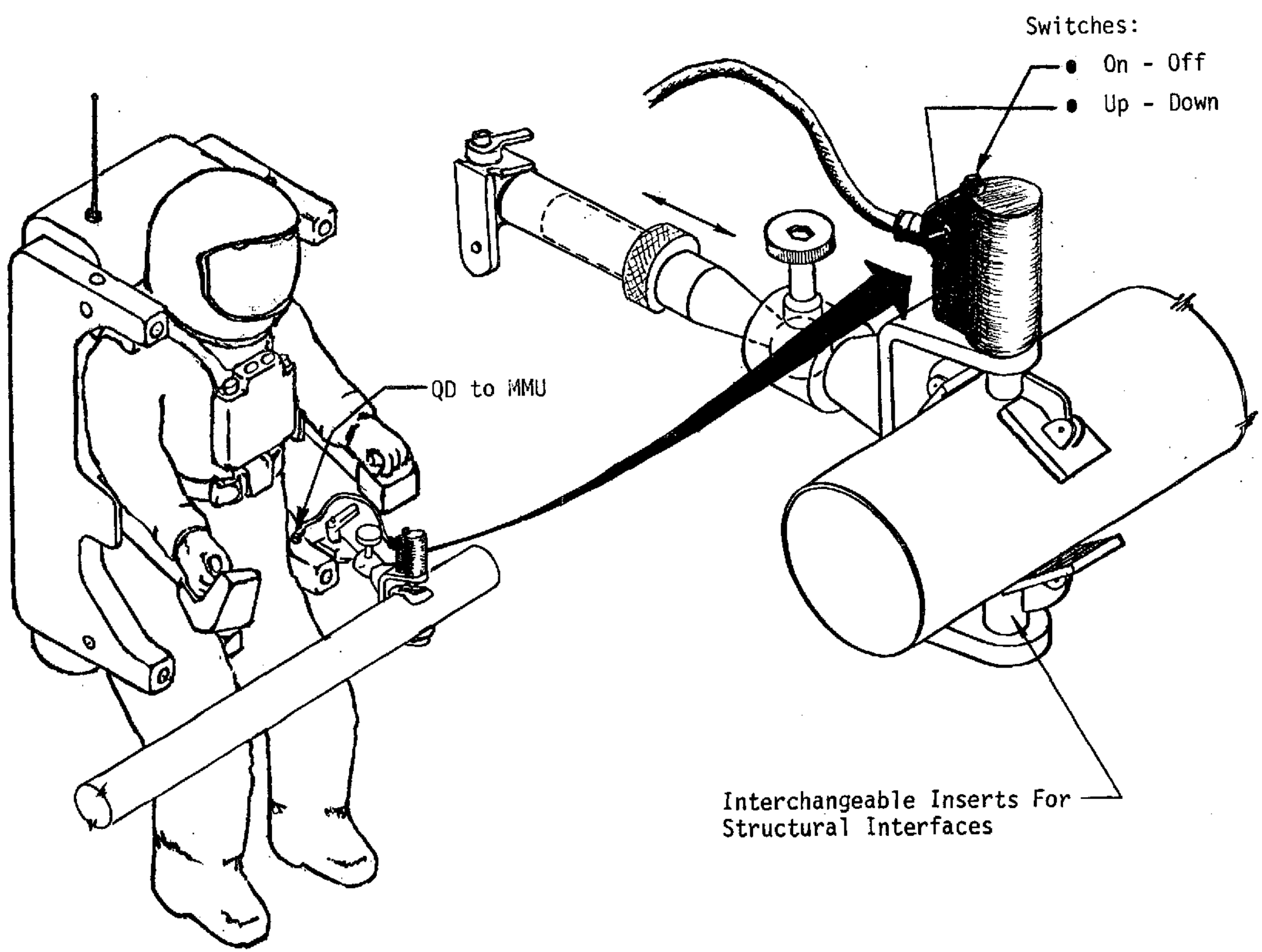


FIGURE 3.24: Pneumatic MMU Clamp Concept

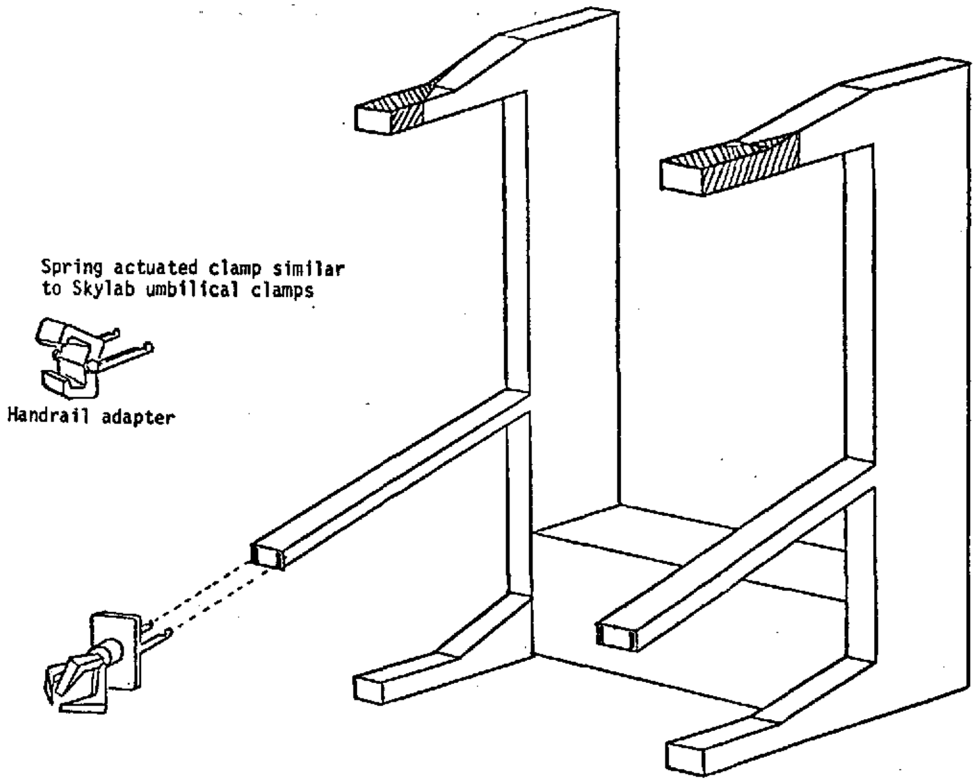


FIGURE 3.25: Grapplers For Restraining MMU to an Unprepared Worksite

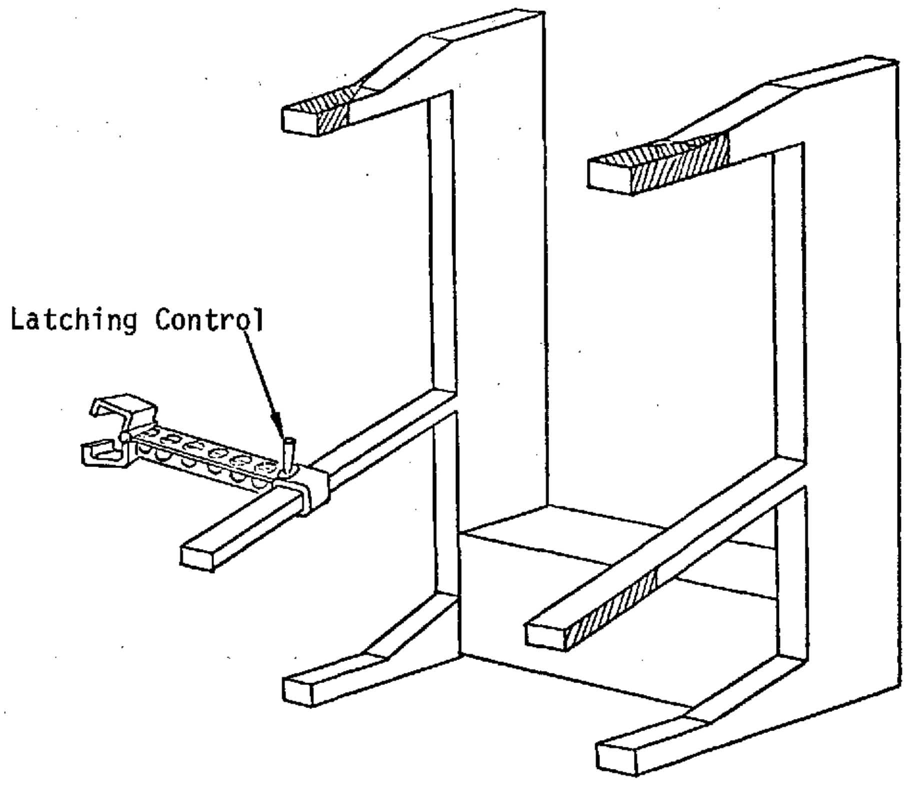


FIGURE 3.26: Side-Mounted Device For Attaching MMU to Unprepared Worksite

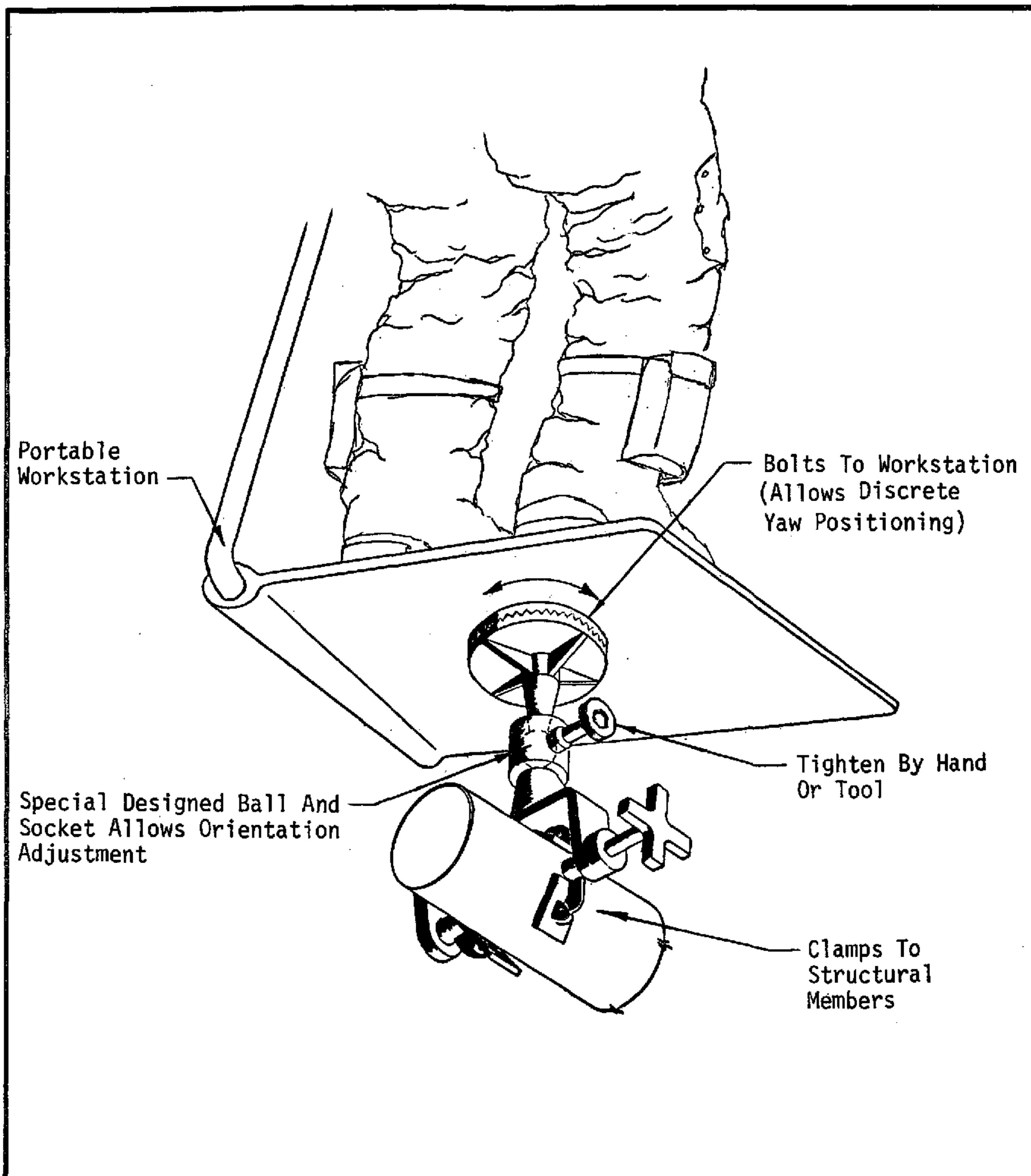


FIGURE 3.27: Universal Clamp-to-Portable Workstation Interface

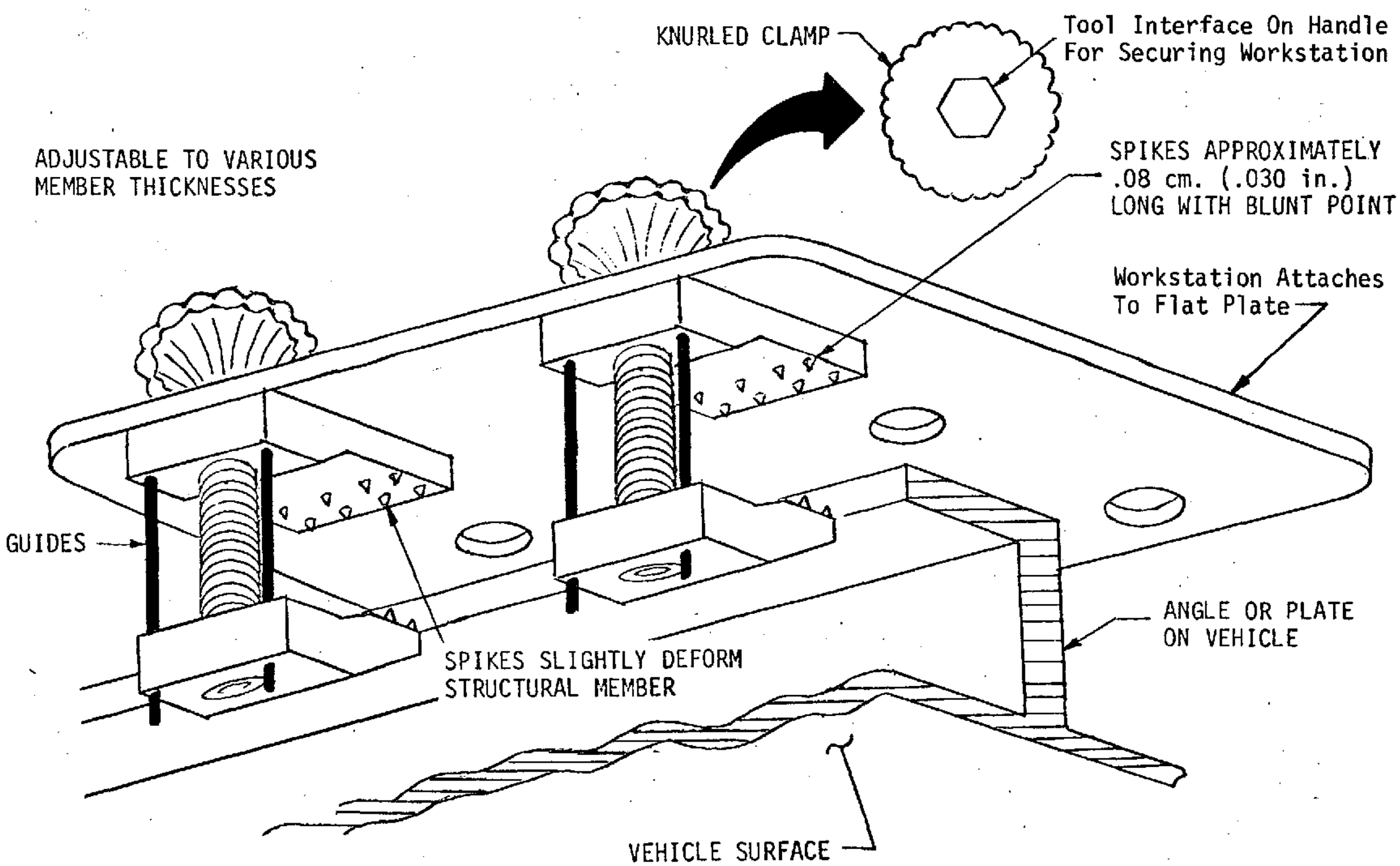


FIGURE 3.28: Workstation-to-Angle/Plate Attachment Concept

sufficiently distribute the loading to the Orbiter structure appear promising. If applied to the Orbiter TPS, all equipment, including the adhesive, must be removed prior to reentry. Adhesive systems with one of the following properties may be applicable:

- Adhesive degrades and releases within a specific time after exposure to the space environment
- Adhesive releases immediately upon application of release agent
  - Release agent is compatible with EMU subsystems and TPS
- Encapsulated (miniature) adhesive release agent capable of being released with a special "radio" frequency input
- Mechanical release of adhesive release agent located in restraint system
- Heat applied/released adhesives utilizing auxiliary MMU power packs
- Mechanical release of adhesive restraints by segments (strength of adhesive must be below .6 kg/cm^2 (8 lb/in^2) to avoid TPS damage)

The availability of adhesives possessing the desired characteristics were not researched by the contractor. The reader is referred to major adhesive manufacturers' specifications and the "Space Shuttle Program, Drawings, Specifications, and Associated Data," Systems Integration and Orbiter Vehicle Development, JSC-07300, August 15, 1974, for detailed information.

Figure 3.29 provides a concept for attaching a set of crewman foot restraints or a portable workstation to a flat surface using three adhesive pads. The adhesive pads incorporate a socket-type interface for the expendable ball attachment devices shown in Figure 3.18. The semi-rigid adhesive pads and their triangular arrangement will compensate for slight surface discontinuity and/or curved surfaces. If the restraint pads can remain on the surface after the EVA mission, the workstation only can be removed and returned to stowage. If the restraint pads are adhered to the Orbiter TPS, both the adhesive pads/fixtures and remaining adhesive must be removed (requires detailed study to determine the amount of adhesive residue allowed to remain on each Orbiter TPS

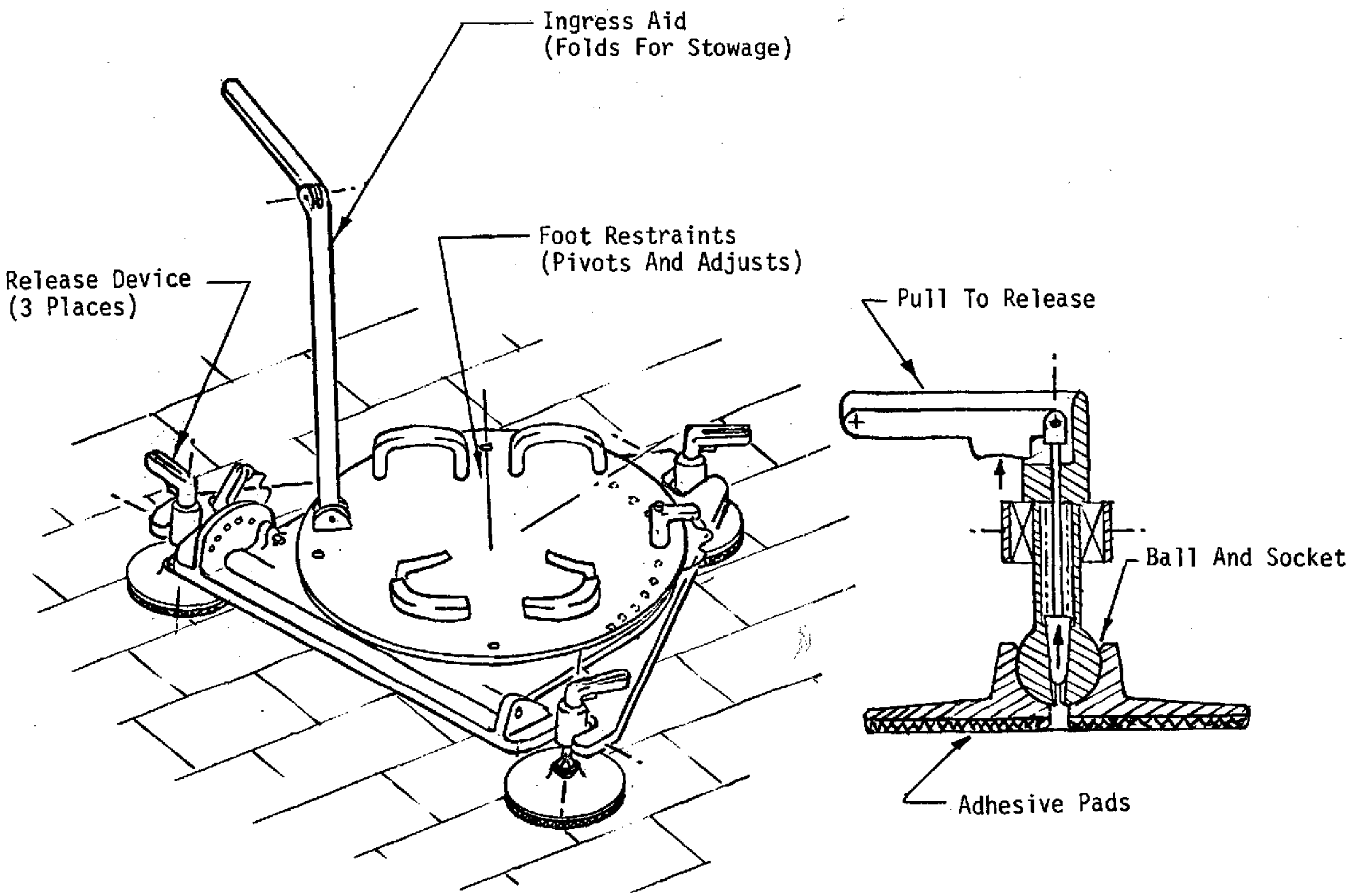


FIGURE 3.29: Foot Restraint Concept--Unprepared Site
(Ball and Socket with Adhesive Pads)

surface). The size of the adhesive pads may vary depending on the force application required at the specific worksite. Each 10 cm. (≈4 in.) diameter adhesive pad with a bonding strength of .4 kg/cm^2 (≈6 lbs/in^2) will provide approximately 35 kg. (75 lbs.) reactive force.

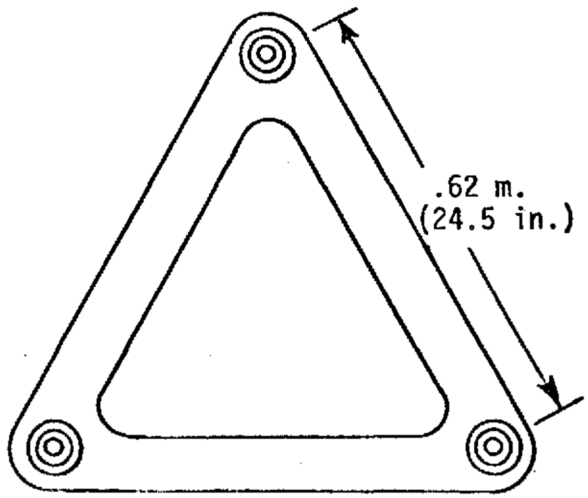
An adhesive restraint system requiring greater reactive force capability than the previous concept is shown in Figure 3.30. The adhesive pad would attach only to relatively smooth surfaces. The restraint fittings located on the adhesive pad swivel to allow proper alignment with the workstation attachment devices. The adhesive pad may be designed for segmented mechanical release or release by adhesive solvents. An application of a portable workstation/ adhesive pad concept is depicted in Figure 3.31. The illustration shows an MMU-clad EVA crewman performing a TPS repair on the Shuttle Orbiter.

Figure 3.32 presents a concept for attaching the MMU to a flat surface using segmented adhesive pads. The pads would be sized depending on the force required at the worksite to perform the desired EVA tasks. For removal, the concept would permit only small portions (strips) of the adhesive bond to be concurrently broken until the complete unit is removed. The adhesive pad interface to the MMU would utilize previously discussed concepts with a contingency jettison capability. An adhesive pad mounted on each control arm, supplemented with flexible tethers, should provide sufficient restraint for most MMU Shuttle applications.

An adjustable tether concept for crewman mobility and stabilization along an extended worksite is shown in Figure 3.33. Tether attachment fittings could be adhered to the Orbiter TPS or adjustable fixtures provided for attaching to the Orbiter wing leading and trailing surfaces, vent openings, access doors, etc. The tether system may also be used as a three-point crewman restraint system for performing low-force EVA tasks. Special care must be exercised to avoid TPS damage when using the tether restraint system for Orbiter repair.

3.1.3 MMU-to-Personnel Rescue System (PRS) Interface

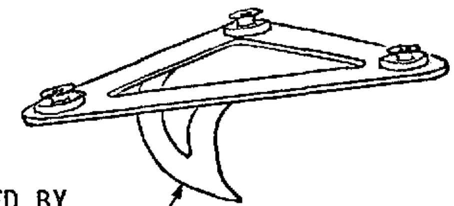
Section 3.1.3 provides concepts developed for attaching the MMU to the



CONCEPT: ADAPTER PAD WOULD PROVIDE INTERFACE FOR WORKSTATION ON ANY FLAT SURFACE

ADAPTER PAD MATERIAL: TBD

ADHESIVE MATERIAL: TBD



NOTES:

- ADHESIVE PAD MAY BE ANY SIZE AND CONFIGURATION FOR ATTACHING HANDHOLDS, HANDRAILS, WORKSTATIONS, TETHER POINTS, ETC.
- THE PAD ADAPTER MAY BE SEMI-RIGID TO ALLOW MOUNTING TO SLIGHTLY CURVED SURFACES.
- ADHESIVE PAD TO BE REMOVED BY RELEASING ADHESIVE SOLVENT.

FIGURE 3.30: Adhesive Pad Workstation Attachment Concept

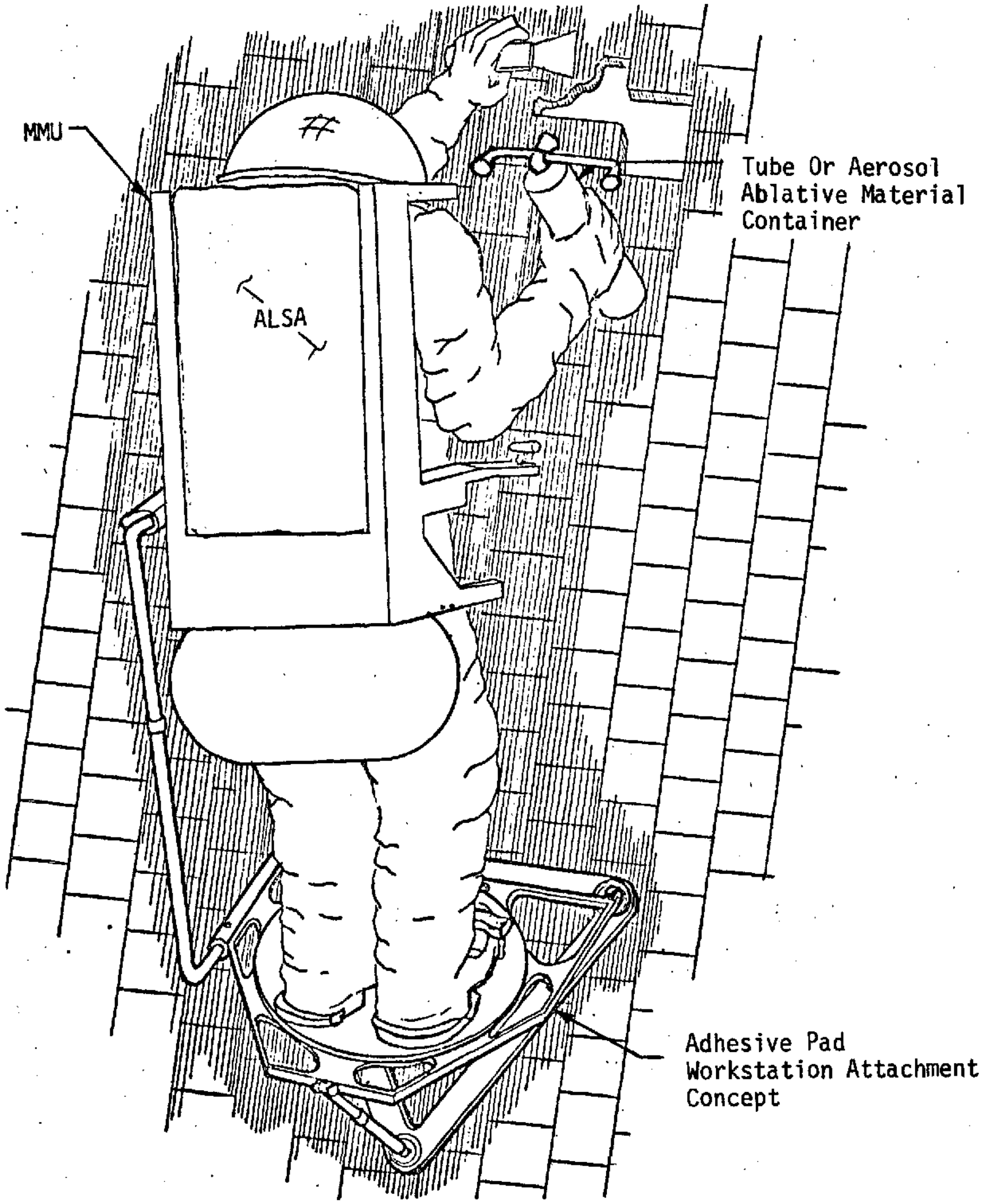


FIGURE 3.31: TPS Repair from Portable Workstation Attached to TPS

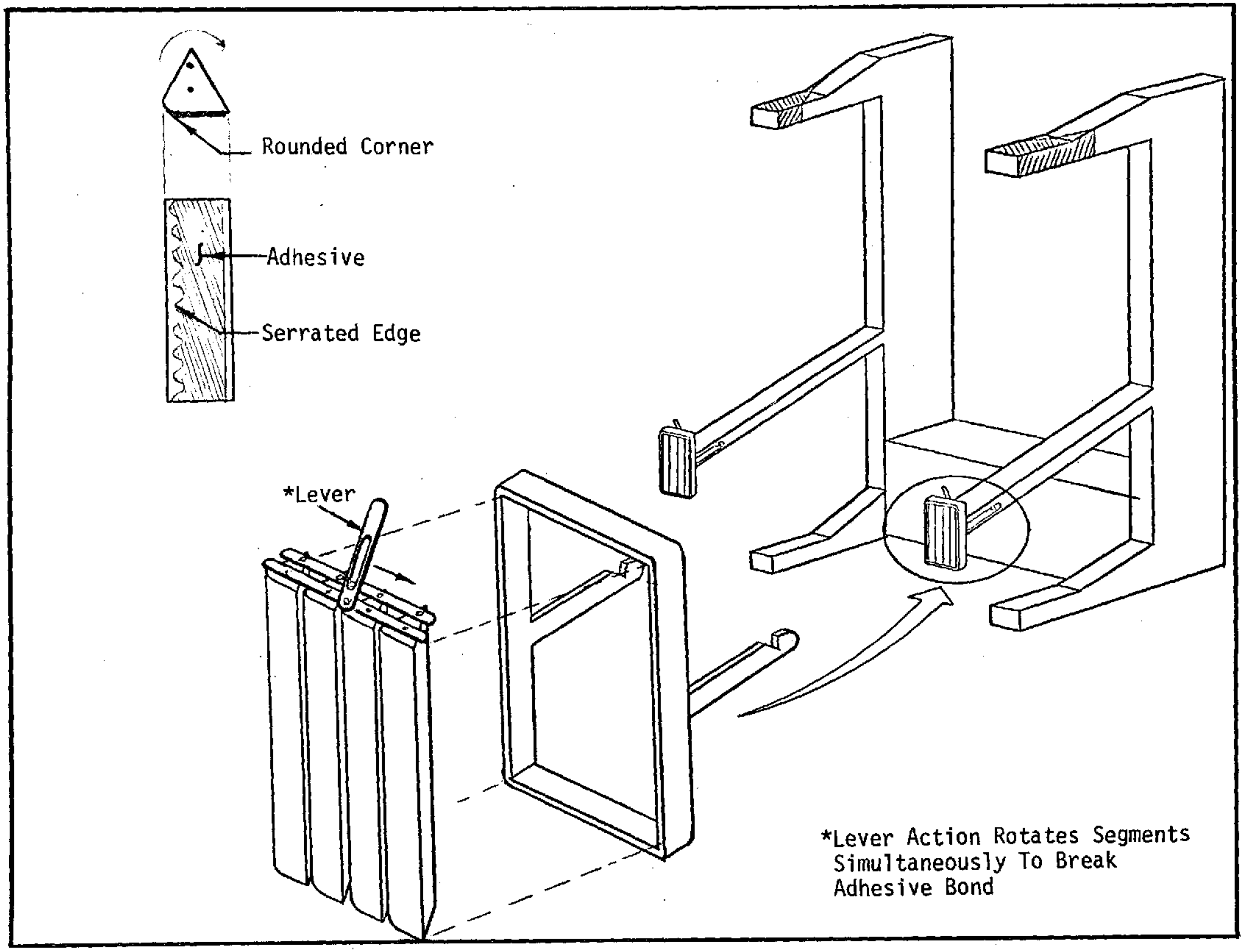


FIGURE 3.32: MMU Adhesive Attachment to Flat Surfaces--Unprepared Worksite

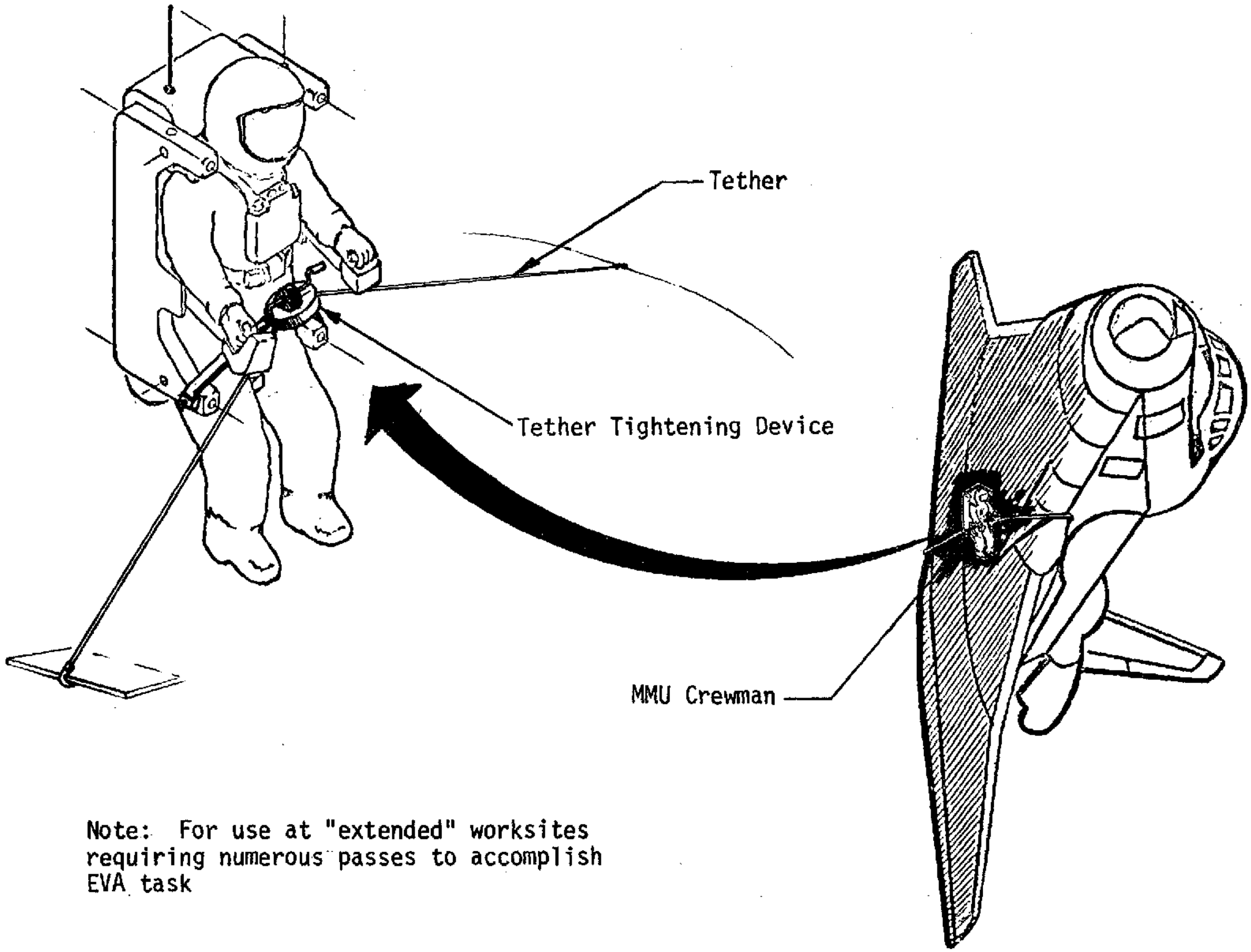


FIGURE 3.33: Adjustable Tether Concept--Shuttle Orbiter Restraint

proposed Personnel Rescue System (PRS). Figure 3.34 depicts a concept in which the MMU is attached to a single PRS via a simple three-point tether arrangement. The tethers may be of a "bungee" material or spring-loaded retractable tethers to maintain tension on the PRS. A three-point attachment concept is recommended: an attachment on each MMU control arm and one on or near the seat structure. This arrangement would allow the PRS to contact the ends of the control arms and the rescue crewman's spacesuit near the knees. Forward visibility would be maintained for MMU maneuvering. Two PRS units may be transported simultaneously by tethering the PRS units together at three points. Another PRS transporting concept may utilize two MMU crewmen with up to three PRS units tethered together and transported between the MMUs. The dual MMU-PRS transporting technique would employ a single tether attachment to the MMUs.

Figure 3.35 depicts a more sophisticated PRS capture/restraint concept. The bifurcated units consist of pneumatic expandable arm structures to grasp the PRS, a systems operations panel, and provisions for emergency PRS oxygen. The force applied to the PRS is controlled by regulating the pressure in the expandable arms. The arms of the unit are stowed in the housing when not in use. The unit is attached to the lower thruster housings by quick release mechanisms with a redundant (contingeny) release capability. Other subsystems, such as PRS coolant circulation, O_2 status, temperature, etc. could be incorporated into the bifurcated PRS capture unit.

The PRS capture concept shown in Figure 3.36 is a mechanical version of the preceding concept. The mechanical concept provides only capture and restraint capabilities. The PRS is restrained by four grappling members configured to accommodate the PRS external configuration. The system may be designed to automatically close upon contact with a PRS or be manually actuated. The grappling members of the PRS capture system are stowed during translation to the PRS site and deployed immediately prior to capture. The force applied to the PRS is controlled by the MMU crewman. The PRS capture unit is attached to the MMU control arms using previously discussed attachment concepts and contingency release provisions.

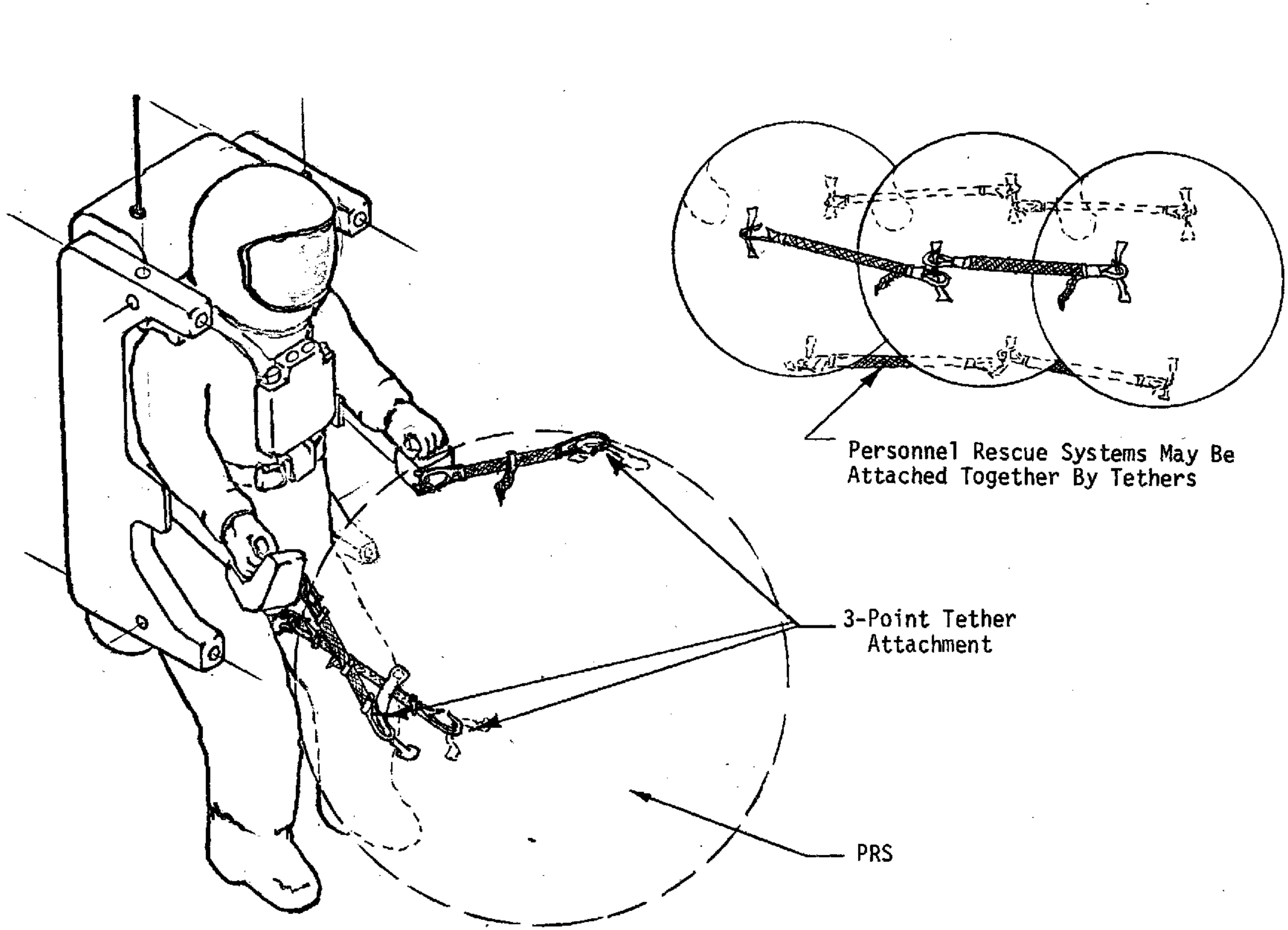


FIGURE 3.34: PRS-to-MMU Attachment Interface--Tether Concept

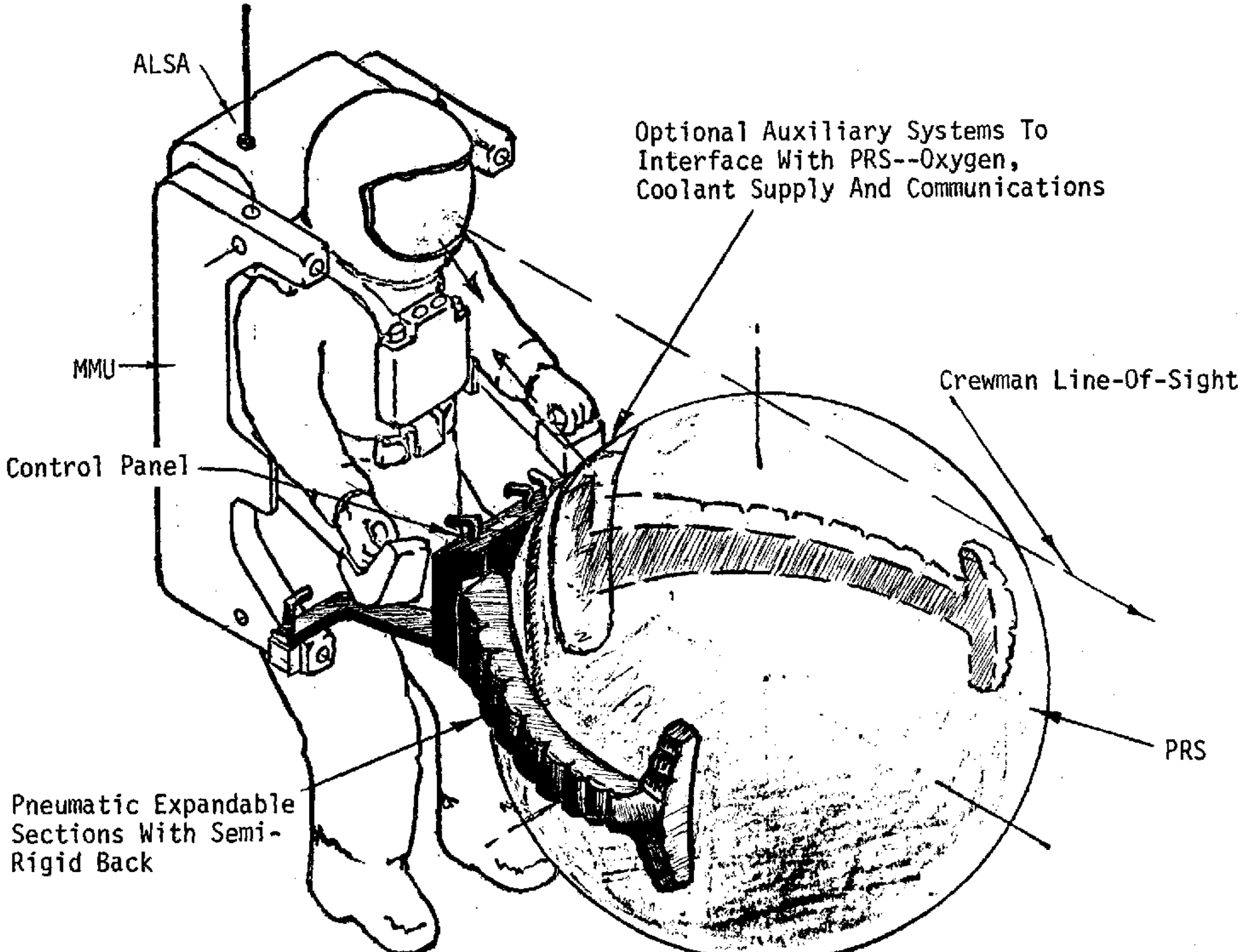


FIGURE 3.35: Personnel Rescue System-to-MMU Interface--Grappler Arm Concept

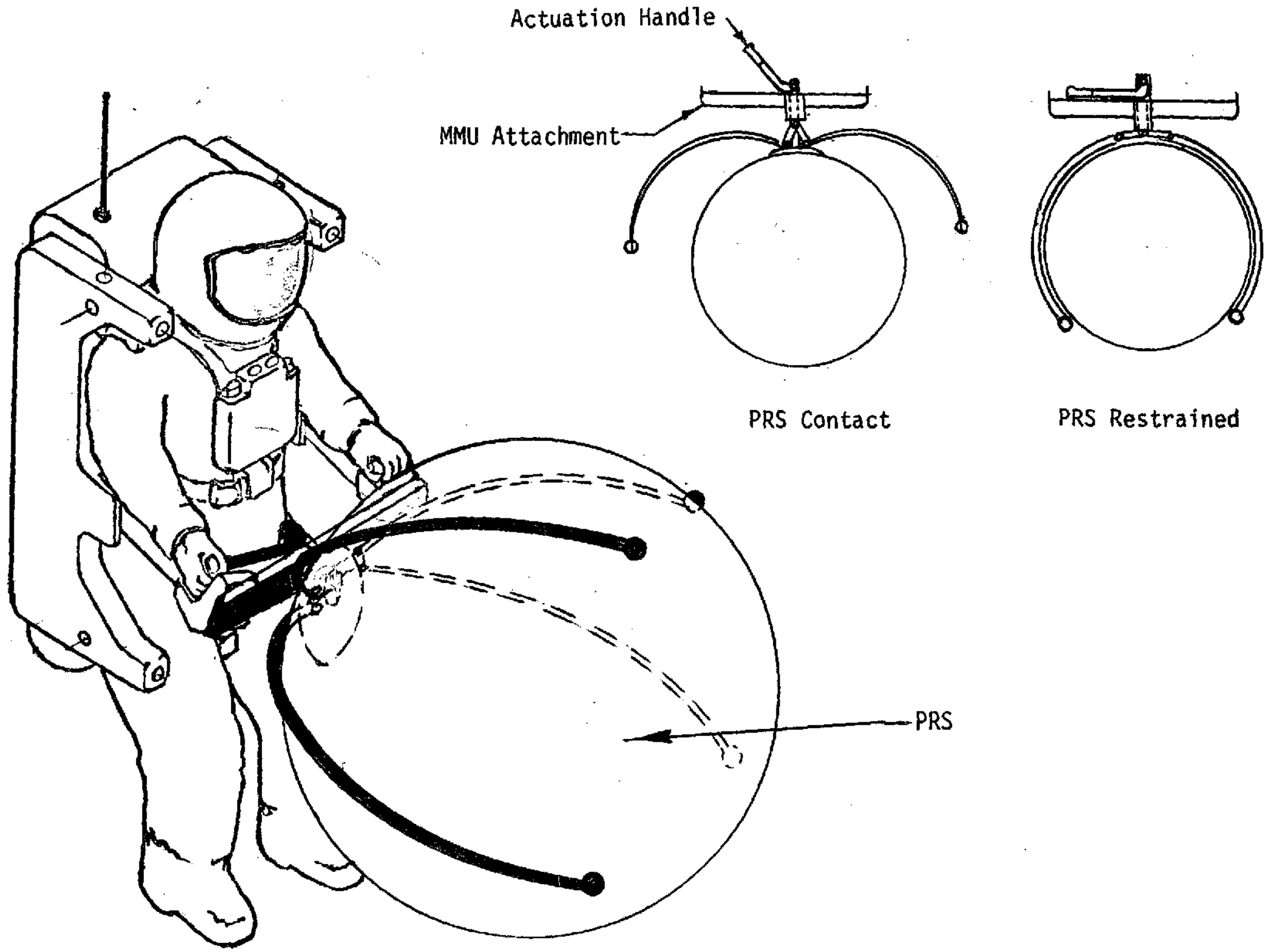


FIGURE 3.36: Mechanical PRS Grappler Device Concept

3.1.4 MMU-to-Suited Crewmen Interface

Attaching a spacesuited crewman in full EMU (Extravehicular Mobility Unit) gear to an MMU is a viable requirement since two complete EMU systems will be used by disabled Orbiter personnel in all rescue operations. In a bail-out rescue situation (i.e., disabled, unstable Orbiter), the MMU may be required to retrieve two free-floating suited crewmen from space. Figure 3.37 illustrates a tether-attachment concept for restraining the crewman with full EMU equipment. A three-point tether attachment arrangement is recommended to stabilize the crewman during MMU rescue maneuvers. Restraining straps, D-rings or other suitable tether interfaces will be required on the spacesuit or EMU equipment. The capture/restraining concept shown in Figure 3.35 is also applicable to spacesuited crewman rescue.

3.1.5 MMU-to-MMU Interface

Orbital conditions may arise that require transporting MMUs to a disabled Orbiter for rescue support and retrieval of disabled free-floating MMUs due to equipment malfunctions or an incapacitated crewman. Figure 3.38 illustrates a concept for mechanical attachments for transporting an unmanned MMU on-orbit. The restraint pin attachment concept allows MMU positioning in a fixed orientation without impeding forward visibility or restricting thruster operation. Receptacles (passive) for restraining pin attachment would be required on the side structure of each MMU. The same receptacles used for MMU restraint during launch and reentry may be utilized for MMU-to-MMU attachment. The ball and socket attachment concept allows the MMU to be oriented for optimum control during transporting maneuvers. After the ball attachment is engaged in the socket, the lever is actuated to secure the MMU being transported in the desired attitude. The ball portion of the attachment mechanism would be mounted on the exterior of the MMU either as a permanent fixture or a quick disconnect for on-orbit attachment. The attachment concepts shown in Figure 3.38 may also be used when the MMU is manned.

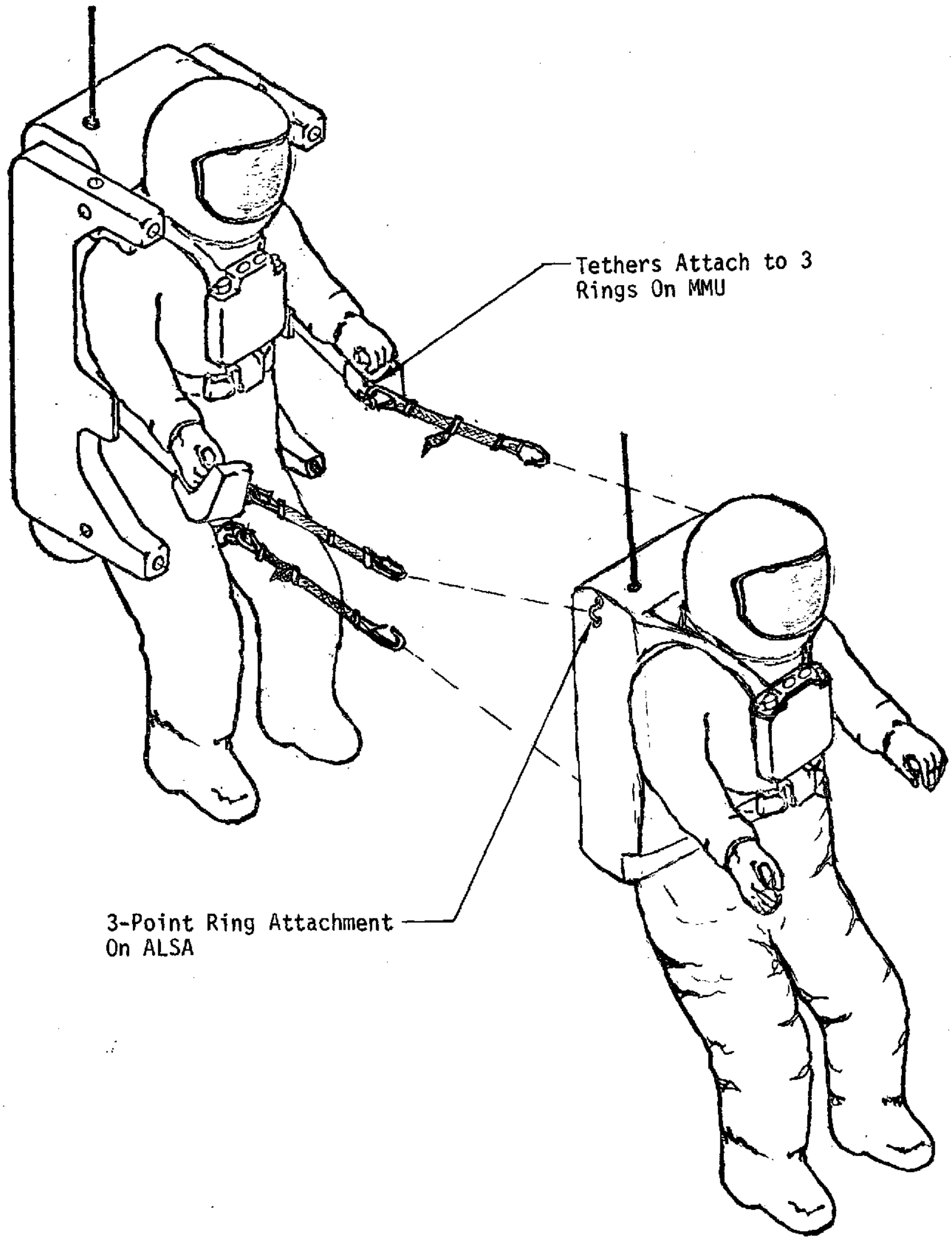


FIGURE 3.37: MMU-to-Spacesuited Crewman Interface--Tether Concept

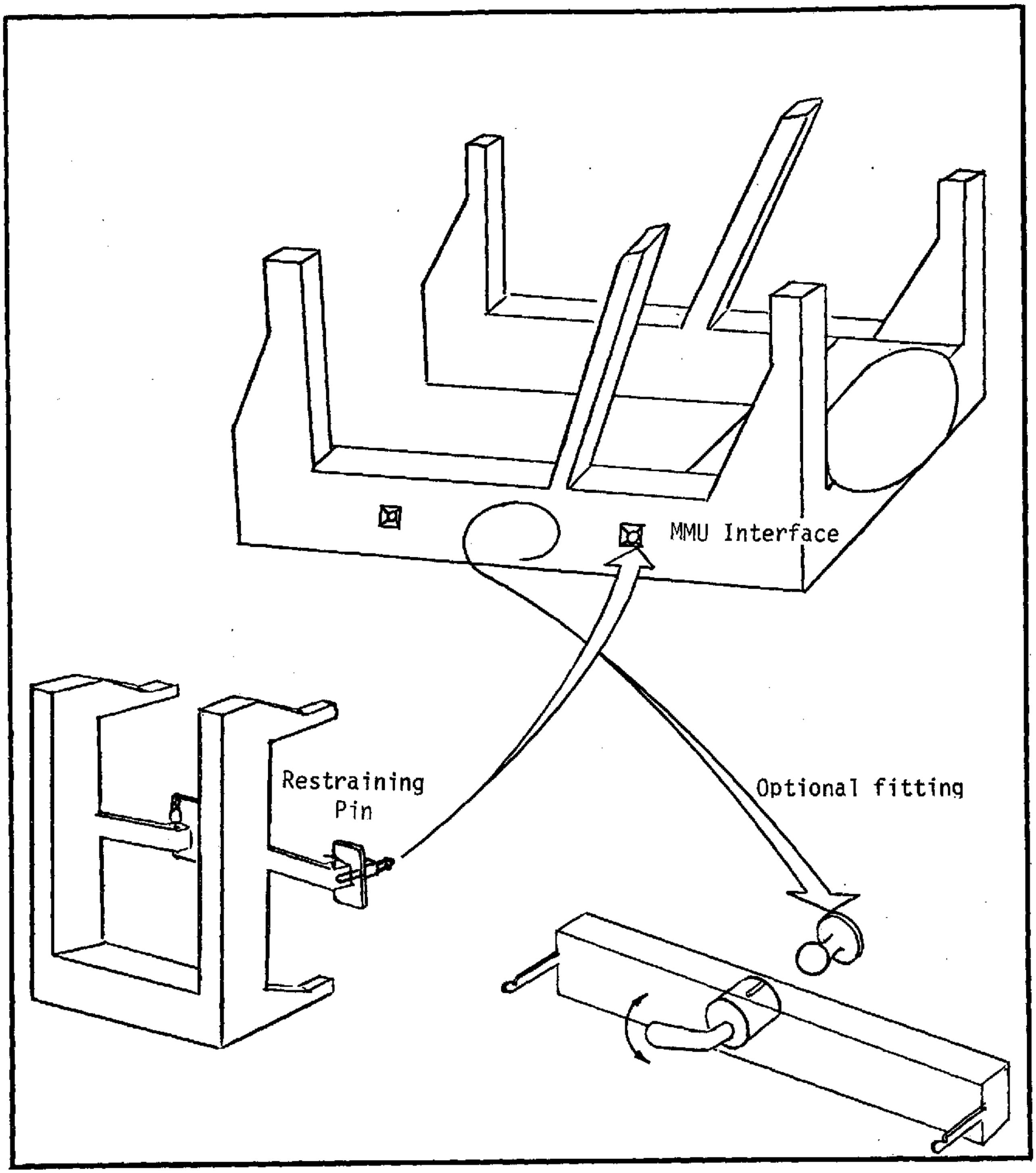


FIGURE 3.38: MMU-to-MMU Attachment--Mechanical Concept

The capture/restraining system concept derived for PRS attachment/restraint could also be utilized in MMU transporting and rescue operations. The concept is illustrated in Figure 3.39.

3.2 MMU ANCILLARY SUBSYSTEM INTERFACES

The MMU crewman will require ancillary equipment, such as lights, cameras, tool attachments, temporary module stowage, and provisions for attaching various supporting equipment during EVA task performance. This section provides conceptual designs of MMU ancillary equipment interfaces to support potential EVA missions. Attempts were pursued to develop concepts which located the equipment and attachment interfaces within the reach and visibility of the crewman while in the MMU. If such designs became impracticable, concepts that provided, as a minimum, crewman reach access were then developed. Equipment attachment at locations inaccessible by the MMU crewman were the least desirable, though required, in several concepts. In many applications, the support equipment remained attached to the MMU throughout the EVA missions and does not require crewman access at the worksite.

Figure 3.40 illustrates common types of equipment interfaces successfully used on previous U.S. space programs. Since the external configuration of the MMU was not available for this study, design of detailed attachment mechanisms was not attempted. Efforts were centered on providing general concepts and locations of the numerous equipment items required to support potential MMU Shuttle applications. As the MMU design program progresses, numerous mechanisms for attaching ancillary equipment can be derived from previous space hardware and modified for MMU application. Totally new attachment hardware requirements are not anticipated. Many ancillary equipment attachment interfaces suggested in the following illustrations are derivations from previously depicted concepts.

The concepts for interfacing ancillary support equipment to the MMU are classified into general categories and presented in the following subsections:

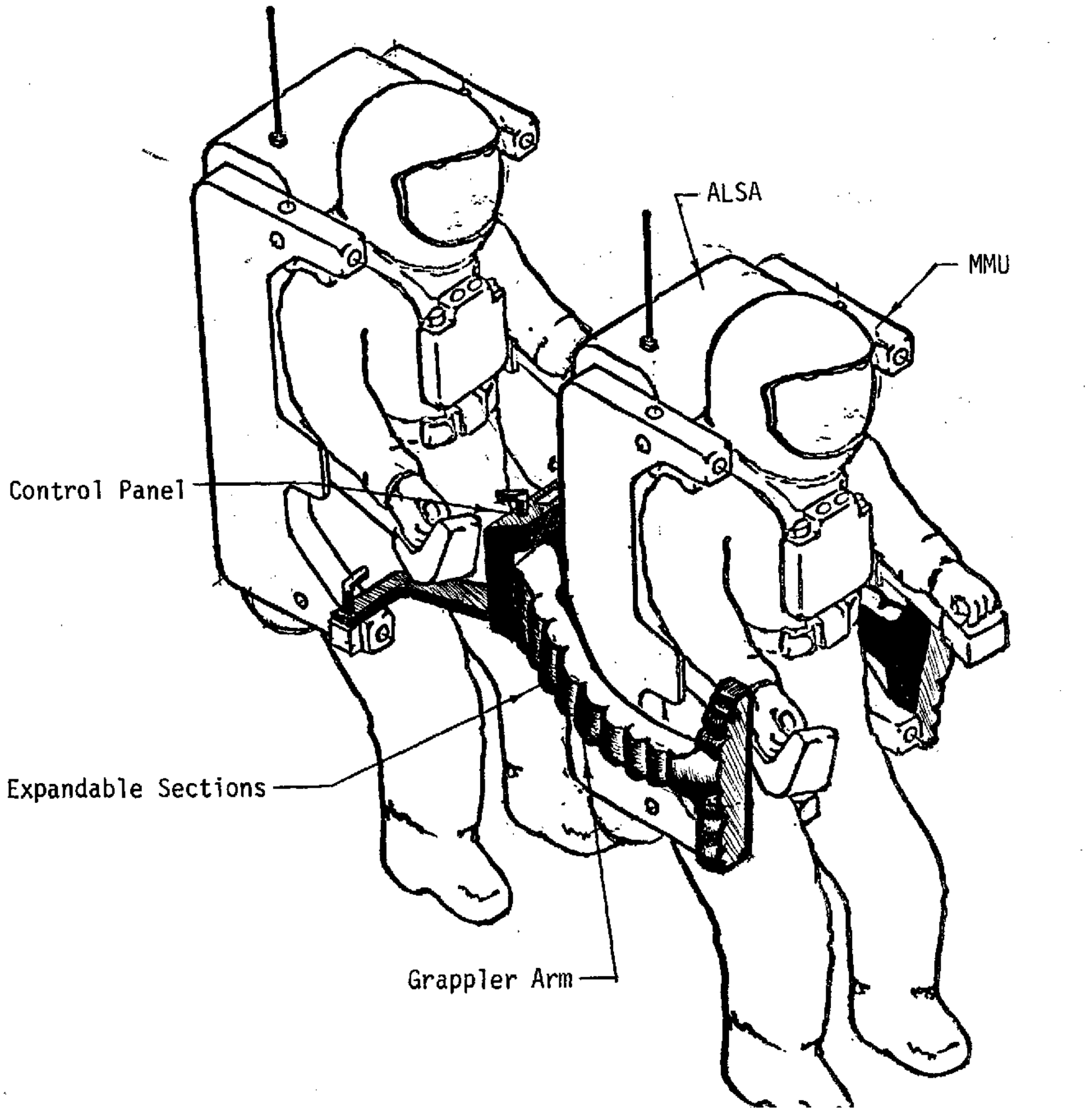


FIGURE 3.39: MMU-to-MMU Capture/Restraint Concept--Grappler Arm Concept

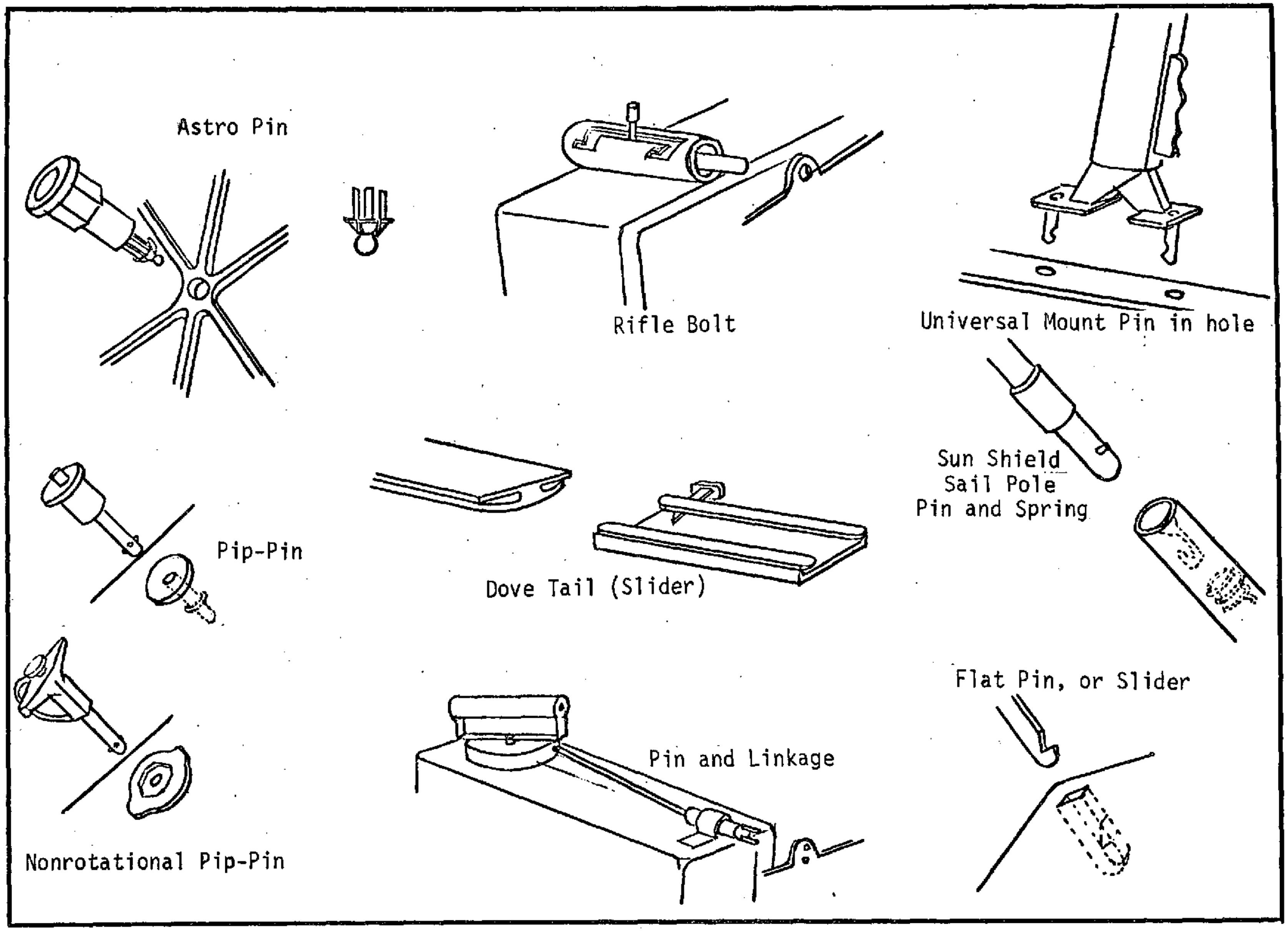


FIGURE 3.40: Space Qualified Attachment/Fastening Equipment Illustrations

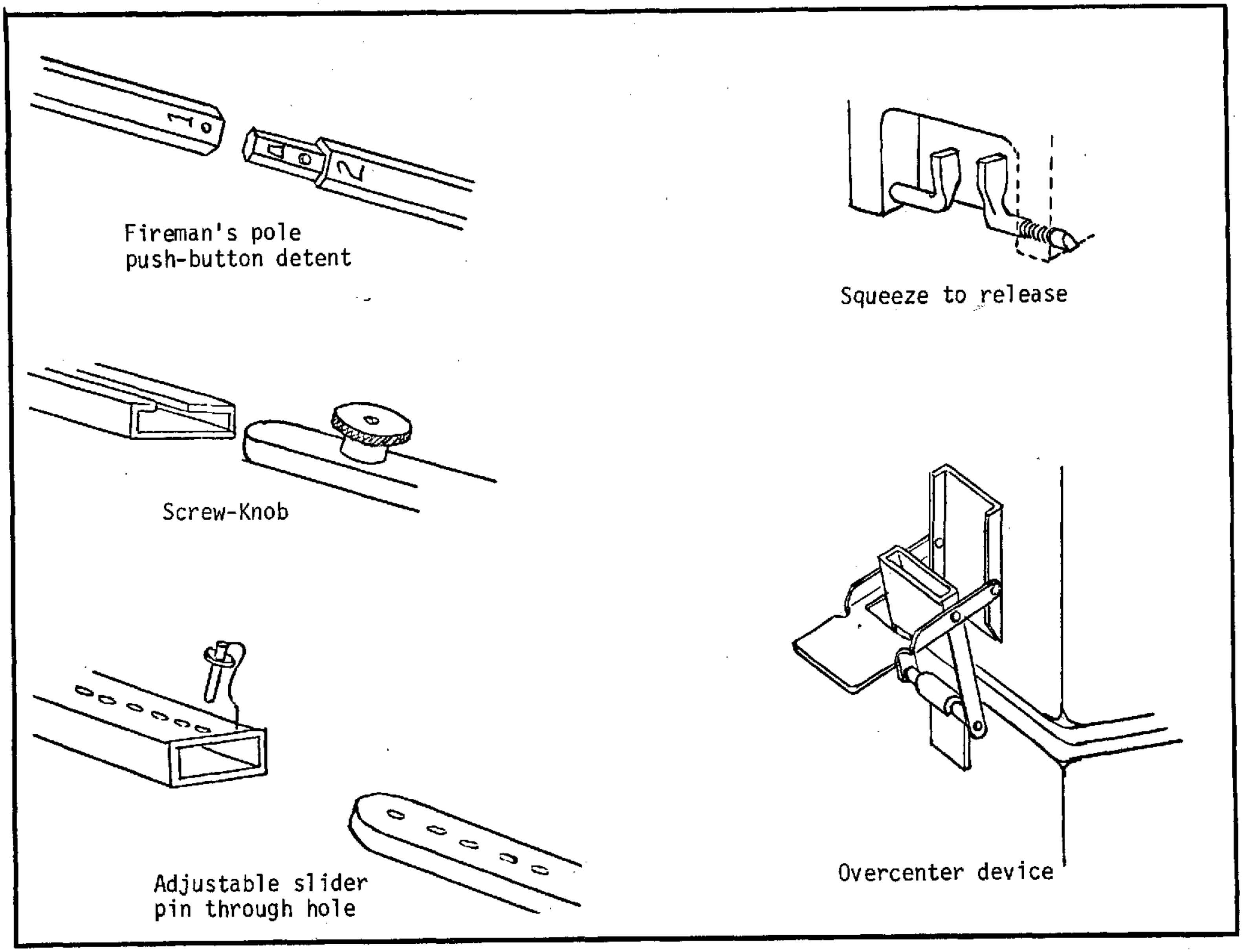


FIGURE 3.40: Space Qualified Attachment/Fastening Equipment Illustrations (con't)

3.2.1 Visibility and Illumination Equipment Interfaces

The MMU will be used in extravehicular activities during both light and dark periods of the earth orbit. Auxiliary lighting may be required at the worksite and MMU stowage location during dark periods and to eliminate shadowing during the light periods. Visibility using indirect reflective surfaces may be required for donning and doffing the MMU, at various worksites, and for "towing" cargo.

The concept in Figure 3.41 provides a total visibility system including mirrors, cameras, lights and an auxiliary power module. The system folds for compact stowage and may be restrained to the MMU by modified pip-pin fasteners. The light mounting arrangement contains a ball-joint device for adjustment and can be locked firmly in place at any desired orientation. Figure 3.42 illustrates a concept of a flexible device for attaching visual aids, cameras, etc. A "joy-stick" control would allow remote manipulation of the attached hardware. A switch arrangement located on the control stick provides power to the MMU support item. An auxiliary power supply could be furnished or an electrical connector for power directly from the MMU system depending on the auxiliary power required. The extra power supply could also be used to power the MMU systems in a contingency situation or to increase MMU mission duration.

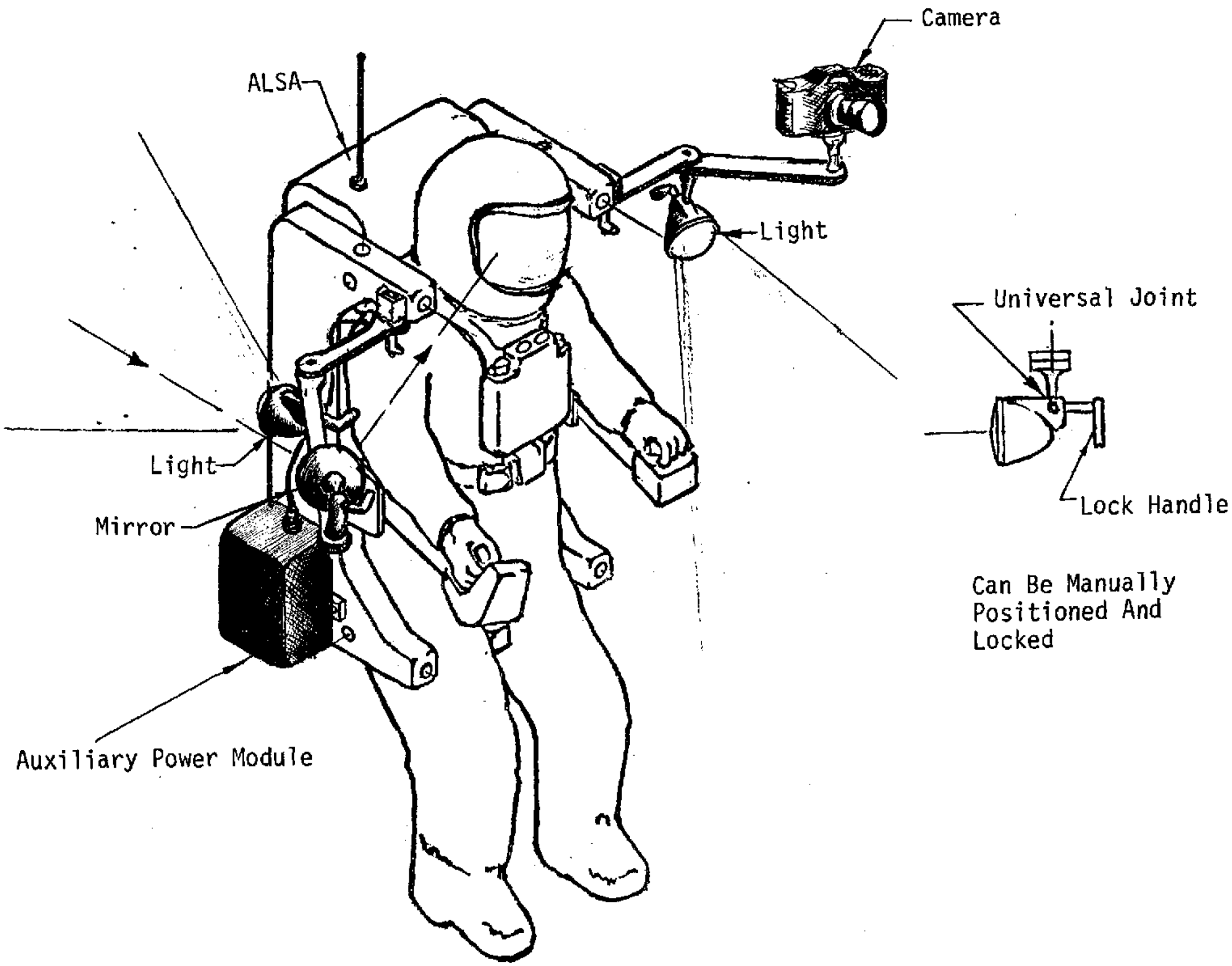


FIGURE 3.41: Ancillary MMU Subsystems for Visual Support--Location and Attachments

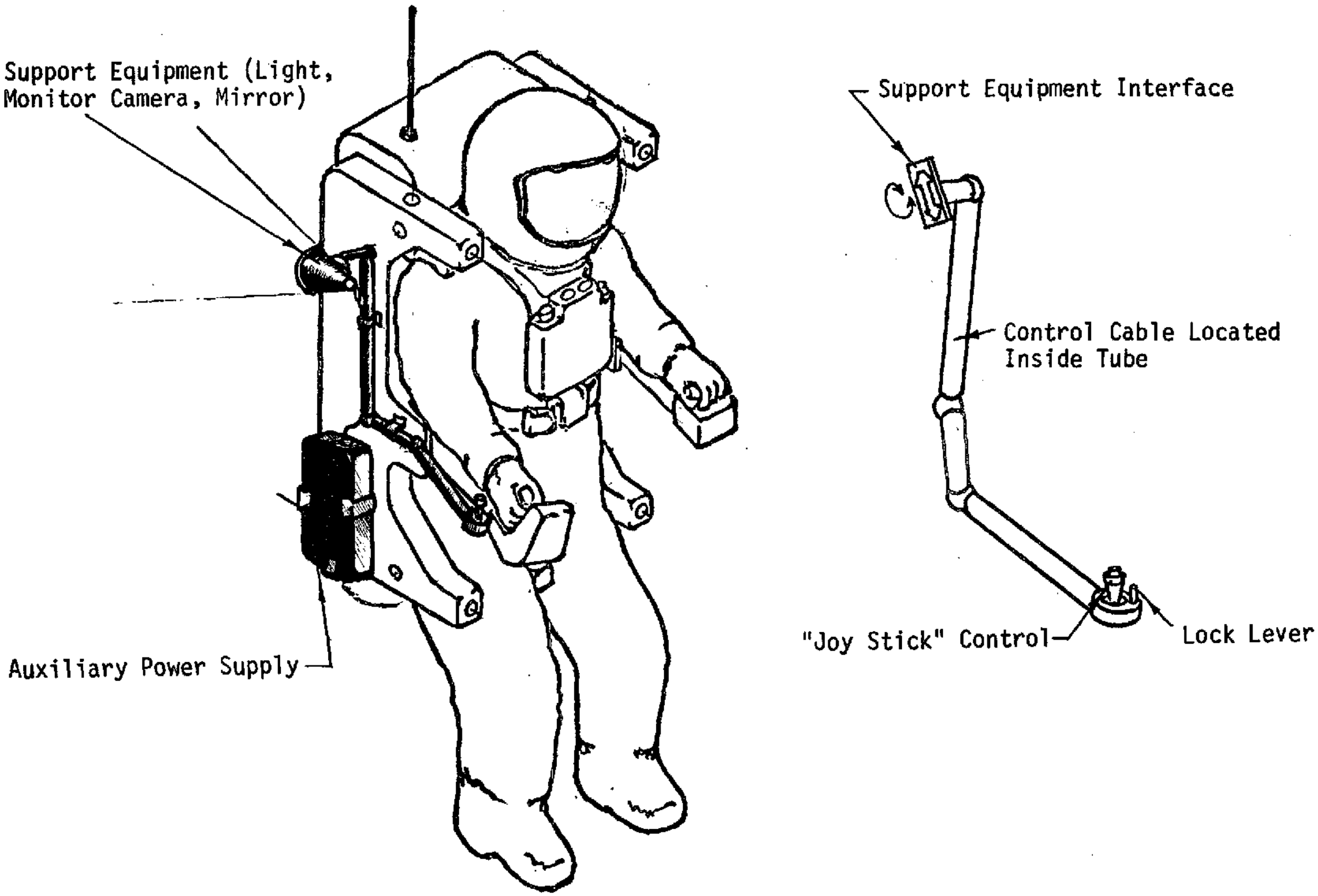


FIGURE 3.42: Remote Control Ancillary Equipment Mounting Concept

3.2.2 Tool Stowage Interfaces

Concepts for tool stowage caddies and their interfaces to the MMU and other support modules are provided in this subsection. Figure 3.43 depicts a tool kit mounted to the side of the MMU control arm. This location provides good visual and reach access to the stowed tools. The kit can be rotated to provide additional access for crewman worksite operations or positioned for optimum tool access. The shaded areas below the control arms identify the crewman's reach capability along the sides of the MMU. Special attachment fixtures for locating support hardware in these areas may be desirable.

The illustration in Figure 3.44 provides a concept for attachment of a tool kit developed on a previous URS/Matrix contract (EVA workstation concept No. 3, Application of EVA Guidelines and Design Criteria, Vol. II, NAS 9-12997, April 1973). The fastener may be a pip-pin type device which interfaces with a slot on the side of the lower thruster housing. The kit also contains an operations checklist, light or camera, and a self-contained power supply. The crewman can access all tool kit attachment devices for contingency release. The tool kit pivots 180^{o} about the forward attach point during MMU maneuvers, if required.

Figure 4.45 illustrates a tool caddy concept and a method for attachment to the MMU. The tool caddy would be in the closed configuration during MMU translation maneuvers. The deployed configuration for crewman access is depicted in the figure. Construction and operation of the tool caddy is shown in Figure 4.46. The bottom panel of the caddy would be constructed to provide rigidity to the unit for interfacing with the MMU and attachment of caddy components. Each panel would have a framework for rigidity and would rotate into detents to hold the tool pouch open or closed as desired. Selected panels could be covered with fabric in a "baggy" fashion and be lined with elastic strips, bungees, springs, hooks or rings for tool restraint. An optional panel could consist of a transparent bag covering a rigid frame and contain "loose" tools. The mouth of the bag would be "self-sealing" to prevent tools from floating free while the crewman is reaching inside to make a tool selection.

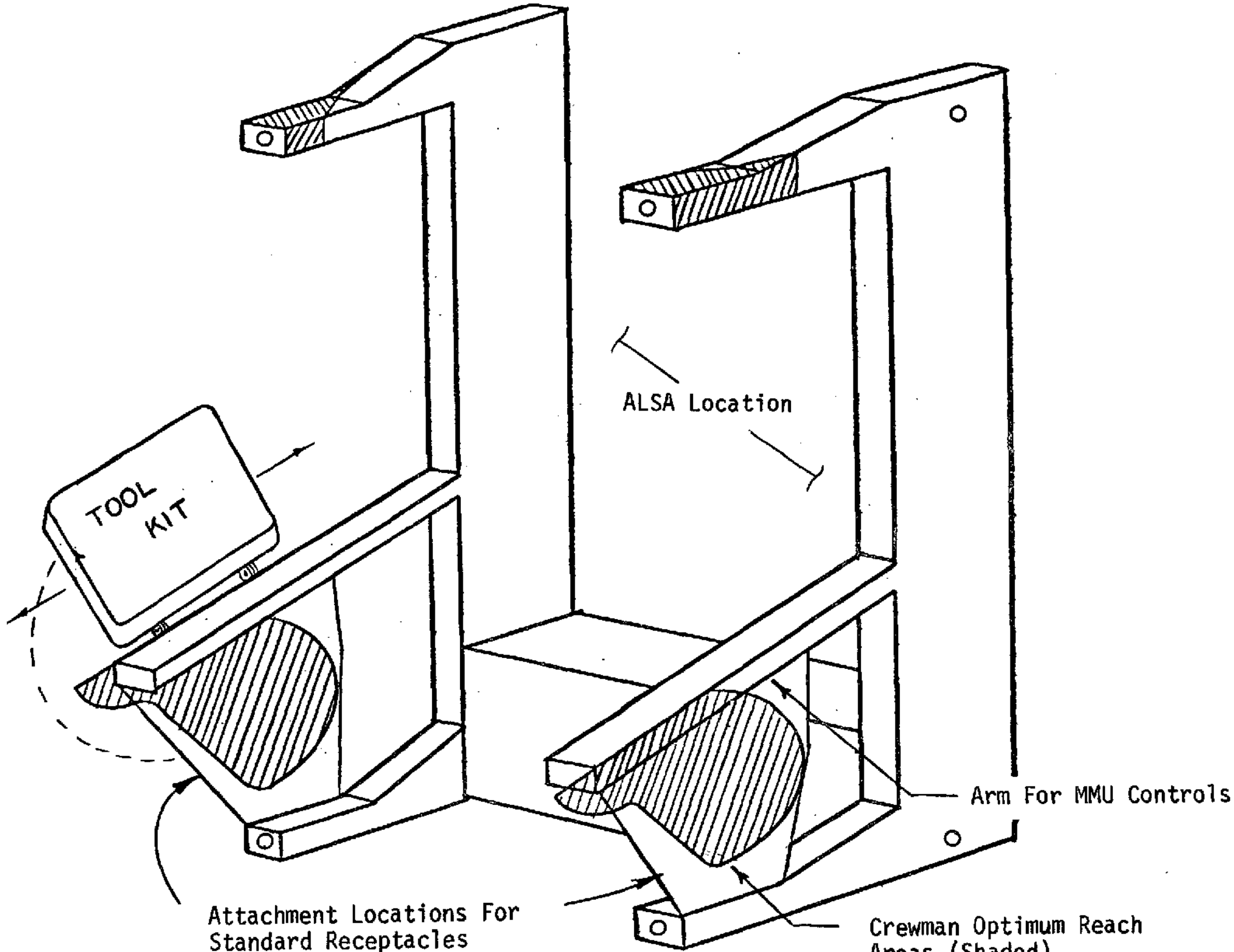


FIGURE 3.43: Tool Kit Attachment Location--Adjustable Concept

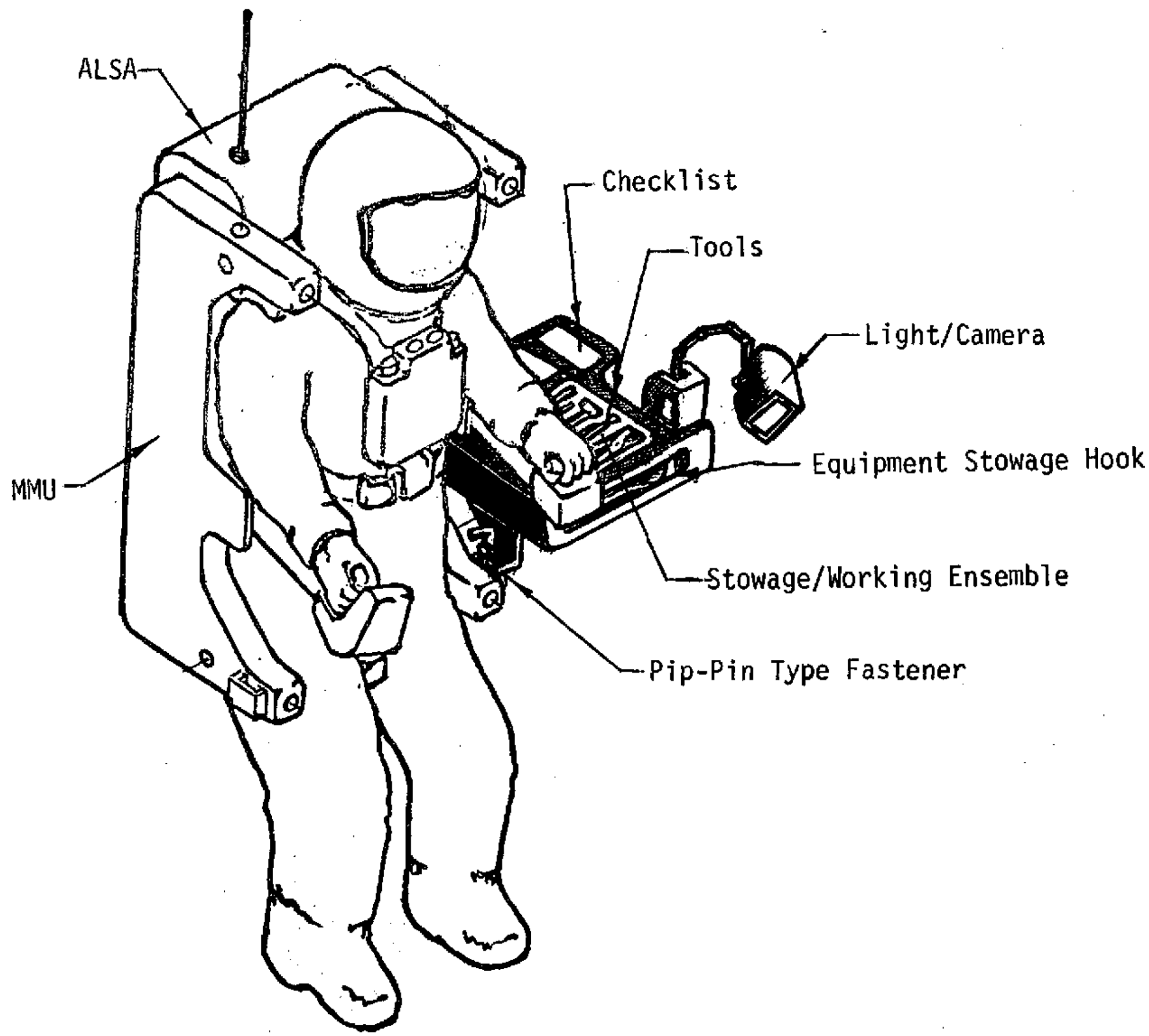


FIGURE 3.44: Tool Kit/Support Subsystem Concept

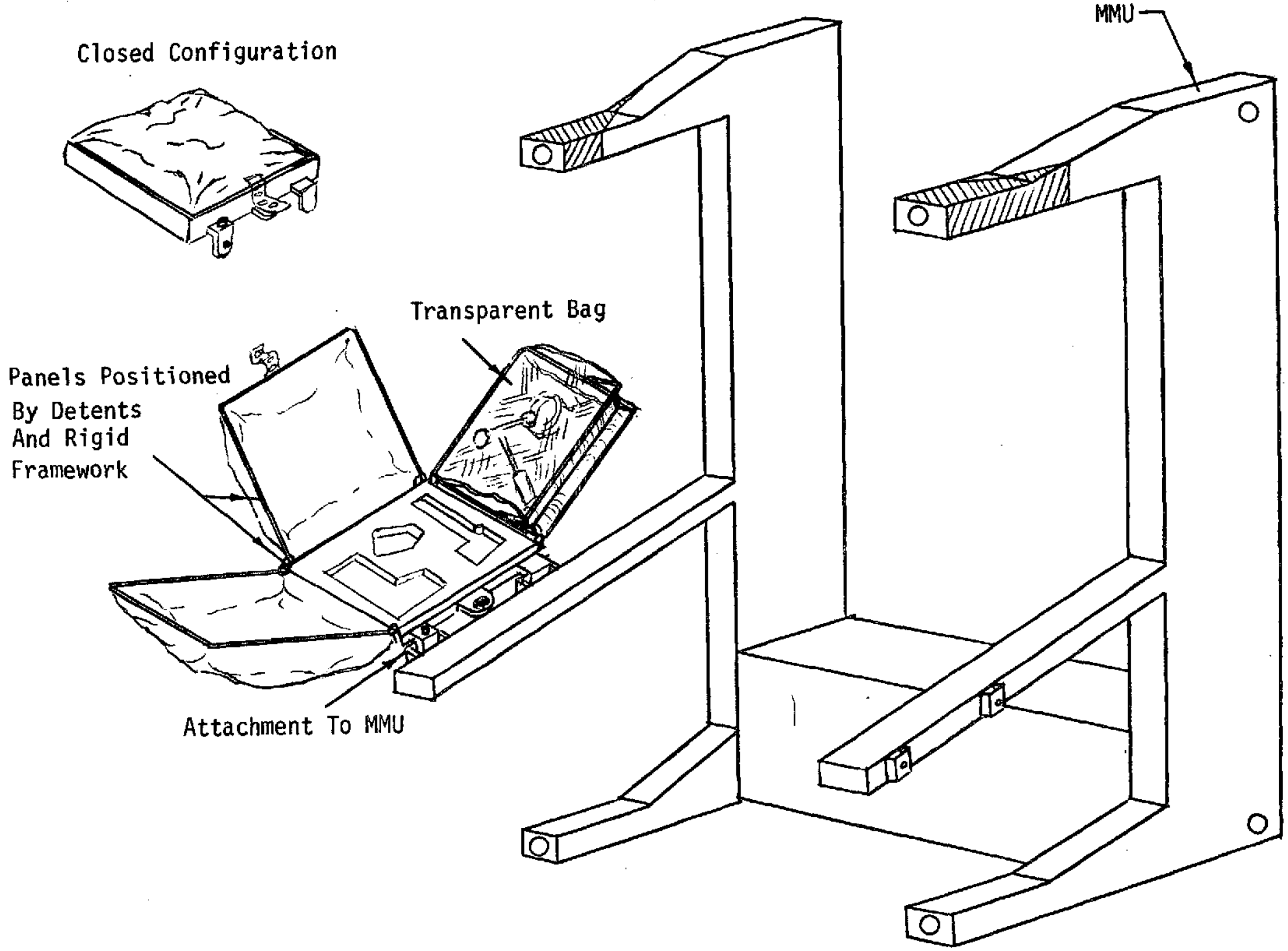


FIGURE 3.45: Tool Pouch and Attachment Concepts

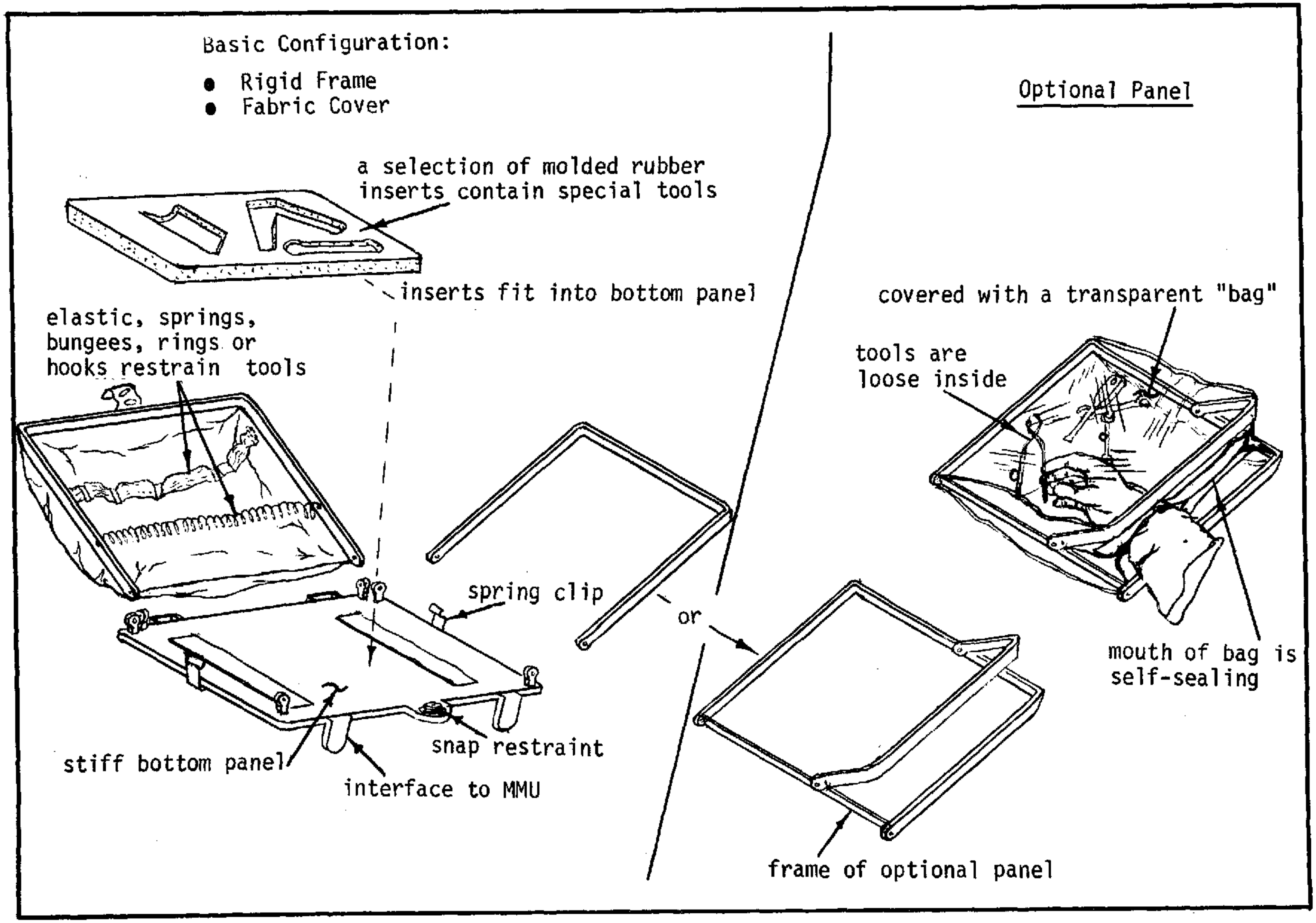


FIGURE 3.46: Tool Pouch Concept--Configuration Details

Special tools could be restrained in a molded rubber insert attached to the bottom panel of the caddy. The caddy may be stowed and launched empty and equipped from the Orbiter or payload tool inventory prior to EVA. Figure 3.47 provides a concept for "stacking" MMU supporting equipment in the area most accessible to the crewman. Standard attachment interfaces would be provided on the various support equipment to effect the stowage arrangement. The equipment would be distributed equally between the two control arms during MMU maneuvering.

3.2.3 Module Replacement Concepts

Concepts for mounting experiment replacement modules, repair kits, and special servicing equipment to the MMU are contained in this subsection. Figure 3.48 depicts a pallet concept for temporary restraint of equipment modules. The pallets attach to the MMU control arms or lower thruster housings by a slotted receptacle and slider-lock arrangement. The equipment modules may be attached to the pallets by tethers, pip-pins, clips or other compatible restraints. The concept illustrates a spring-clip restraint with a safety tether backup and also a pip-pin restraint to interface with a standard hole pattern on the pallet. Various sized and irregularly shaped modules could be stowed and transported on the pallet by utilizing a combination of restraining devices.

The concept in Figure 3.49 illustrates a three-point attachment design to secure a stowage/restraining "bar" to the MMU. The bar would incorporate removable interfaces for restraining EVA support hardware and equipment for servicing payloads. The bar may also provide a mounting interface for "universal" attachment devices, such as the Skylab universal mount. Figure 3.50 provides a bracket concept for mounting stowage containers to the MMU. The bracket would attach to the lower thruster housing with a quick disconnect restraint mechanism and rotate to the front of the MMU for transporting. The concept depicts a set of stowage drawers for housing various supplies required for the EVA missions. The containers and support bracket would incorporate a jettison capability for contingency situations.

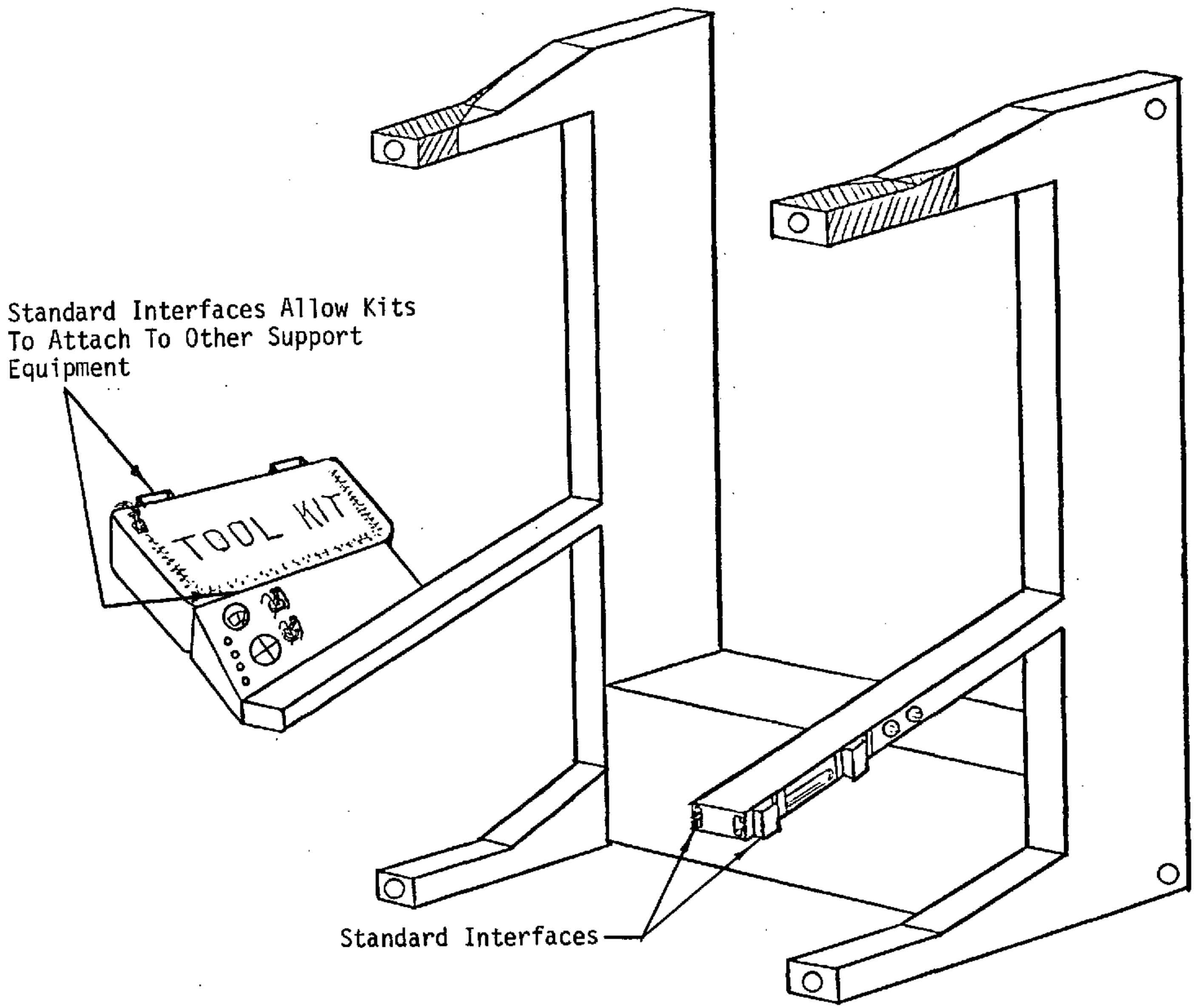


FIGURE 3.47: MMU/EVA Support Equipment "Stacking" Concept

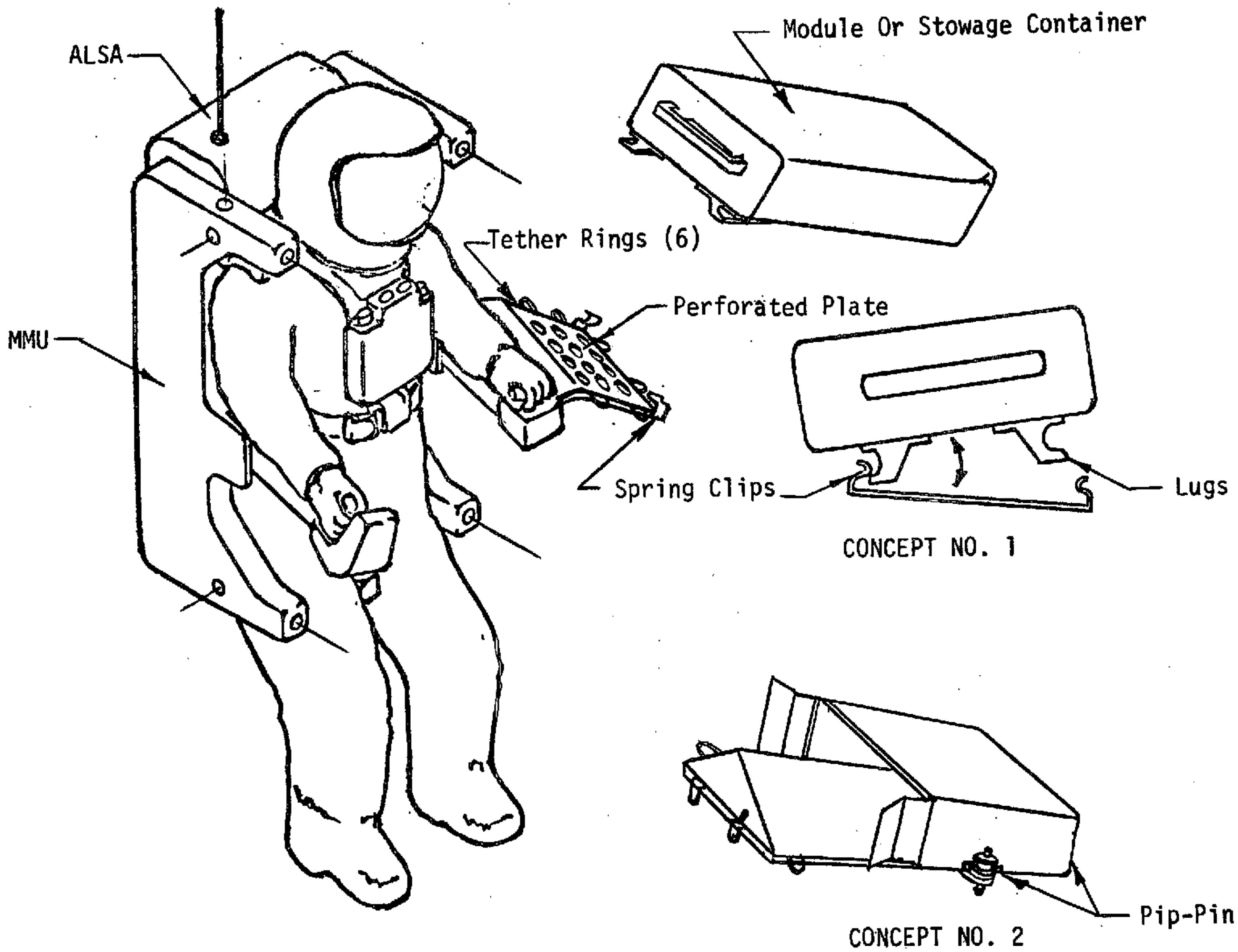


FIGURE 3.48: Ancillary Support Equipment Restraint Pallet Concept

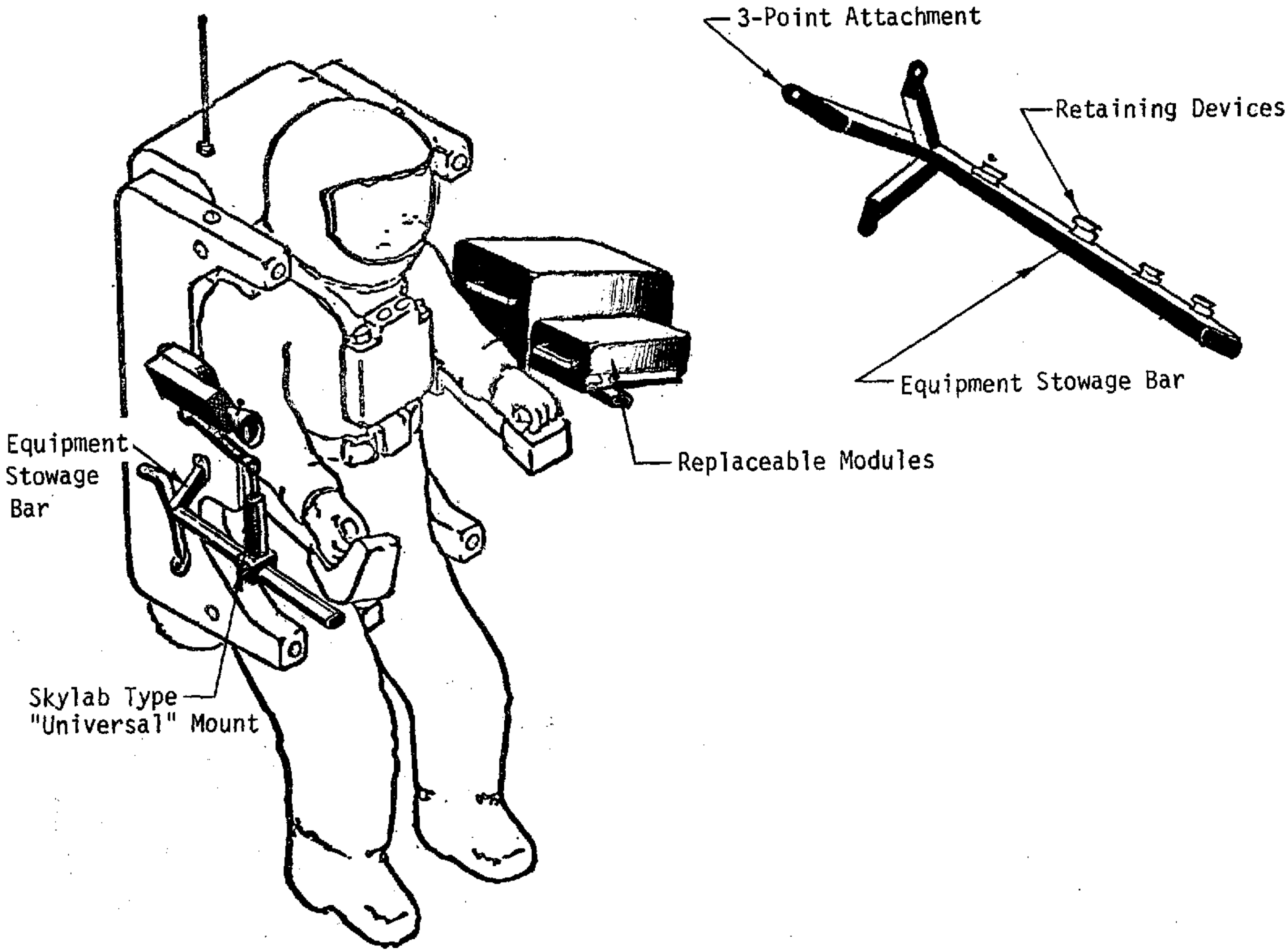


FIGURE 3.49: Ancillary Equipment Stowage Bar Concept

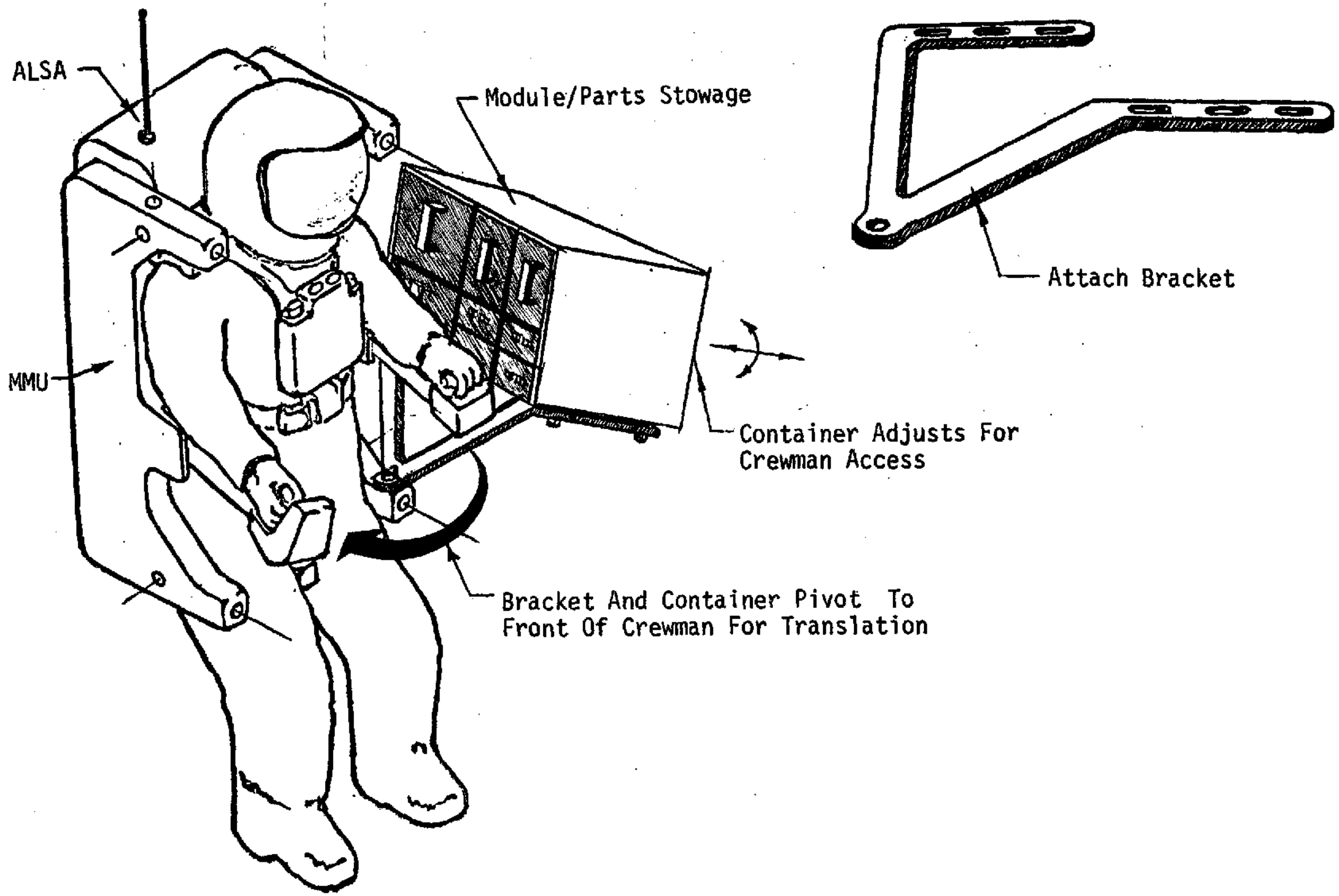


FIGURE 3.50: Orbital Systems Servicing Module Attachment Concept

3.2.4 Consumables Resupply Concept

Resupply of consumables to free-flying satellites may be an economical payload application for the MMU. Figure 3.51 shows an arrangement for resupplying propellant from a stowage tank mounted on the MMU. The stowage tank and support panel would be integrated to minimize external line routing and connectors. The consumables resupply system would be mounted to the side of the MMU prior to donning. The support panel would incorporate the necessary hoses, quick disconnects and controls for effecting safe consumables transfer. The support panel would also contain pressure gauges, warning indicators, etc. for systems' status during resupply operations. The consumables resupply system would pivot 270^{0} about the forward attach point and attach to the opposite control arm housing for MMU translation/maneuvers.

Figure 3.52 depicts an auxiliary MMU propellant stowage tank attachment concept for extending the travel-maneuvering range. The tanks would be mounted on each side of the MMU prior to crewman donning. Quick disconnect fittings are provided for plumbing into the primary MMU propellant subsystem. Valving for switching to the auxiliary propellant units is located for rapid access by the MMU crewman.

3.2.5 Data Acquisition Concepts

Figures 3.53 and 3.54 show concepts which provide mounting techniques for attaching data acquisition equipment to the MMU. Figure 3.53 depicts a concept for real-time experiment monitoring using a remote video system mounted on the MMU. The system would utilize the same video components being considered for free-flying teleoperator applications with modified equipment packaging for the MMU interface. The data acquisition equipment would include a miniature monitor for crewman-signal evaluation, data recording and video-signal relay to the Orbiter. The data acquisition concept would also be applicable to Orbiter and payload inspection and surveillance tasks.

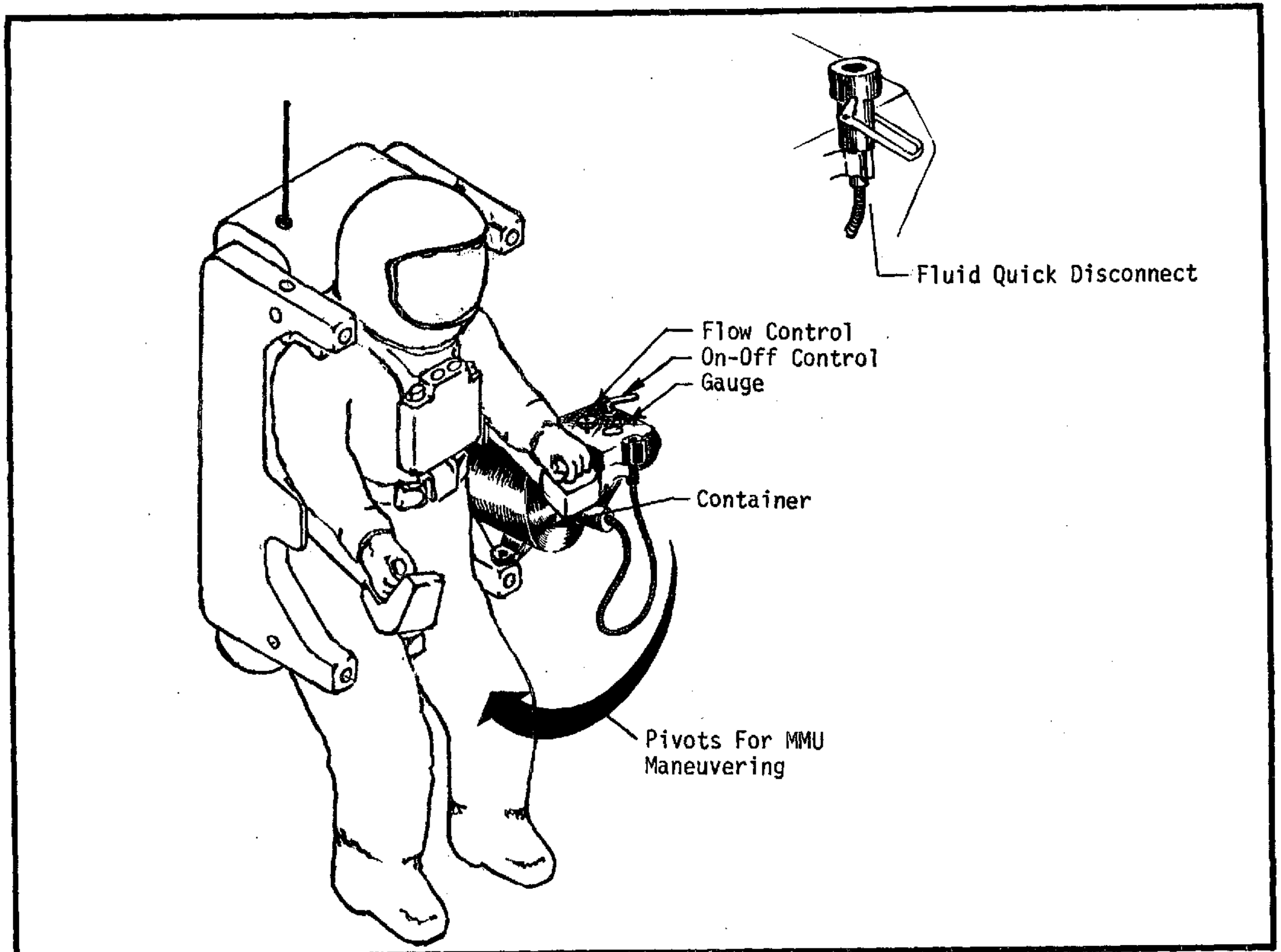


FIGURE 3.51: Consumable Resupply System Concept

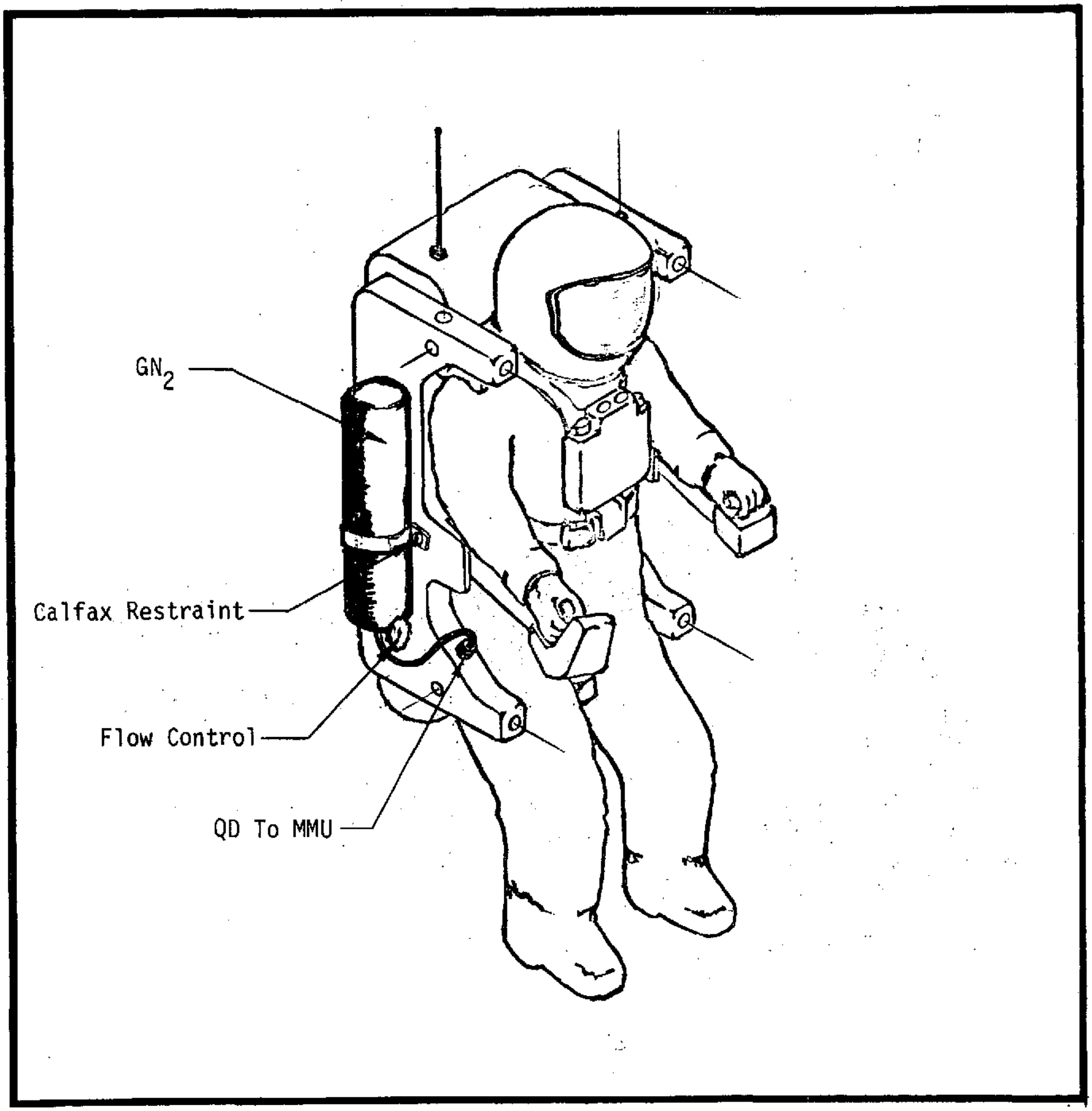


FIGURE 3.52: MMU Auxiliary Propellant Stowage Concept

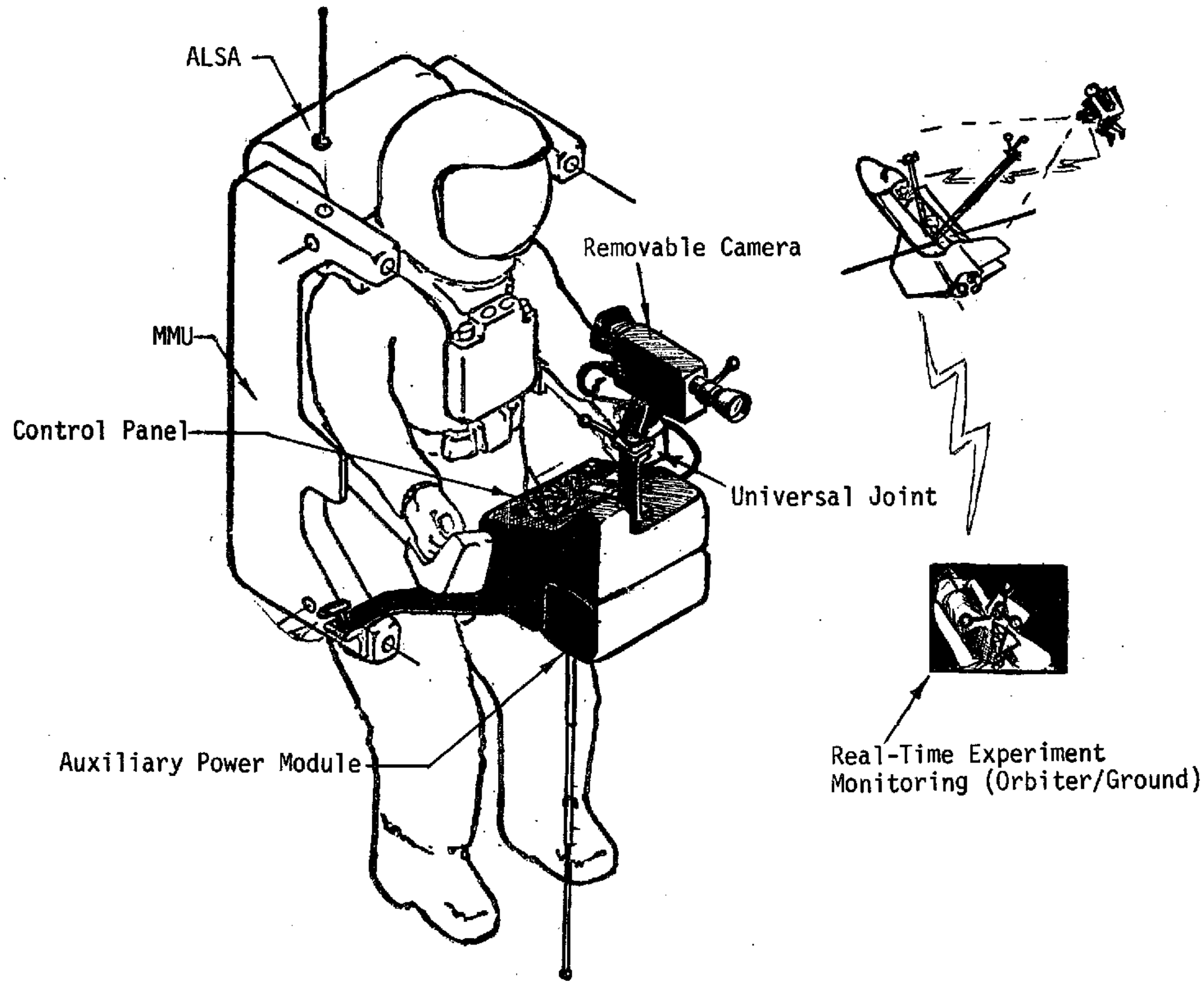


FIGURE 3.53: Data Acquisition Concept--Remote Video Inspection/Surveillance

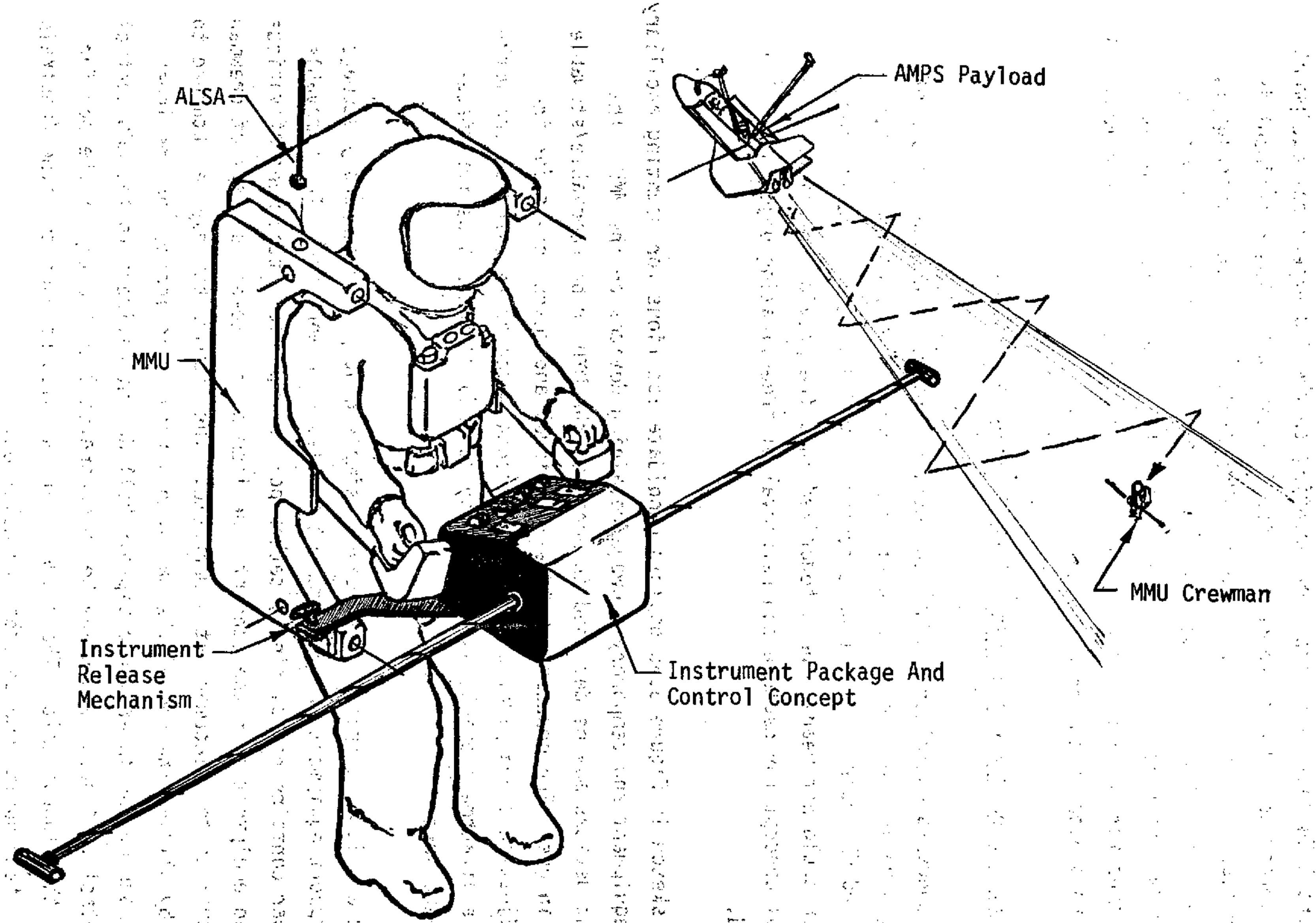


FIGURE 3.54: Data Acquisition Equipment Concept--Wake Detection and Measurement

Figure 3.54 shows a concept for mounting to the MMU experiment equipment for wake detection and measurements in the Orbiter path. The experiment is currently planned to be conducted on the AMPS payloads by other techniques; however, the MMU application appears highly feasible, particularly with an auxiliary MMU propellant stowage capability. The booms shown in the figure are retracted for MMU maneuvering. The experiment equipment is autonomous and requires no support from the MMU systems.

3.2.6 Miscellaneous Equipment Attachment/Retrieval Concepts

The concepts contained in this subsection provide alternate methods of attaching a variety of general support items that may be required for EVA missions and MMU operations. (The concepts provided in this miscellaneous subsection could not readily be categorized into the previous sections.) An additional concept for capture and retrieval of free-floating objects is also presented.

The sketch in Figure 3.55 depicts candidate locations for mounting ancillary support equipment and temporary stowage/retaining devices on the MMU. The attachment devices may be designed integral to the MMU or be removable/stowable when not in use. The concepts would allow visual and reach access for in-flight adjustments and pivot clear of the frontal area as required at the work-site. The attachment brackets would employ "standard" interfaces for space-suited operations.

Figure 3.56 illustrates a relatively simple concept for temporary stowage of EVA support equipment and replacement modules at a worksite. The removable stowage bar contains hooks, rings, tether points, etc. for attachment of various configured equipment. In the concept, the item being stowed is a set of crewman foot restraints for placement at a worksite. The stowage bar may be attached to the unit by sliding the end of the bar into a receptacle located on the lower thruster housing and inserting a pip-pin ball detent device into the MMU control arm receptacle. A push button may be incorporated into the top of the bar for releasing the stowage unit. The stowage bar may also be used to tether/restrain equipment items during MMU on-orbit translation.

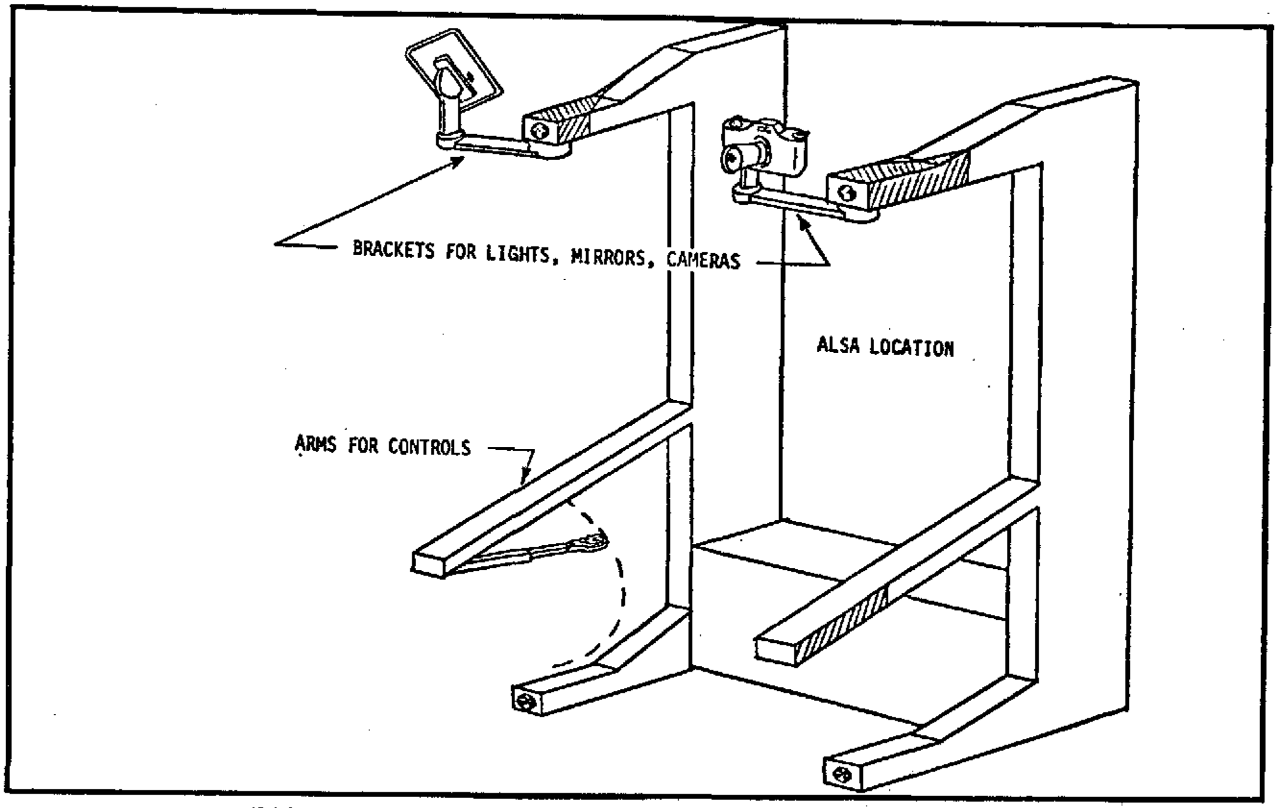


FIGURE 3.55: Ancillary Equipment Candidate Locations

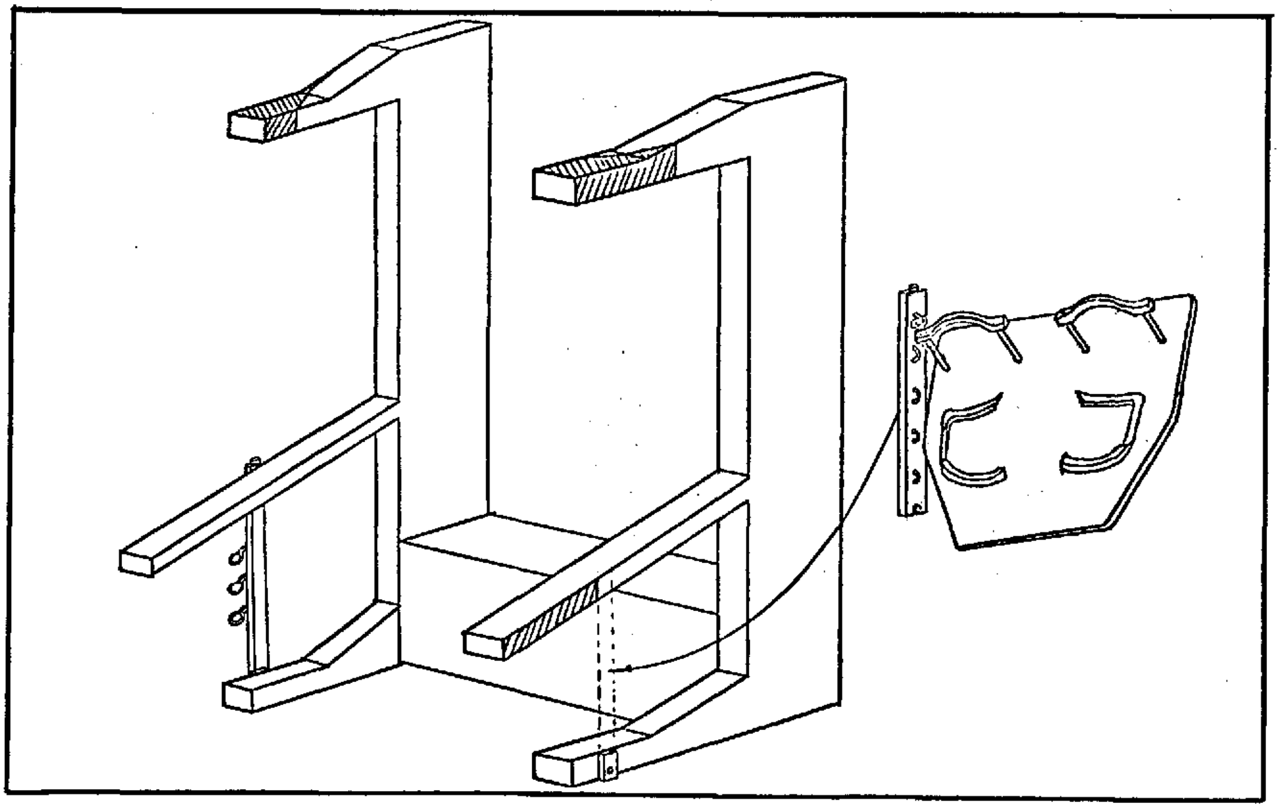


FIGURE 3.56: Equipment Stowage Bar Concept

The concept shown in Figure 3.57 represents a computer programmed operations checklist displayed on a monitor for detailed on-orbit experiment systems maintenance. The checklist procedures would be programmed on the Orbiter or at a ground-based station and transmitted to the MMU attached monitor. The checklist system would allow real-time repair and calibration operations to be performed based on experimenter (located in the Orbiter or earth base) observations and inputs. The MMU checklist system receiving unit with alphanumeric display would allow the crewman to display any procedure required. A tape recorder could be incorporated into the system for crew comments for later analysis. The checklist system would mount to the MMU control arm and/or lower thruster housing. The system would replace the mechanical checklists (document and spacesuit cuff types) used on previous space programs.

Other less-sophisticated checklist concepts for MMU-EVA applications are shown in Figure 3.58. A "scroll" concept with the checklist printed on continuous rolls and displayed on a screen may be applicable where extensive procedures are required for EVA operations. The proper checklist would be inserted into the viewer prior to EVA. The viewer may be manually actuated by hand cranks or electrically driven. A second concept would provide standard loose-leaf checklists in a special binder. The binder would position the pages for optimum viewing using a cam/spring mechanical system to automatically position the pages.

The concept shown in Figure 3.59 depicts an extendible boom mounted to the MMU for access to payload and Orbiter areas inaccessible to the MMU. The boom could access areas to retrieve debris, open access doors, retrieve film data, etc. End effectors for interfacing to various configurations would be stowed with the boom system. The boom could be electrically actuated with manual backup or purely mechanical. The mounting arrangement would provide sufficient latitude to allow positioning the unit from an EVA worksite or MMU restraint. The boom unit may also be applicable in transporting the MMU-crewman combination along an extended worksite for inspection, monitoring or light force application tasks.

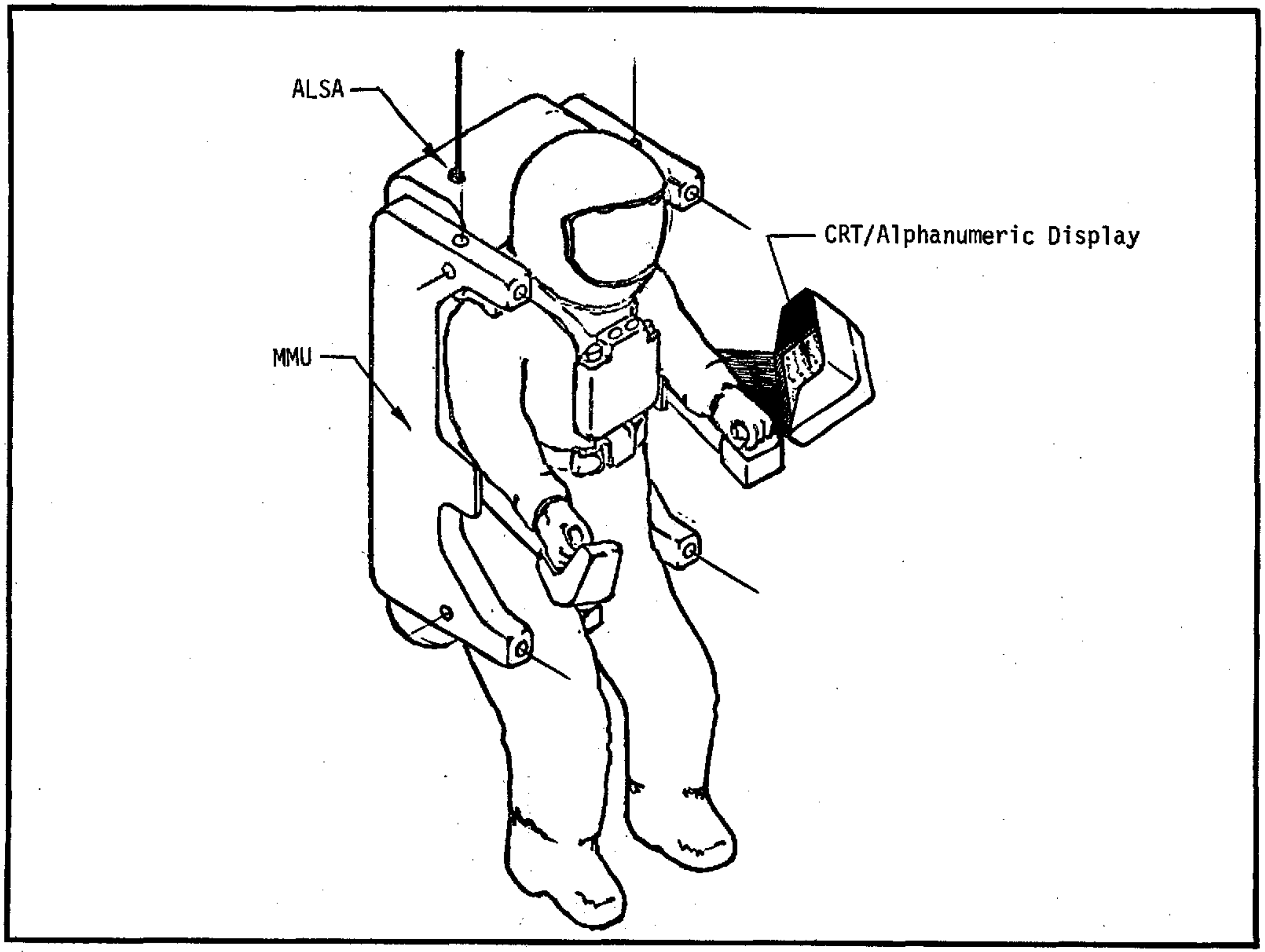


FIGURE 3.57: Computerized Checklist Display Concept

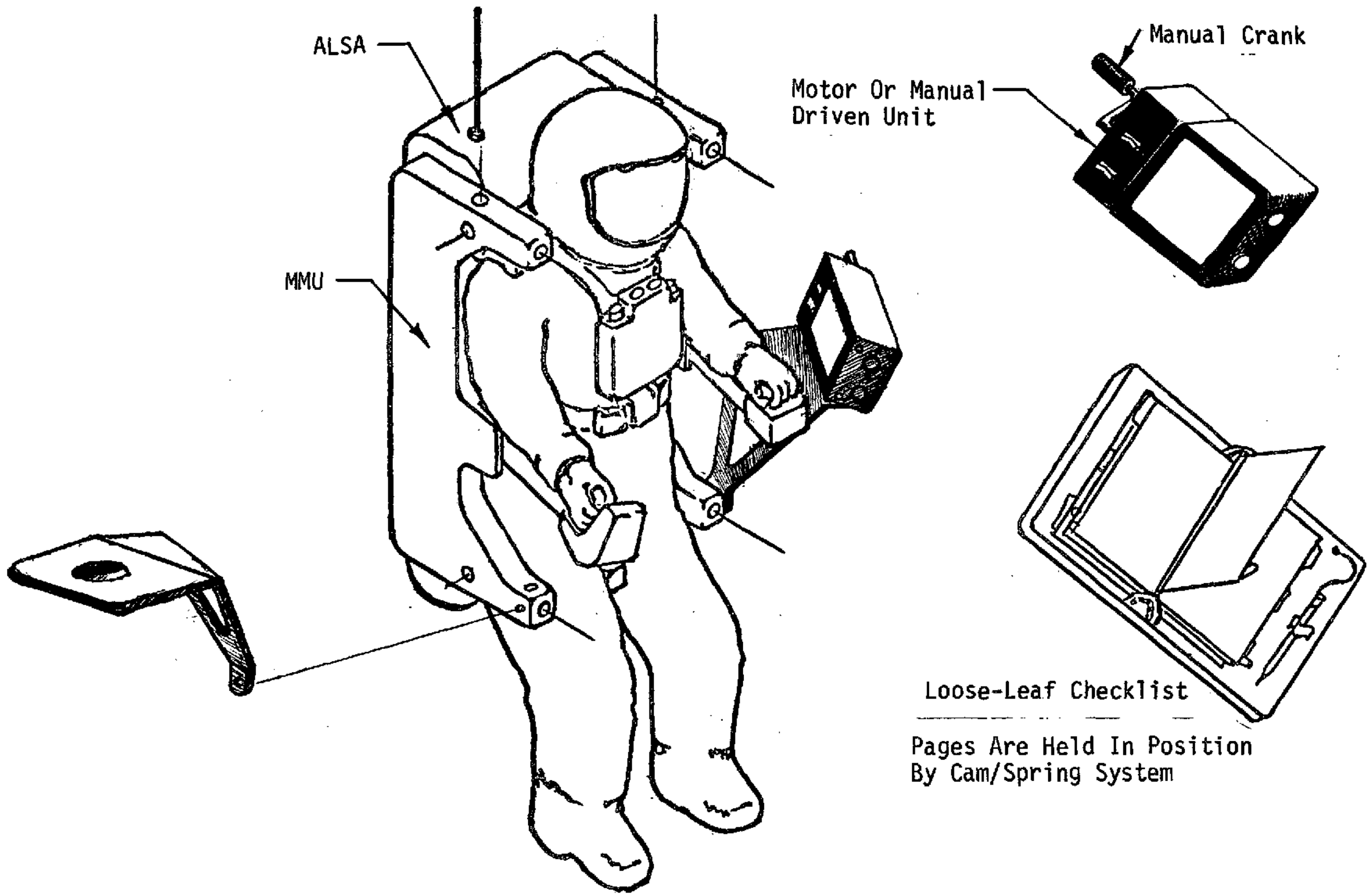


FIGURE 3.58: Procedures Checklist Concepts--Automatic/Manual

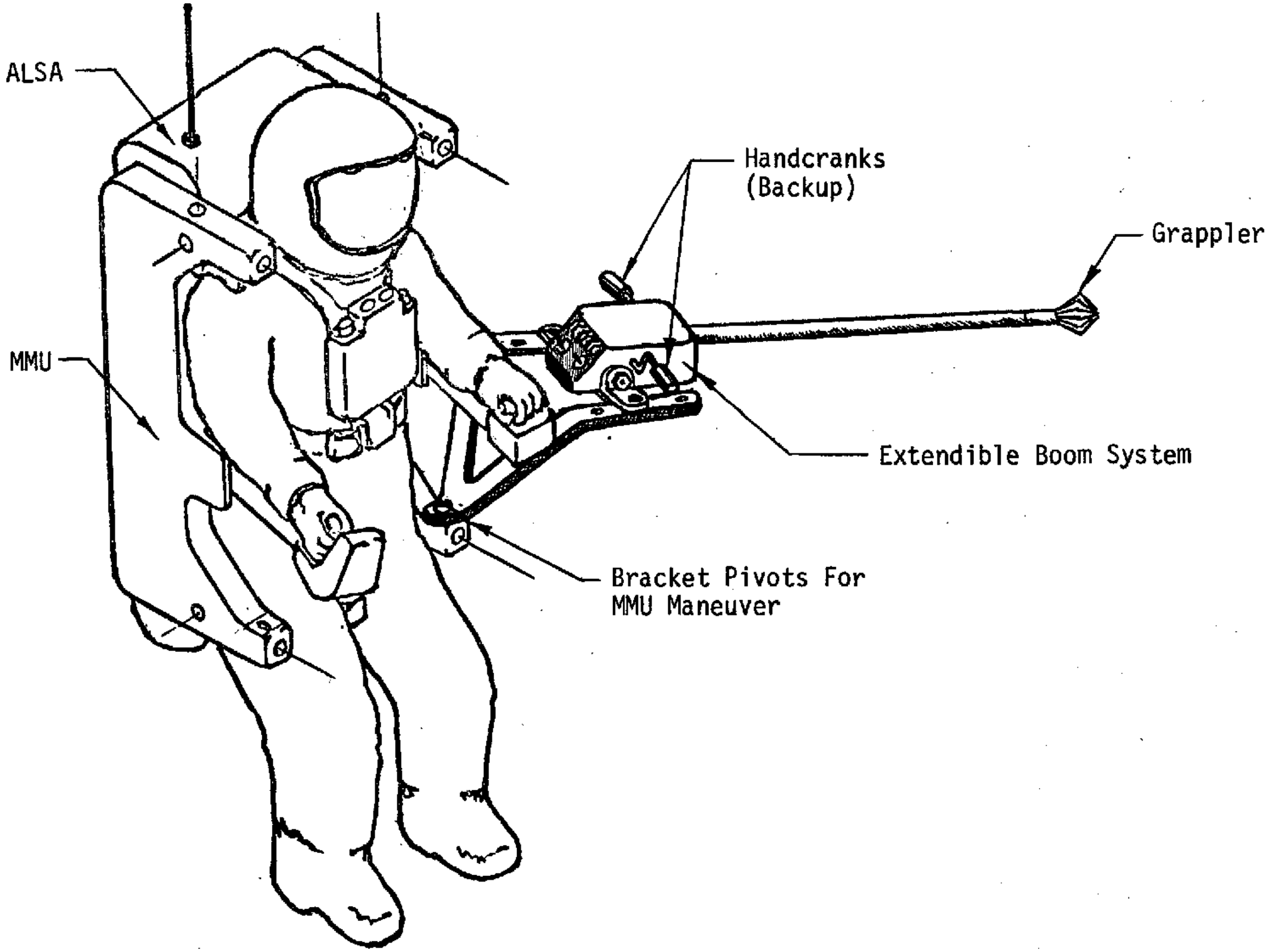


FIGURE 3.59: Extendible Boom System Concept

A basic method of equipment transfer on-orbit is the use of a stowage bag or net. The concept depicted in Figure 3.60 utilizes a mesh bag for retrieval and transfer of equipment ranging from space debris to personnel rescue systems (PRS). The entrance to the net would be spring-loaded to open automatically by tether line acutation. A "drawstring" device would be used to close the net after equipment capture. An advantage of the capture net is the retrieval and transfer of irregular shape and size objects not initially designed for on-orbit retrieval. The crewman may be required to translate in the aft direction while towing the net. Mirrors may be required to aid translation. The net system will fold into a compact package for on-orbit stowage.

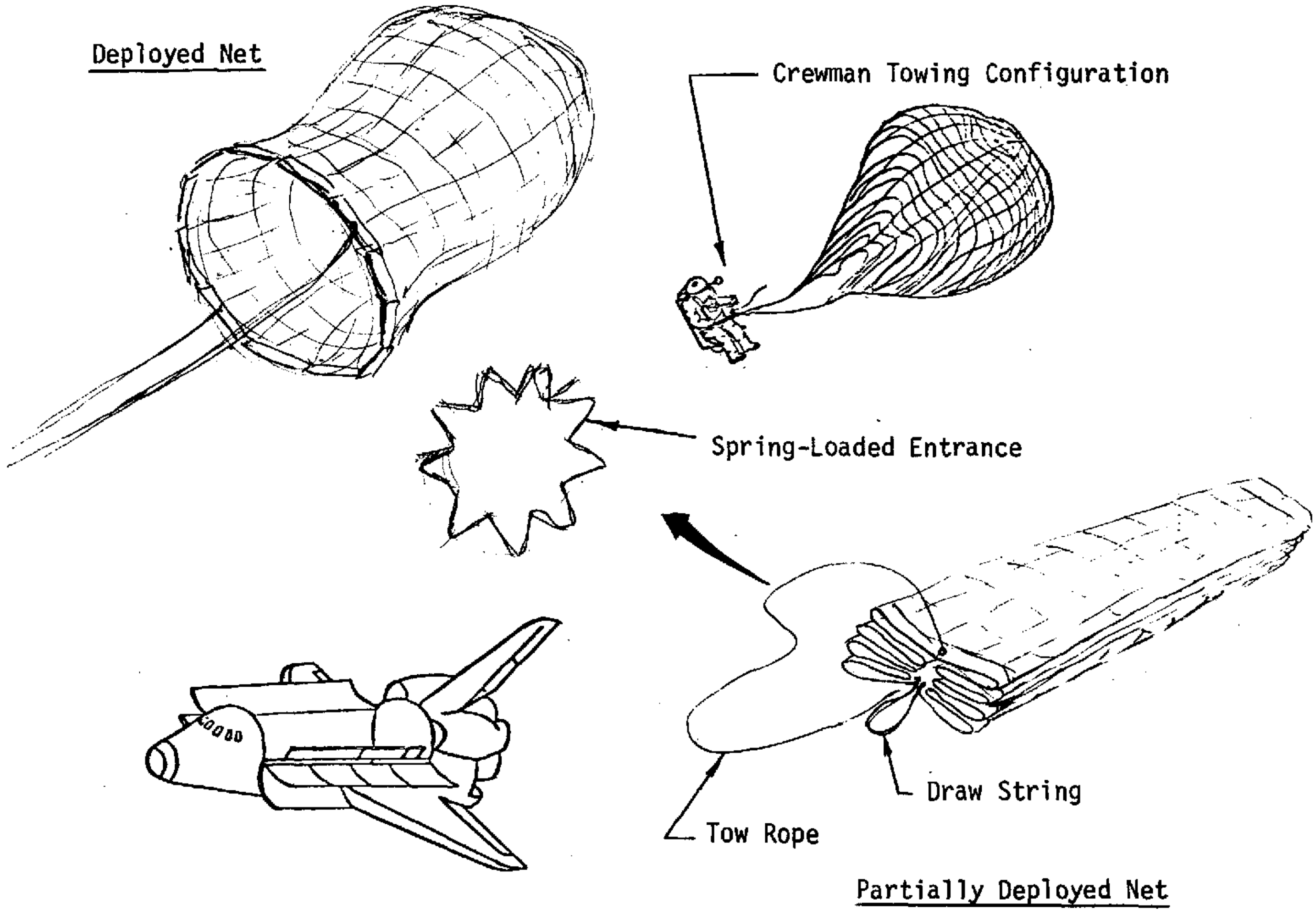


FIGURE 3.60: Cargo Capture/Transfer Net Concept

4.0 GENERAL MMU CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study has emphasized applications of the Manned Maneuvering Unit to the Space Shuttle Program as providing a versatile utility capability to support nominal and contingency orbital operations (see Volume I). Ancillary equipment concepts were developed to support the MMU-EVA operations and broaden MMU applications. The study results conclude that the MMU, equipped with appropriate support hardware and restraints, may be an essential and economical entity of the U.S. space program orbital elements. While remote manipulator systems and automation may provide feasible alternatives to performing EVA, the physical interface between man and machine, human judgment and real-time decision making are key factors in man versus machine selection. Man has fully demonstrated, particularly during the Skylab Program, that he can be an integral part of the spaceflight complex by adding the elements of judgment and reliability--characteristics not provided by mechanical or automated systems alone.

Recommendations

The Manned Maneuvering Unit Mission Definition Study was performed in a time frame when most Shuttle payloads were only in the conceptual design phase. Preliminary analysis indicated that many of the mission payload planners and designers are not cognizant of the potential capabilities of the MMU-EVA crewman system relative to orbital applications. A program by NASA is recommended to distribute available MMU physical, operational and performance characteristics/data to the payload development community for consideration prior to payload final design initiation. Designing for on-orbit servicing could become an asset to many payloads.

The MMU attachment and ancillary equipment concept development effort was performed using introductory artist concepts of the MMU prior to initiation of MMU preliminary design. Therefore, the supporting systems conceptual designs were developed for integration into various interface configurations. The conceptual design effort indicated that the following should be considered during MMU preliminary design:

- Human factors engineering approach to operational interfaces
- Provide MMU external configuration to minimize visual and reach restrictions
- Provide standardized interfaces for MMU restraint (launch/reentry, EMU) and support equipment attachments
- Integrate utility connectors on the exterior of the MMU (e.g., power, propellant)
- Provide a capability for auxiliary propellant tanks and power supply.

In the design of MMU restraint and ancillary support equipment attachments, the following should be considered:

- Provide an integrated, removable MMU service/restraint station to include launch, service, don/doff and reentry
- Standardize support equipment attachment mechanisms and man-machine interfaces, when possible
- Use space qualified off-the-shelf support equipment and attachment devices, where applicable.

The following developmental programs are recommended to coincide with and/or immediately follow the MMU preliminary design program to avoid possible MMU systems redesign:

- Develop an MMU flight service/restraint station for mounting to the Orbiter, payloads and pallets
- Conduct studies and/or develop adhesives and adhesive release techniques for space application

- Develop Orbiter Thermal Protection System (TPS) repair kits for MMU application
- Develop MMU and MMU-crewman combination worksite attachment mechanisms
- Develop EMU-to-MMU attachment system
- Conduct dynamic MMU cargo transfer (including PRS, EMU, MMU) simulations to determine MMU transporting capabilities
- Conduct dynamic MMU-to-free-floating equipment simulations to determine capture systems' design criteria.

Longer range MMU programs should include:

- Develop MMU navigation equipment for extended distance missions and safety
- Adapt free-flying teleoperator video and data acquisition systems to the MMU.