MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

FINAL REPORT — VOLUME I
BOOK 1 FLIGHT ARTICLE REQUIREMENTS
AND
APPENDIX A
MISSION REQUIREMENTS

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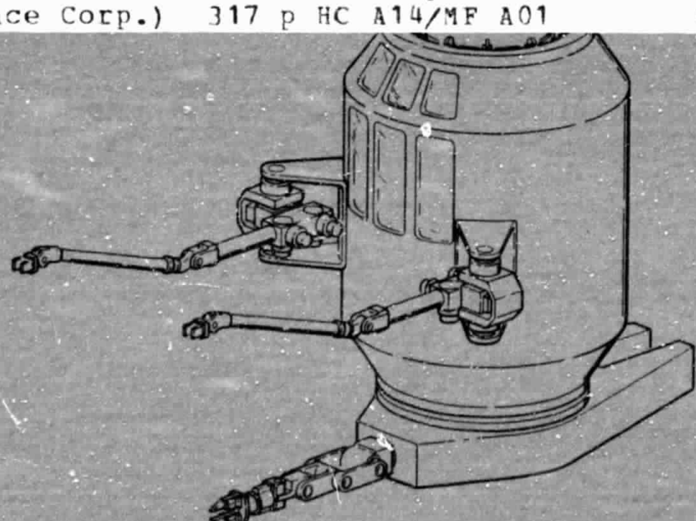

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AND
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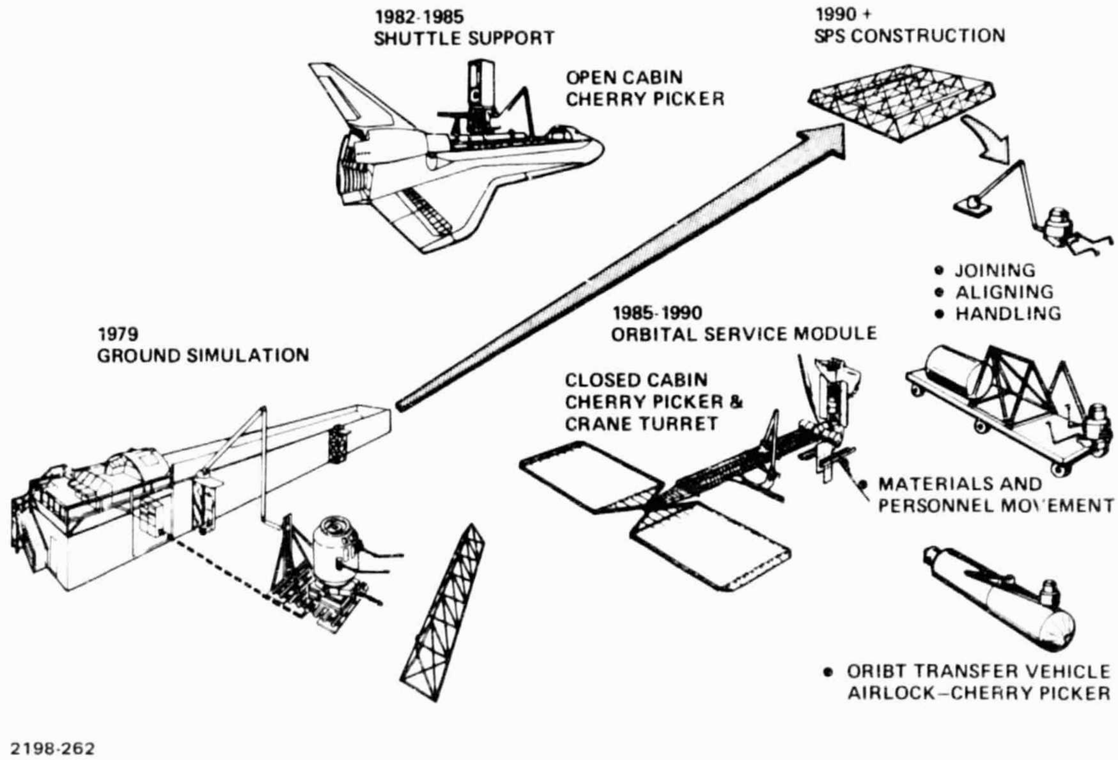

Orbital Construction Support Equipment Development Universal Manned Remote Work Station

FOREWORD

The Introduction of the Space Transportation System (STS) has removed many of the constraints of payload volume and mass to orbit that has inhibited low-cost space operations. This permits satellite servicing, scientific observation, and structural assembly on a scale heretofore unobtainable. The Manned Remote Work Station (MRWS) is one of the tools that can assist the astroworkers in efficient, cost-effective orbital operations. The initiation of development efforts leading to a MRWS is a fundamental step toward achieving space construction objectives as illustrated by the scenarios in the figure on the opposite page. Activity starts with introduction of a development test article in a ground base simulation program where key system elements are tested and design parameters defined. This simulation will be performed at the Manipulator Development Facility located at Johnson Space Center, building 9A. This facility contains a 56-ft by 80-ft air bearing floor and a 50-ft hydraulically actuated manipulator arm for simulating the Shuttle remote manipulator system (RMS). The MRWS development test article will be mounted to one of various sized air bearing platforms that can be mounted to the simulator manipulator.

This document defines the requirements for several configurations of flight articles that span the time interval from 1982 to the year 2000. These requirements provide the basis to design MRWS development test articles and establish tests and simulation objectives for the resolution of development issues.

The basic document contains mission system and subsystem requirements for four MRWS configurations:

- Open cherry picker
- Closed cherry picker
- Crane turret
- Free flyer.

Appendix A is a compilation of future missions that could utilize the MRWS. It describes the missions and spacecraft, provides task analysis, and indicates issues to be resolved.

Appendix B contains the trade and design definition studies that were done during the definition of the flight article MRWS. Studies are catalogued under each MRWS configuration and contain system and subsystem trades/design definitions pertinent to particular configurations, especially those necessary to define development simulators.

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CONTENTS (contd)

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ILLUSTRATIONS

TABLES

ACRONYMS

ABE	Arm Based Electronics
BFR	Bilateral Force Reflecting
C&D	Controls and Displays
C&DH	Communications and Data Handling
CCTV	Closed Circuit Television
DEP	Design Eye Point
DOF	Degrees-of-Freedom
ECLS	Environmental Control and Life Support
EMU	Extravehicular Mobility Unit
EPS	Electrical Power Subsystem
EVA	Extra Vehicular Activity
GEO	Geosynchronous Orbit
GPC	General Purpose Computer
HUD	Head-Up Displays
LDEF	Long Duration Exposure Facility
LEO	Low Earth Orbit
LSS	Large Space Structures
MCIU	Manipulator Control Interface Unit
MMS	Multimission Spacecraft
MMU	Manned Maneuvering Unit
MRWS	Manned Remote Work Station (open platform, closed cabin, crane turret, and free flyer)

ACRONYMS (contd)

OCDA	Orbit Construction Demonstration Article
OCP	Open Cherry Picker
POTV	Personnel Orbital Transfer Vehicle
PM	Power Module
PRS	Personnel Rescue System
RAP	Record and Playback
RMRC	Resolved Motion Rate Control
RMS	Remote Manipulator System
RRC	Resolved Rate Control
RTG	Real-Time Guidance
SCAFE	Space Construction Automated Fabrication Experiment
SCB	Space Construction Base
SCM	Space Construction Module
SIMS	Shuttle Imagins Microwave System
SOA	State-of-the-Art
SOW	Statement of Work (Request for Proposal)
SPEE	Special Purpose End Effector
SPS	Solar Power Satellites
SRMS	Shuttle Remote Manipulator System
SSSA	Space Station Systems Analysis
STS	Space Transportation System

DEFINITIONS

C.P. Arm	Robust arm that supports cherry picker MRWS
Crane Arm	Robust arm used as crane
Manipulator	Dexterous manipulator mounted on MRWS
Stabilizer	Mounted on cherry picker for moving high mass items or for stabilizing MRWS. Manually operated or remotely controlled

Section 1

FLIGHT ARTICLE DESIGN GUIDELINES

The following establishes the objectives and scope of the program:

- The manned Remote Work Station (MRWS) shall have the capability to support various types of construction operations
- The MRWS shall be reusable
- The MRWS shall be capable of being transported to and from orbit in the Space Shuttle Orbiter
- The design of MRWS shall be essentially independent of the large system constructed in space
- The MRWS will be a multipurpose vehicle capable of operating in various modes:
  - base mounted
  - rail mounted
  - free flyer
  - cherry picker
- The MRWS could be either an open or closed (pressurized) vehicle
- The flight system concept design and requirements shall be based on functions and operational tasks in support of in-orbit fabrication, assembly, and deployment of large space systems
- Interface requirements between the Space Transportation System (STS), support for orbiting elements, and other manned or remote controlled equipment will be defined
- Operational requirements will be defined considering manned or remote control equipment operations at the construction site
- Design requirements will be established for three time phases:
  - Near-Term 1982-1985
  - Mid-Term 1986-1990
  - Far-Term 1991-2000.

Section 2

FLIGHT ARTICLE MISSION REQUIREMENTS

2.1 REFERENCE MISSIONS

The following missions are the references used to establish MRWS requirements:

2.1.1 Near-Term

- Servicing of multimission modular spacecraft
- Servicing of long duration exposure facility
- Assembly of large space structure platform
- Assembly of space construction automated fabrication experiment
- Assembly of initial space construction base
- Servicing of space telescope.

2.1.2 Mid-Term

- Assembly of microwave power transmission development Article
- Assembly of photovoltaic solar collector Development Article
- Assembly of 100-m radiometer
- Assembly of 61-m communications antenna.

2.1.3 Far-Term

- Photovoltaic solar power satellite
- Thermal solar power satellite.

2.2 ORBIT

The MRWS shall operate at all earth orbital inclinations and altitudes including geosynchronous orbit.

2.3 MISSION DURATION

Near-term mission duration shall be seven days without resupply. Mid-term operation duration shall be 28 days with resupply every seven days. Far-term mission capability shall be five years with resupply every seven days and periodic maintenance.

2.4 CREW

- The MRWS shall be capable of being operated by one person
- The closed cabin MRWS shall provide habitation for 10-hr shifts
- The open platform MRWS shall be compatible with 6-hr extra vehicular activity (EVA).

2.5 OPERATIONS

- The MRWS shall be capable of staying in orbit unattended for one year. Subsystems will be capable of being restarted after normal servicing
- The MRWS shall operate for both single and multiple shifts
- Crew transfer between Orbiter or other habitability modules and the open platform MRWS shall be by a suited EVA astronaut
- Crew transfer between Orbiter or other habitability modules and the closed cabin MRWS shall be in a shirt sleeve pressurized environment
- The MRWS shall have a minimum orbital lifetime of 10 years with in orbit maintenance.

Section 3

FLIGHT ARTICLE SYSTEM REQUIREMENTS

The following defines the overall configuration, safety, reliability, maintenance and interface requirements:

3.1 REFERENCE CONFIGURATIONS

3.1.1 Open Cherry Picker MRWS

The baseline configuration (Figure 1) definition follows:

- The MRWS shall support the EVA astroworkers and provide unobstructed reach for the astroworker to perform space tasks
- The MRWS shall consist of:
  - A platform with a restraint system to secure the EVA astroworker
  - Stabilizer attached to the platform
  - Illumination
  - Stabilizer Controls and displays
  - RMS controls and displays
  - Tool storage (small hand tools)
  - Provisions for large tools
  - P/L handling devices
  - RMS mechanical and electrical interfaces
  - Provisions for storage in P/L bay
- The platform shall be mounted to the Orbiter RMS utilizing the stabilizer fixture that interfaces with standard snare-type end effector
- Electrical power, controls, and data shall be routed through the RMS internal cabling utilizing the payload mounted grapple fixture special purpose end-effector connector
- The open cherry picker MRWS shall fold for storage in the Orbiter payload bay. Its folded volume shall not exceed 1.5 cu m and it shall be mounted adjacent to the EVA hatch at the starboard Manned Maneuvering Unit (MMU) donning station attachment points

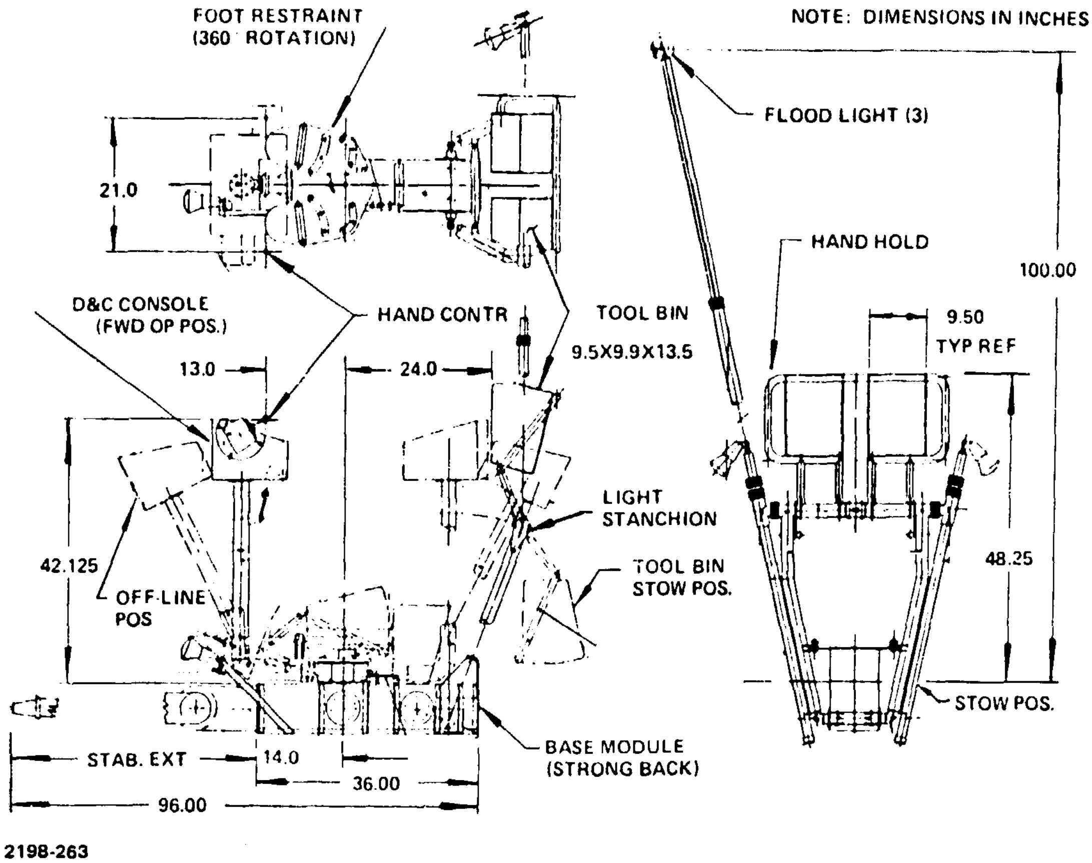

Figure 1. OCP-DTA General Arrangement

- The mass shall not exceed 200 kg for the basic configuration summarized in Table 1.

3.1.2 Closed Cherry Picker MRWS

The baseline configuration (Figure 2) definition follows:

- The MRWS shall support the astronaut in a shirtsleeve environment, provide dexterous manipulators and visability to perform tasks
- The closed cabin cherry picker MRWS shall consist of:
  - A closed pressurized cabin that supports the astronaut with appropriate restraints
  - An environmental control system that provides life support
  - A platform that allows the cabin to rotate $\pm 180^{\circ}$
  - Stabilizer attached to the platform
  - Controls and displays for the stabilizer
  - Two dexterous manipulators mounted to each side of the cabin
  - Controls and displays for the manipulators
  - Controls and displays for the RMS/crane
  - Communication subsystem
  - Thermal control subsystem
  - Illumination subsystem
  - Interface provision between the cabin and platform for structural attachment, electrical power, control, and data
  - Interface provisions between the platform and cherry picker arm for structural attachment, electrical power, control, and data
  - Tools, materials and end effector storage on the platform
- Provide a hatch for crew ingress/egress and berthing/docking system compatible with the Orbiter and habitability modules
- The MRWS shall be compatible with stowage in the Orbiter payload bay
- The mass shall not exceed 2500 kg for the baseline configuration defined in Table 2.

3.1.3 Crane Turret MRWS

The baseline configuration (Figure 3) definition follows:

- The MRWS shall support the astroworker in a shirtsleeve environment, provide controls and visability for crane arms to perform tasks

TABLE 1

OPEN CHERRY PICKER MRWS MASS ESTIMATE

ITEM	MASS, kg
STRUCTURE	(35)
• PLATFORM	6
• BEARING TUBE	19
• (2) STANCHIONS	5
• CONTROL & DISPLAY CONSOLE & SUPPORT	5
MECHANICAL	(77)
• STABILIZER	38
• BEARING (FOOT RESTRAINT)	5
• STABILIZER FIXTURE	5
• (2) RETENTION/STOW DEVICE	29
CREW SUPPORT	(14)
• TOOL STORAGE BIN	4
• FOOT RESTRAINT	9
• TETHERS	1
CONTROLS & DISPLAYS	(14)
ELECTRICAL POWER SUPPLY	(14)
• WIRING, ETC	12
• LIGHTS (3)	2
CONTINGENCY (25%)	(38)
TOTAL DRY	192

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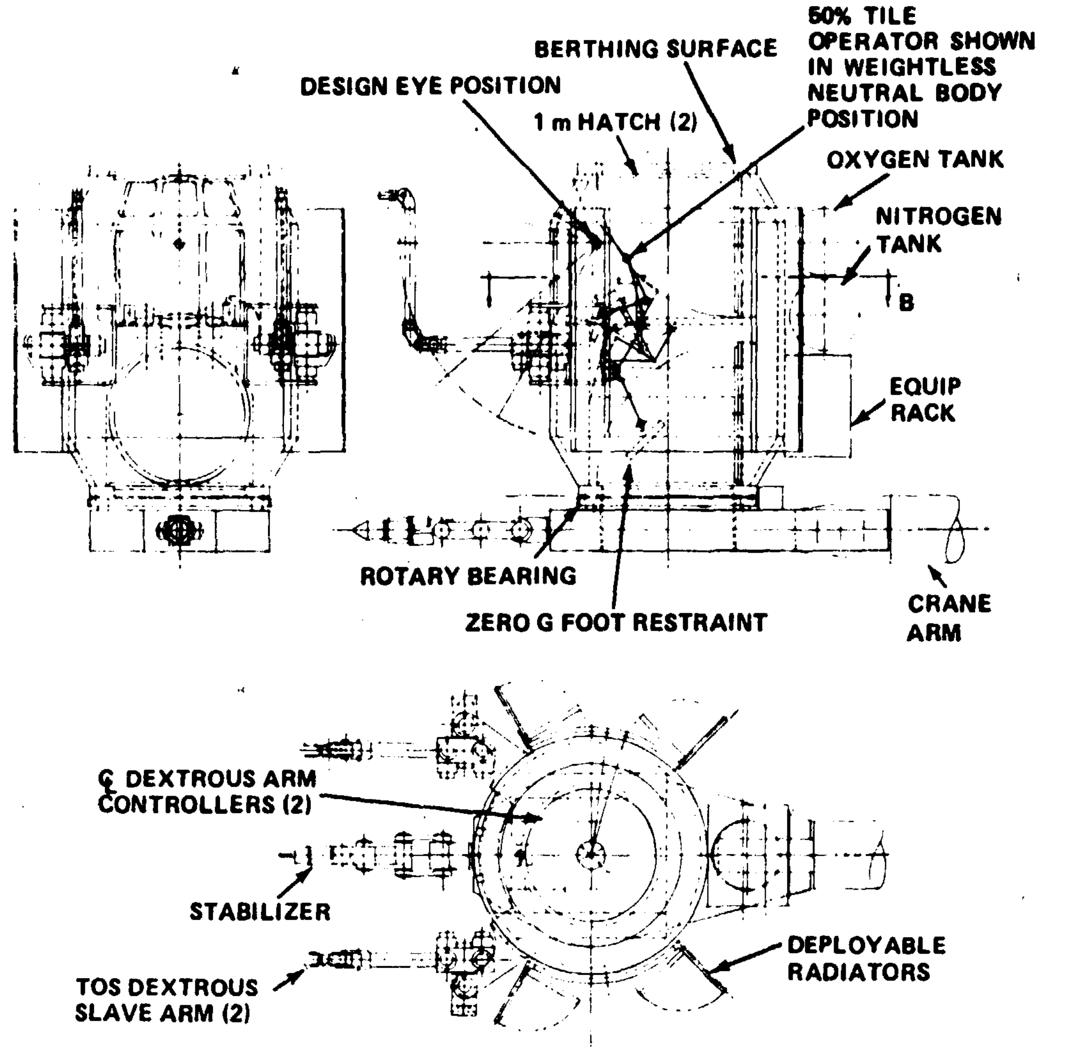

CABIN I.D.	170(67)–cm(in.)
CABIN HEIGHT	249(98)
OVERALL HEIGHT	290(114)
VOLUME TO IML	4.8(168)–$m^3(ft^3)$
PRESSURE	1.03(14.7)–kg/cm^2(psi)

WINDOW AREA	$m^2(ft^2)$
• FWD	0.65(7.0)
• UPPER	0.23(2.5)
TOTAL	0.88(9.5)

DISPLAY AREA	$m^2(ft^2)$
• FWD CONSOLE	0.17(1.8)
• L/R SIDE CONS	0.40(4.2)
• L/R VERT	1.53(16.4)
TOTAL	2.10(22.4)

RADIATOR AREA 13.38(142)–$m^2(ft^2)$

HEAT LOAD	WATTS
• WINDOW	225
• METABOLIC	350
• CO_2 REMOVAL	50
• INTERNAL ELEC	822
• EXTERNAL ELEC	3113
• AFT EQPT BAY	228
TOTAL	4788

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Figure 2. Closed Cherry Picker One-Man Operation

TABLE 2

CLOSED CHERRY PICKER MRWS MASS ESTIMATE

ITEM	1-MAN CAB kg
STRUCTURE	(549)
• BASIC	228
• HATCHES & WINDOWS	52
• SUPPORT/CONSOLES	154
• ROBUST ARM INTERFACE	155
ENVIRONMENTAL PROTECTION	(55)
ENVIRONMENTAL CONTROL SYSTEM	(150)
MECHANICAL	(516)
• MANIPULATOR–SLAVE	103
• MANIPULATOR–MASTER	62
• STABILIZER	38
• ROTARY BEARING	313
BERTH INTERFACE	(147)
DOCKING INTERFACE	
ELECTRICAL POWER SUPPLY/ INSTRUMENTATION	(113)
COMM/STAB. & CONTROL	(36)
CONTROLS & DISPLAYS	(91)
CONTINGENCY (25%)	(414)
TOTAL DRY	2071
CREW	77
PRS	0
TOTAL	2148

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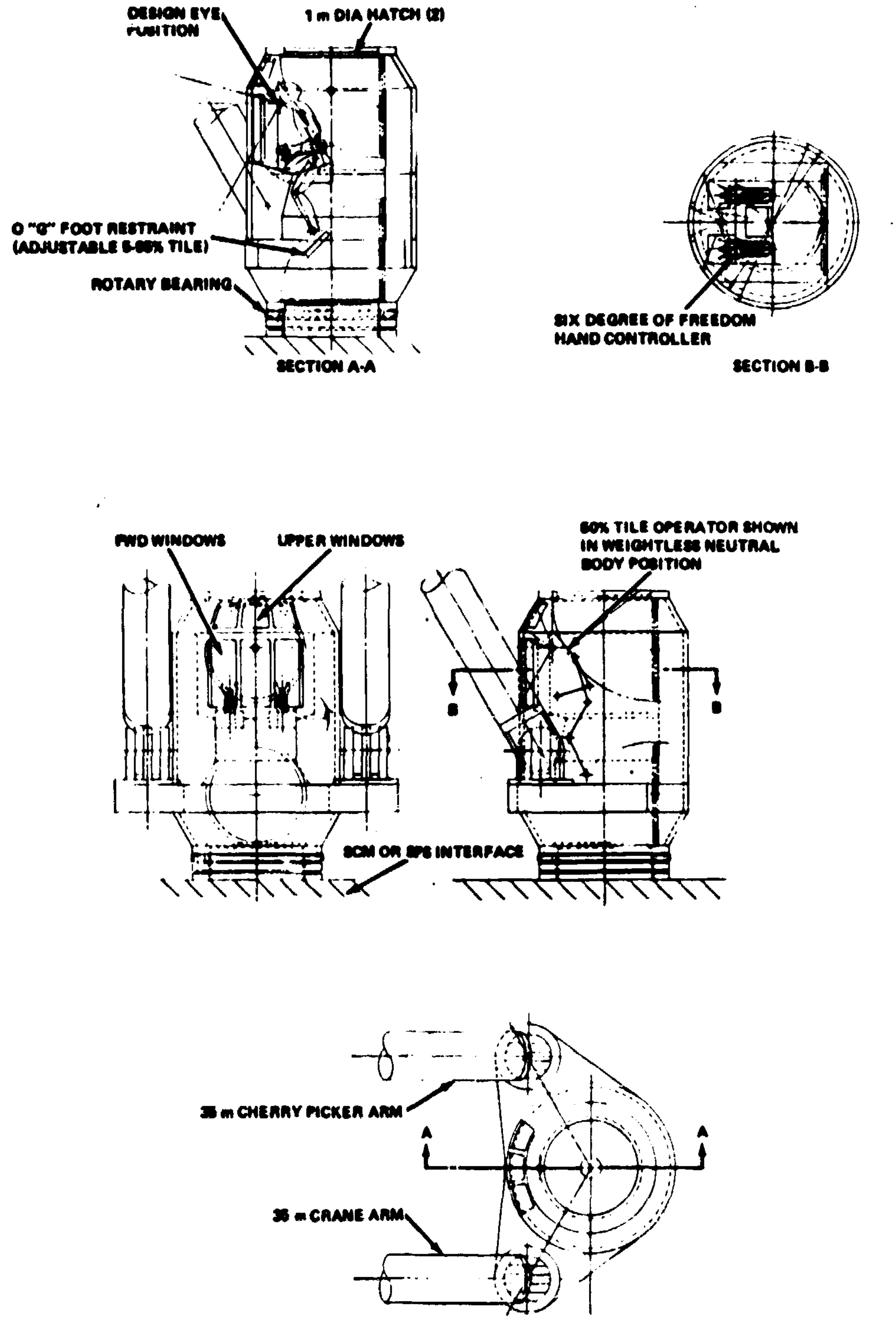

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Figure 3. Crane Turret MRWS

- The crane turret MRWS shall consist of:
  - A closed pressurized cabin that supports the astroworker with appropriate restraints
  - An environmental control system that provides life support
  - A platform that supports the cabin and two cranes
  - Rotary bearing interface between the crane platform and space construction base (SCB) that allows $\pm 180^{\circ}$ rotation. This interface also provides electrical power for operation of the crane turret MRWS. Provisions shall be made for an electrical power source when the MRWS is operated remote from the SCB
  - Controls and displays for the cranes
  - Communication subsystem
  - Thermal control subsystem
  - Illumination subsystem
- Provide a hatch for crew ingress/egress. Also provide a second hatch and berthing/docking for use as a cherry picker MRWS air lock.

3.1.4 Free Flyer MRWS

The baseline configuration (Figure 4) definition follows:

- The MRWS shall support the astroworker in a shirtsleeve environment, provide dexterous manipulators and visability to perform orbital tasks
- The free flyer MRWS shall consist of:
  - A closed pressurized cabin that supports the astroworker with appropriate restraints
  - An environmental control system that provides life support
  - A platform that allows the cabin to rotate $\pm 180^{\circ}$
  - Stabilizer attached to the platform
  - Controls and displays for the stabilizer
  - Two dexterous manipulators mounted on each side of the cabin
  - Controls and displays for the manipulators
  - Mounting for control and propulsion thrusters on the platform
  - Guidance and navigation equipment

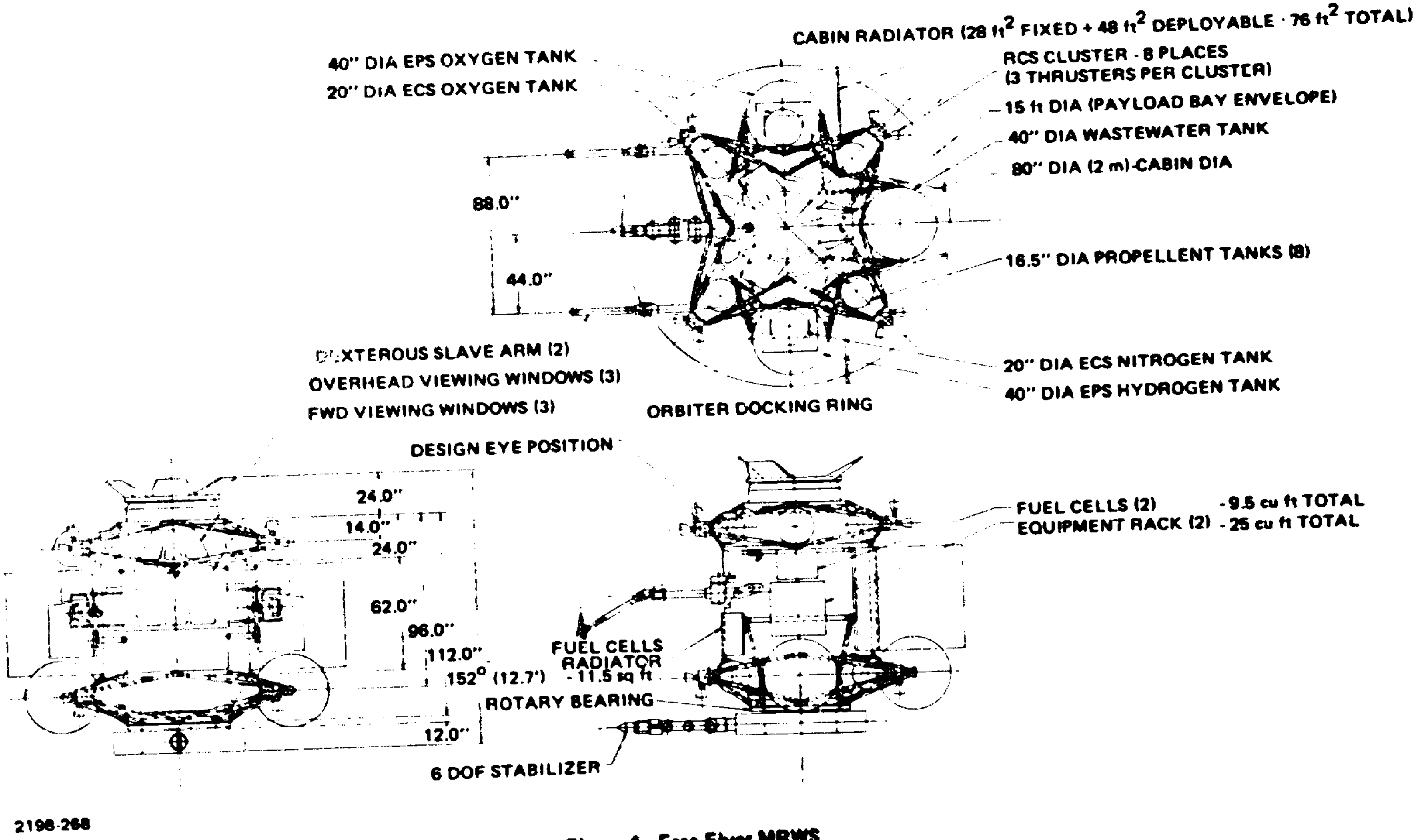

Figure 4. Free Flyer MRWS

- Controls and displays to permit crew selection of attitude and orbital maneuvers
- Communication subsystem
- Electrical power source
- Thermal control subsystem
- Illumination equipment
- Tools, materials and end effector storage on the platform

- Provide a hatch for crew ingress/egress and berthing/docking system compatible with the Orbiter and habitability modules

- The mass shall not exceed 3925 kg.

3.1.5 Coordinate Systems

All MRWS configurations shall use the coordinate system specified in Figure 5.

3.2 SAFETY

- No single malfunction or credible combination of malfunctions and/or accidents shall result in the potential of injury to personnel

- Catastrophic and critical hazards shall be eliminated or controlled

- The MRWS shall provide the capability for performing critical functions at a nominal level with any single component failed or with any portion of a subsystem inactive for maintenance

- The MRWS shall provide the capability to perform critical functions at a reduced level with any credible combination of two component failures, or with any credible combination of a portion of a subsystem inactive for maintenance and failure of a component in the remaining portion of the subsystem

- For those malfunctions that may result in time-critical emergencies, provisions shall be made for:

  - The automatic switching to a safe mode
  - Caution and warning aboard the MRWS when tended

- A pressure relief capability shall be provided for the MRWS tanks (e.g., propellant tanks) which automatically limits the maximum pressure

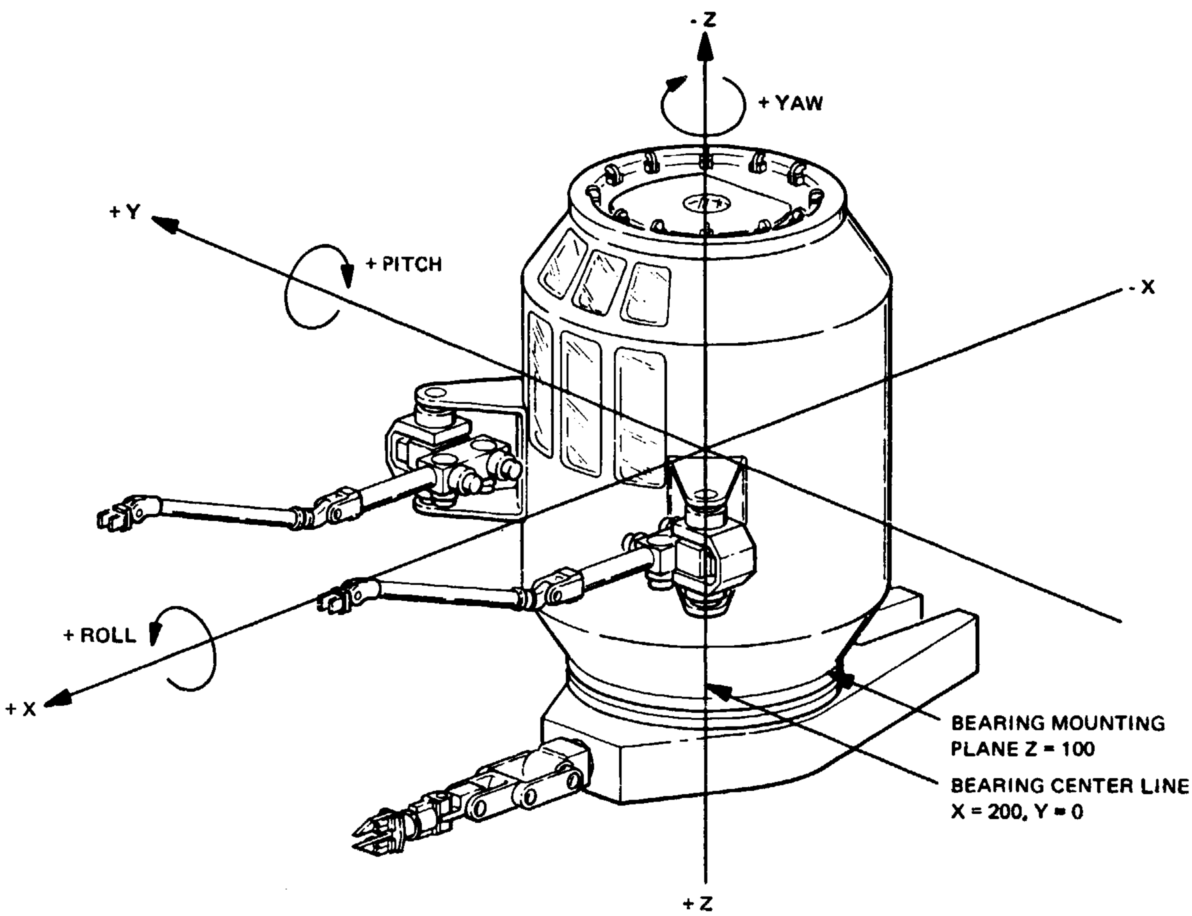

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Figure 5. MRWS Coordinate System

- Venting capability shall be provided for MRWS tanks for safely venting unused residuals during retrieval operations
- RF communication capability shall be available between the Orbiter Habitation Module and the MRWS for command and control functions
- The critical command and control circuitry shall be designed to a fail-operational/failsafe as a minimum
- Conservative factors of safety shall be provided where critical single failure point modes of operation cannot be eliminated (pressure vessels, pressure lines, valves, etc).

3.3 RELIABILITY

- The mission success reliability goal for the MRWS shall be 0.97 minimum for all missions. Redundancy levels will be selected and defined to meet this criterion for all missions
- The MRWS shall be capable of operating with all critical functions performed within specified values following one component failure or any portion of a subsystem inactive for maintenance. This condition shall continue until maintenance can be performed
- Subsystem or component failures shall not propagate sequentially. As a minimum, equipment shall be designed to be fail-operational/failsafe
- All critical life limited components and subsystems shall be designed to allow in-orbit inspection
- Equipment or material sensitive to contamination shall be handled in a controlled environment. Fluids and materials shall be compatible with the combined environment in which they are used
- Redundant paths shall be located so that an event which damages one path is not likely to damage the other.

3.4 MAINTAINABILITY

- The MRWS shall be designed to provide access to equipment interfaces, equipment installations, and service umbilicals requiring inspection, servicing, or verification

- The MRWS shall be capable of having planned maintenance performed within 8 hr turnaround
- The MRWS flight subsystems and their replacement modules shall be designed such that they are accessible and capable of being removed and installed within 24 hr turn around time. The times to remove and replace the various modules shall be identified and shall be demonstratable
- The MRWS flight subsystems shall be capable of checkout, alignment, (if required) connection, inspection and verification of electrical, fluid and mechanical interfaces during MRWS operations.

3.5 ELECTROMAGNETIC CAPABILITY

The MRWS system shall be designed to the compatibility requirements of MIL-STD-461 and MIL-STD-462 to assure that:

- The MRWS operations shall not be limited by electromagnetic interactions due to the electromagnetic emissions and susceptibilities of its subsystems
- The MRWS shall not be a source of interference to or a victim of interference from nearby electrical and electronic equipments and systems.

3.6 RADIATION

The closed cabin MRWS shall be designed to provide adequate protection for the crew from radiation as defined in Table 3, Allowable Radiation Dosage Limits.

3.7 INTERFACES

3.7.1 Open Cherry Picker MRWS

- The platform shall interface mechanically and electrically with the Orbiter RMS grapple fixture as shown in Figures 6 and 7
- The Orbiter shall provide 250 W of power to MRWS via the RMS as shown in Figure 7
- The Orbiter RMS control station shall have the capability of selecting either OCP control of the RMS or Orbiter control of the RMS

TABLE 3

ALLOWABLE RADIATION DOSAGE LIMITS

	PRIMARY REF. RISK	ANCILLARY REFERENCE RISKS		
	(5 cm)	BASE MARROW (5 cm)	SKIN (0.1 mm)	LENS & EYE (3 mm)
1-YEAR AVERAGE DAILY RATE		0.2	0.6	0.3
30-DAY MAXIMUM		25	75	37
QUARTERLY MAXIMUM*		35	105	52
YEARLY LIMIT		75	225	112
CAREER LIMIT	400	400	1200	600

*MAY BE ALLOWED FOR TWO CONSECUTIVE QUARTERS FOLLOWED BY 6-MONTH RESTRICTION TO STAY WITHIN YEARLY LIMIT.

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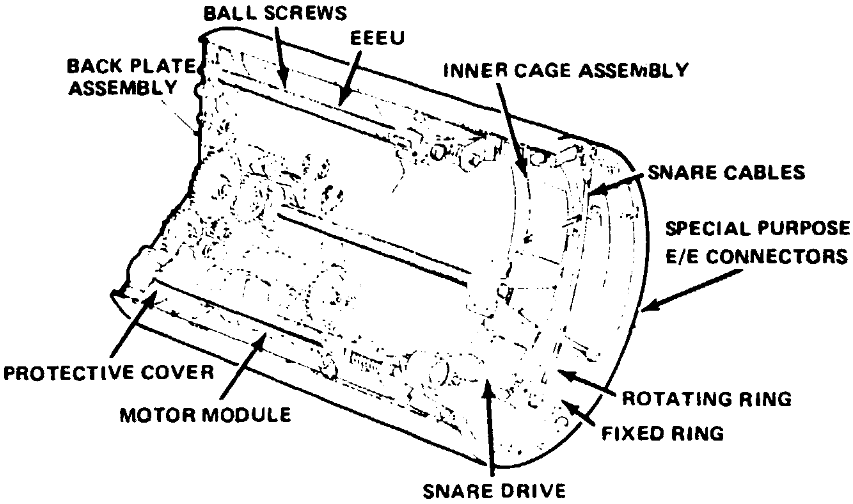
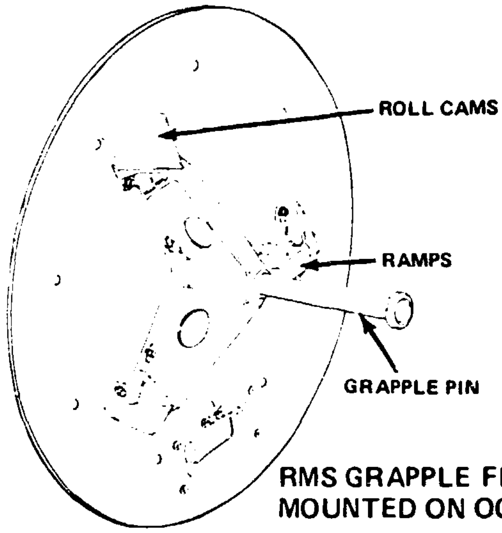
– PROVIDE MECH/ELECTRICAL/SIGNAL INTERFACE

– RMS GRAPPLE MRWS



SNARE TYPE RMS END EFFECTOR



RMS GRAPPLE FIXTURE MOUNTED ON OCP

INTERFACE REQUIREMENT

- MECHANICAL – CANADIAN SNARE END EFFECTOR AND GRAPPLE FIXTURE
  - – PRECAPTURE MISALIGN LIMITS – 4 in. ± 15°
  - – CAPTURE SPEED – 0.33 TO 0.95 ft/sec
  - – RIGIDIZE SPEED – 8 TO 5.7 in./sec
  - – TORQUE CAPABIL. – 350 ft-lb
  - – RELEASE IMPULSE – 0.3 lbf-sec

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Figure 6. OCP/RMS Mechanical Interface Definition

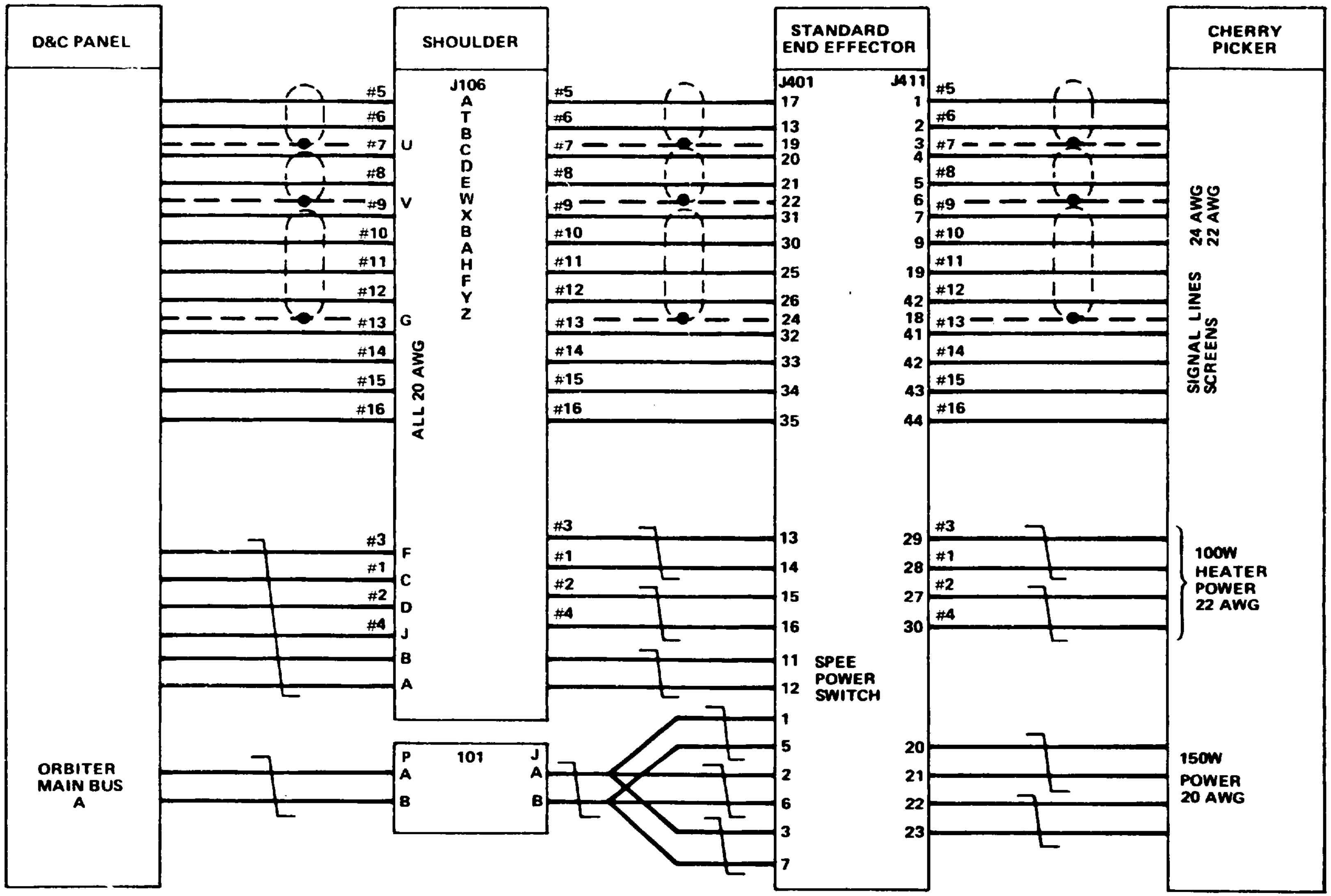

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Figure 7. Orbiter RMS Standard End Effector/Open Cherry Picker Electrical Wiring Interfaces

- Provisions shall be provided in the Orbiter to permit cherry picker MRWS control of either port or starboard RMS
- Provide mounting for the MRWS storage in the Orbiter payload bay with quick release capability in a location compatible with RMS reach. This location shall be near the cabin EVA hatch on the starboard side of the payload bay as shown in Figure 8
- Provide Orbiter back up control for stabilizer end effector release.

3.7.2 Closed Cherry Picker MRWS

- Provide mounting for the MRWS in the Orbiter payload bay to permit coupling to the spacelab tunnel as illustrated in Figure 9. This mounting should provide quick release capability from the tunnel and payload bay support
- The MRWS shall interface mechanically and electrically with the Orbiter RMS grapple fixture
- Provide communication capability via the RMS signal lines
- Controls shall be provided at the Orbiter RMS control station to permit selection of cherry picker MRWS control of the RMS
- Interface units shall be provided in the Orbiter to permit cherry picker MRWS control of either port or starboard RMS.

3.7.3 Crane Turret MRWS

- Provide mechanical interface between the crane platform and space construction base at the rotary bearing. Also provide electrical power to the MRWS across this rotating interface
- Provide crane arm mecahnical, control and data interface with the MRWS at the crane turret platform
- Provide communication capability via the electrical interface at the MRWS/platform interface.

3.7.4 Free Flyer

- Provide the capability to mount the free flyer MRWS in the Orbiter payload bay
- Communications shall be compatible with the Orbiter and space construct base.

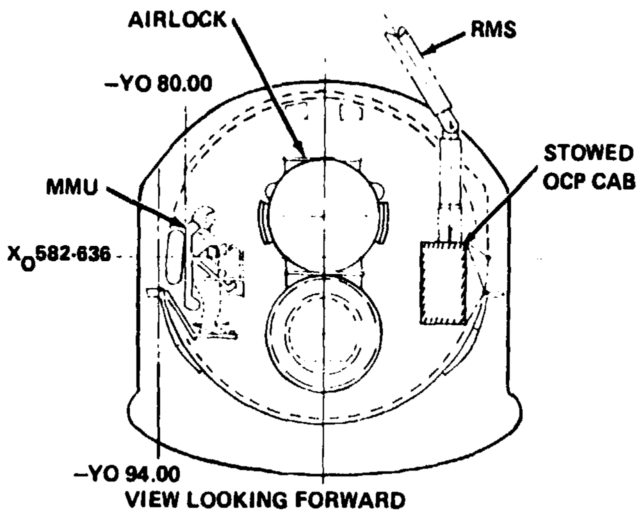

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Figure 8. OCP Stowed at MMU Donning Station

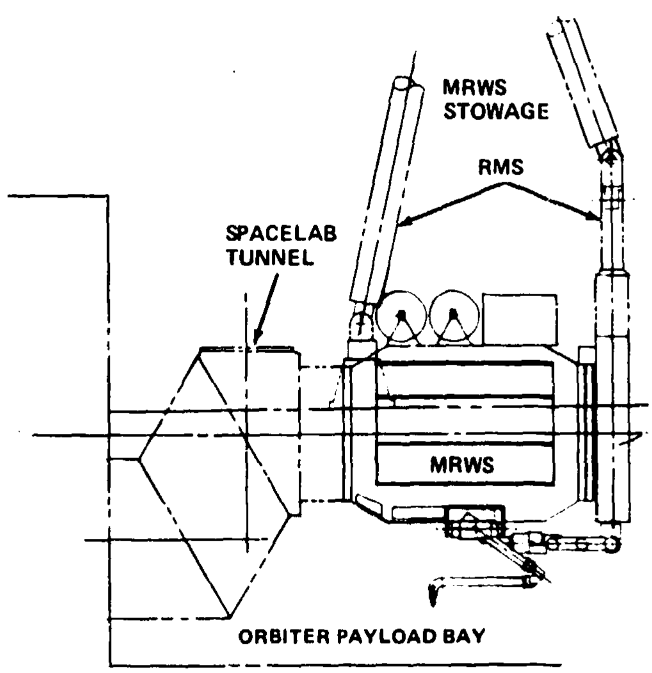

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Figure 9. MRWS Coupled to Spacelab Tunnel

Section 4

OPEN CHERRY PICKER SUBSYSTEM REQUIREMENTS

4.1 STRUCTURE/MECHANICAL

- All major load-carrying structures of the structural subsystems shall be designed to a safe life of a minimum 10 years in orbit with a scatter factor of 4.0. Life limitations shall be identified
- As a goal, failsafe design concepts shall be applied to all critical structure so that failure of a single structural member shall not degrade the strength of stiffness of the structure to the extent that the crew is in immediate jeopardy
- The structure shall be designed to resist damage resulting from accidental impact during crew activities
- Safety factors used for structural design shall be consistent with those currently used for manned operations
  - Primary Structure
    - Ultimate Strength: A factor of 1.5 x limit load shall be applied
    - Yield Strength: A factor of 1.2 x limit load shall be applied
- Structures shall be designed to withstand temperature cycling between -433°K to 366°K
- The structure shall be designed to withstand Orbiter launch and landing loads specified in JSC-07700, Volume XIV
- The open cherry picker (OCP) shall be designed to be folded and unfolded by an EVA astronaut to facilitate Orbiter payload bay storage.

4.2 COMMUNICATIONS

The OCP operator shall utilize the EMU for communications with the Orbiter, EVA astroworker and space construction base as applicable.

4.3 ELECTRICAL POWER

- The open cherry picker MRWS shall receive 28 vdc Orbiter power, up to 250 W, via the RMS grapple fixture electrical connector
- The distribution system shall provide circuit protection devices for all power equipment
- The Electrical Power Subsystem (EPS) shall have a maintained life time of not less than 10 years. Elements may be replaced in total or in modular for form for maintenance or for growth up-rating.

4.4 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

The OCP operator shall utilize the Extravehicular Mobility Unit (EMU) for ECLS.

4.5 THERMAL CONTROL

- Passive thermal control approach should be utilized where appropriate, or if not feasible, the design should minimize system complexity and weight
- The subsystem shall not require selected orientation in orbit to maintain its thermal control function.

4.6 CREW ACCOMMODATIONS

- An existing foot restraint that is mounted to a rotating platform (Figure 10) will be utilized for the OCP
- A safety tether shall be provided
- Provide a waist restraint to be used in conjunction with foot restraint as needed
- The open platform equipment shall not inhibit crew reach (Figure 11) to perform assembly tasks.

4.7 STABILIZER (CONTROLLER AND SLAVE)

- The OCP MRWS shall have one stabilizer located on the platform extending forward and shall be capable of being installed/detached in orbit

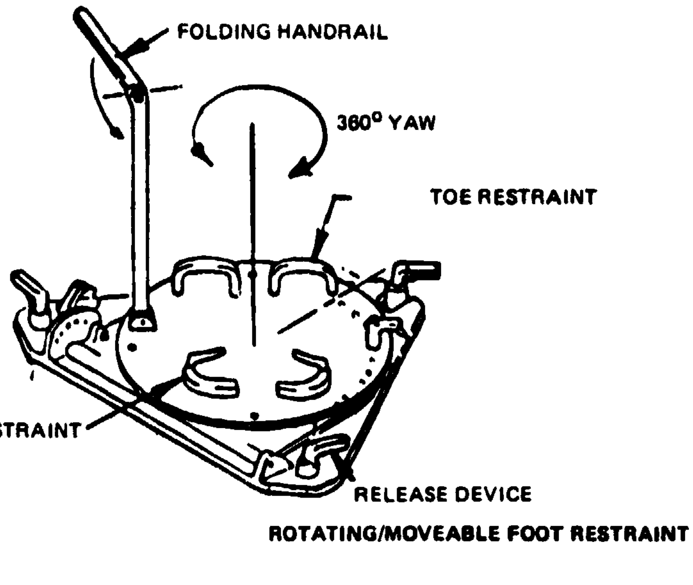
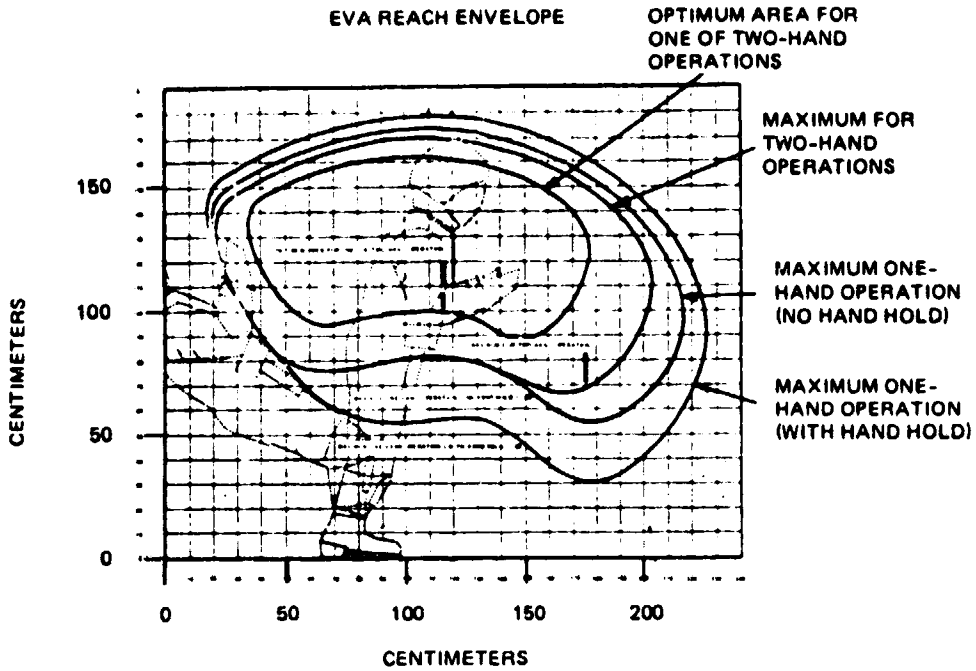


Figure 10. OCP Foot Restraint

- The stabilizer shall have 3 DOF as defined in Figure 12
- The stabilizer characteristics are:

Reach	1.3 m
Tip force (locked)	40 lb
Tip moment (locked)	4000 in.-lb
Accuracy	± 1 cm
Resolution	± 2 mm
Velocity	1.1 cm/sec

- The stabilizer master control shall be a resolved rate controller(s)
- The tip shall have mechanical and electrical interfaces to accept end effectors
- Provide controls to actuate end effector functions, e.g., open/close jaws
- The stabilizer joints shall lock in existing position at power removal
- Back driving shall not damage the stabilizer.



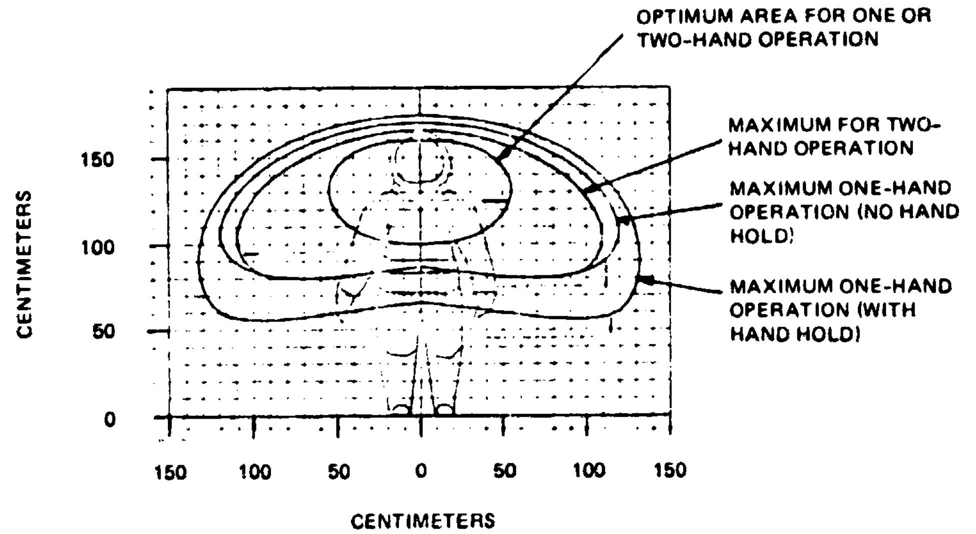


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Figure 11. Extravehicular Mobility Unit Reach Capability

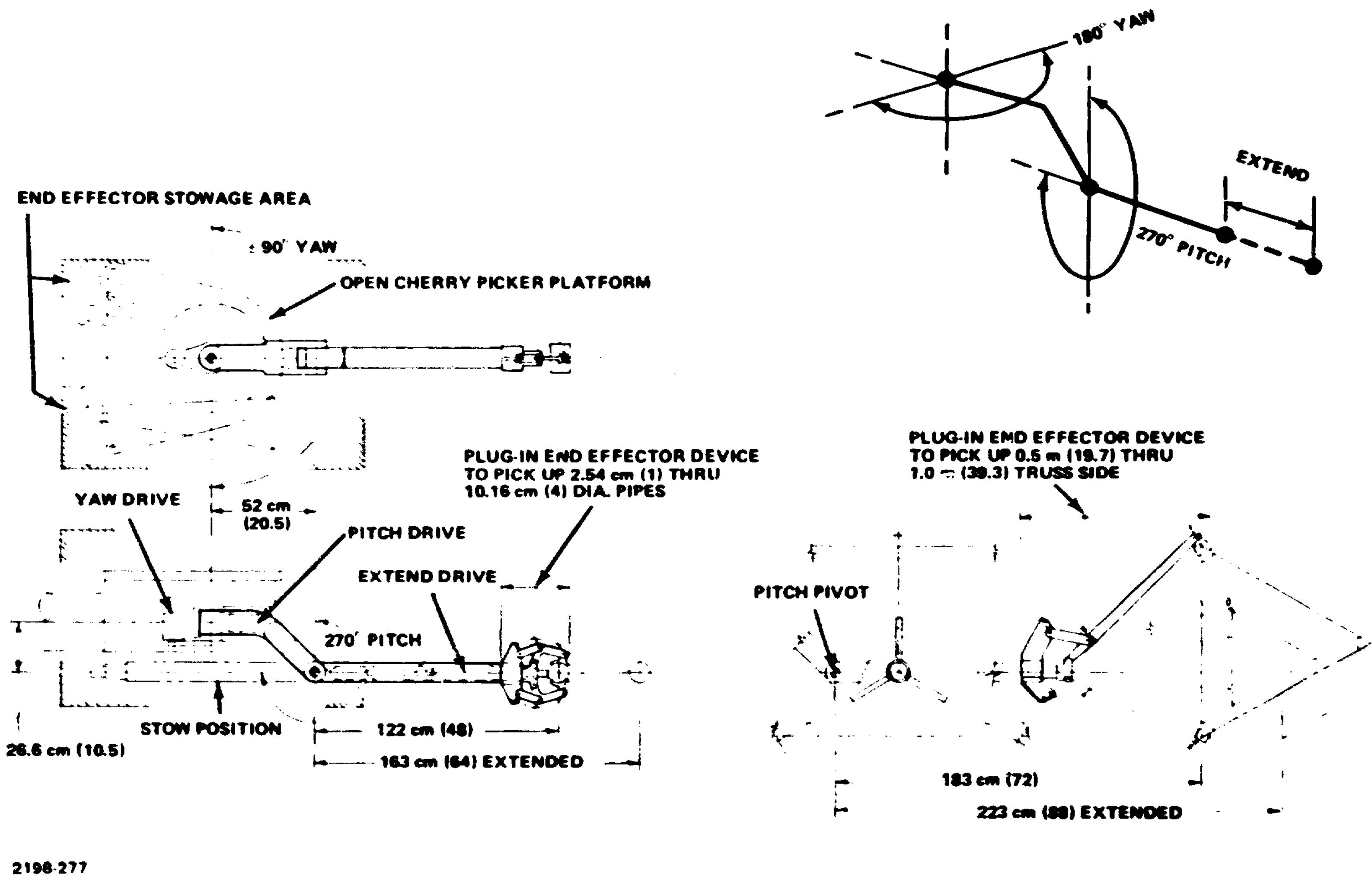

Figure 12. Three-Degree-of-Freedon Stabilizer

4.8 CHERRY PICKER ARM CONTROL

- Provide Orbiter RMS/cherry picker arm control from the OCP utilizing the same type of controllers used for the Orbiter RMS
- The capability shall be available to select control of an alternate Orbiter RMS/crane arm
- The capability shall be available to the OCP operator to control individual RMS joints
- Interface units shall be provided for open cherry picker RMS control as shown in Figure 13.

4.9 ILLUMINATION

- Lights shall be mounted on the OCP to provide 50 ft-c of luminous intensity within the reach of the OCP operator
- The lights shall be adjustable by the OCP operator for direction and reach.

4.10 CONTROLS AND DISPLAYS (C&D)

- A C&D console shall be mounted convenient to the operator during OCP RMS maneuvers and when controlling the stabilizer
- The panel shall provide accommodations for mounting the RMS and stabilizer controllers
- Controls and displays panel shall be moveable so that the operator is not constrained while performing space tasks.

4.11 SOFTWARE

Utilize existing Orbiter software for control of the RMS.

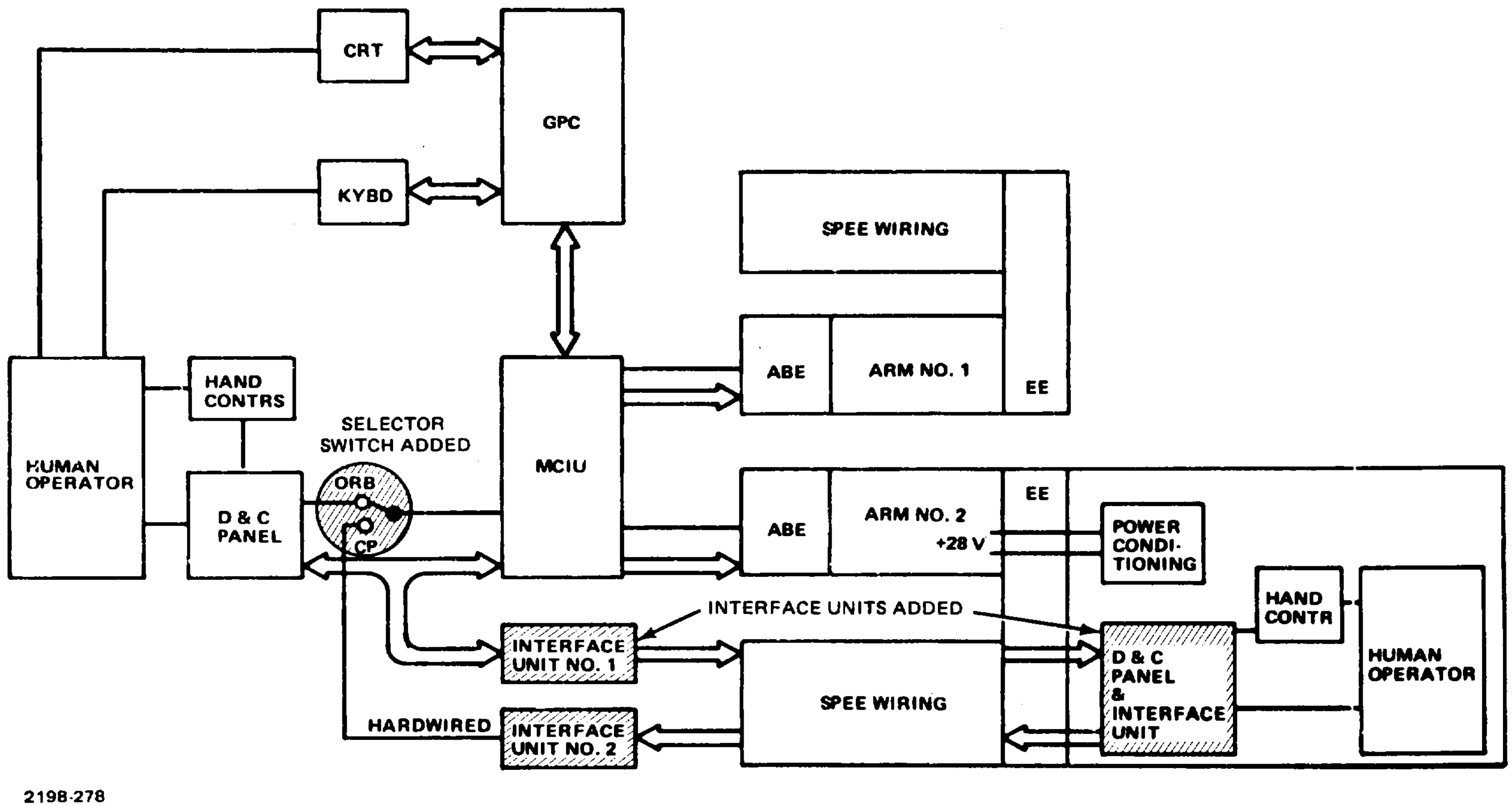

Figure 13. Orbiter/RMS/OCP Block Diagram

Section 5

CLOSED CHERRY PICKER SUBSYSTEM REQUIREMENTS

5.1 STRUCTURE/MECHANICAL

- All major load-carrying structures of the structural subsystems shall be designed to a safe life of a minimum ten years in orbit with a scatter factor of 4.0. Life limitations shall be identified
- As a goal, failsafe design concepts shall be applied to all critical structure so that failure of a single structural member shall not degrade the strength of stiffness of the structure to the estent that the crew is in immediate jeopardy
- The structure shall be designed to resist damage resulting from accidental impact during crew activities
- Safety factors used for structural design shall be consistent with those currently used for manned operations
  - Primary Structure
    - o Ultimate Strength: A factor of 1.5 x limit load shall be applied
    - o Yield Strength: A factor of 1.2 x limit load shall be applied
  - Cabin Pressure Structure
    - o Ultimate Strength: A factor of 2.0 x maximum relief valve pressure shall be applied
  - Windows, Doors, etc
    - o Ultimate Strength: A factor of 3.0 x maximum relief valve pressure shall be applied
- Fracture mechanics analyses shall be used to access flow growth, life and proof test requirements
- Closed cabin meteoroid protection shall be provided by the MRWS design consistent with the meteoroid flux given in TM X-53865, second edition, dated August 1970. The design goal will be to provide sufficient protection to assure an 0.995 probability of no mission failure resulting from meteoroid penetration

- Structures shall be designed to withstand temperature cycling between -433°K to 366°K
- Radiation Protection: The closed cabin MRWS shall provide radiation protection for the crew so that safe daily radiation skin dosage is not exceeded for 90 days missions in low earth orbit (LEO) and geosynchronous orbit (GEO), excluding solar flares. A warning system shall be implemented to permit the crew to enter a storm shelter during solar flare activities
- All subsystem equipment which does not require manned interface in the pressurized cabin shall be mounted externally
- The closed cabin shall be designed to withstand berthing and docking loads of TBD
- The structure shall be designed to withstand Orbiter launch and landing loads specified in JSC-07700, Volume XIV.

5.2 COMMUNICATIONS AND DATA HANDLING (C&DH)

- The C&DH subsystem shall be designed to provide communications with the orbiter and other cooperating vehicles
- The communications system shall provide the following capability:
  - Reception, transmission, processing, and distribution of voice channels
  - Generation, processing, distribution and transmission of television signals
  - Transmission and reception of EVA voice
  - Acquisition and transmission of telemetry data
- The communication links between the MRWS and the Orbiter shall operate at S-band frequencies
- Capability for voice conference shall be provided between the Orbiter, cooperative space vehicles and EVA astroworkers
- Closed circuit TV shall be provided for support of special area monitoring
- MRWS attitude constraints shall not be required to maintain acceptable communications
- Provisions for back-up voice communications via RMS/cherry picker arm hardwire to Orbiter/Space Construction Base.

5.3 ELECTRICAL POWER

- Electrical power requirements for the closed cherry picker, crane turret and free flyer MRWS are contained in Table 4
- The closed cherry picker MRWS shall receive 28 vdc Orbiter power via the crane electrical connector
- Fixed base MRWS shall receive 28 vdc power via hardware directly from the orbiting element
- Fuel cell 28 vdc power source shall be used for non-fixed base MRWS
- The Electrical Power Subsystem (EPS) shall have a maintained lifetime of not less than 10 years. Elements may be replaced in total or in modular form for maintenance or for growth up-rating
- The distribution system shall provide circuit protection devices for all power equipment.
- Emergency power (1 kWh) for non-fixed base MRWS shall be provided by nickel cadmium batteries.

5.4 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

- The cabin atmosphere shall consist of 70% oxygen and 30% nitrogen maintained at 14.7 ± 0.5 psia
- Carbon dioxide shall be removed by a regenerable solid amine system
- Cabin temperature shall be maintained at $80^{\circ} \pm 5^{\circ}F$
- Humidity shall be controlled to maintain dew point at $50^{\circ} \pm 5^{\circ}F$
- Emergency pressurization shall maintain the cabin at 8 ± 0.5 psia for 1/2 hour when leakage equivalent to 1/4 inch diameter hole.
- Consummables shall be provided for seven days of operations (three 8-hr shifts)
- Crew metabolic requirements are:

Average load	-	1200 BTU/hr
Peak load	-	1600 BTU/hr
CO_2 generation	-	5.0 lb/day
H_2O generation	-	18 lb/day

TABLE 4

SUBSYSTEM REQUIREMENTS – ELECTRICAL POWER

	CLOSED CHERRY PICKER	CRANE	FREE FLYER
• LOAD (W)			
CABIN	822/533	822/533	834/533
EXTERNAL	3113/0	3503/0	1882/19
AFT BAY	228/71	228/71	298/12
TOTAL	4163/604	4553/604	3014/694
• ENERGY (kWh)			
9 hr	38	41	27
7 DAYS	699	765	506
1 hr EMERGENCY	0.6	0.6	0.7

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- Consumables shall be provided for two repressurizations of the MRWS cabin per week
- Consumable requirements are:

	Oxygen	Nitrogen
Cabin leakage @ 0.4 lb/day	2.8	11.2
Metabolic @ 4.2 lb/day	29.4	-
Two repressurizations - 168 ft^3	7.5	30.0
Total/week - lb	39.7	41.2

5.5 THERMAL CONTROL

- Passive thermal control approach should be utilized where appropriate, or if not feasible, the design should minimize system complexity and weight
- Provide thermal heat rejection system to maintain/remove cabin heat

Cabin interior heat load:	
Metabolic (1200 BTU/hr)	350
CO_2 removal	50
Electrical equipment	845
Solar input (windows)	255
Total - Watts	1500

- Provide thermal radiators to reject cabin heat (approx. 85 ft^2)
- The subsystem shall not require selected cabin orientation in orbit to maintain its thermal control function.

5.6 CREW ACCOMMODATIONS

- Shirt sleeve access to be provided through a 1 m diameter hatch. An alternate means of egress shall be provided
- Crew neutral body position in zero gravity per JSC-09962, modified to selected tolerance angles as shown in Figure 14.
- Accommodate male and female operators in the 5th to 95th percentile anthropormeric range

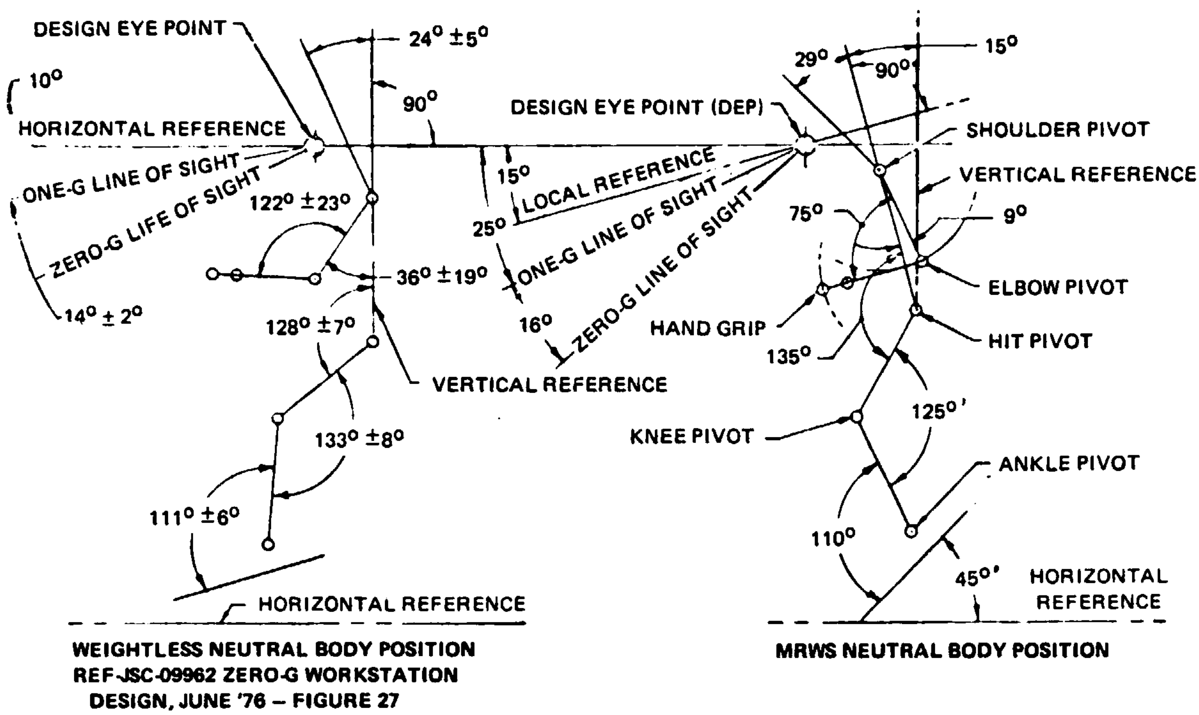

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Figure 14. Crew Neutral Body Position in Zero Gravity

- Design eye point (DEP) X = +54.6 cm, Y = O & Z = -190.5 cm references for vision, control reach and position
- An adjustable foot restraint system that place the crew at DEP
- Foot restraints shall be primary form of restraint
- Windows sized to provide view of manipulator slave arm(s) and stabilized through their full range of motion defined in Figure 15.
- Continuous noise levels will not exceed 50db in the 600 to 4,800 Hz range, and 700 db above 4800 Hz
- Provide capability for donning a Personnel Rescue System (PRS)
- Provide stowage for:
  - PRS
  - Tools for general repair
  - Portable light
  - Radiation dosimeter
  - First aid kit
  - Carry on food (1000 calories/shift)
  - Trash
  - Personal hygiene items
- Portable water, hot and cold sufficient for three shifts/day, seven days
- Foot preparation area (rehydration)
- Equipment installation will be capable of reacting to crew impact loads (300 lb)
- Provide for human waste (urine and feces) collection and disposal.

5.7 DEXTROUS MANIPULATOR (MASTER AND SLAVE)

- The closed cabin MRWS shall have two slave manipulators, one located on each side of the cabin, that shall be capable of being installed/detached in orbit
- The manipulators shall have seven axes of rotation as defined in Figure 16

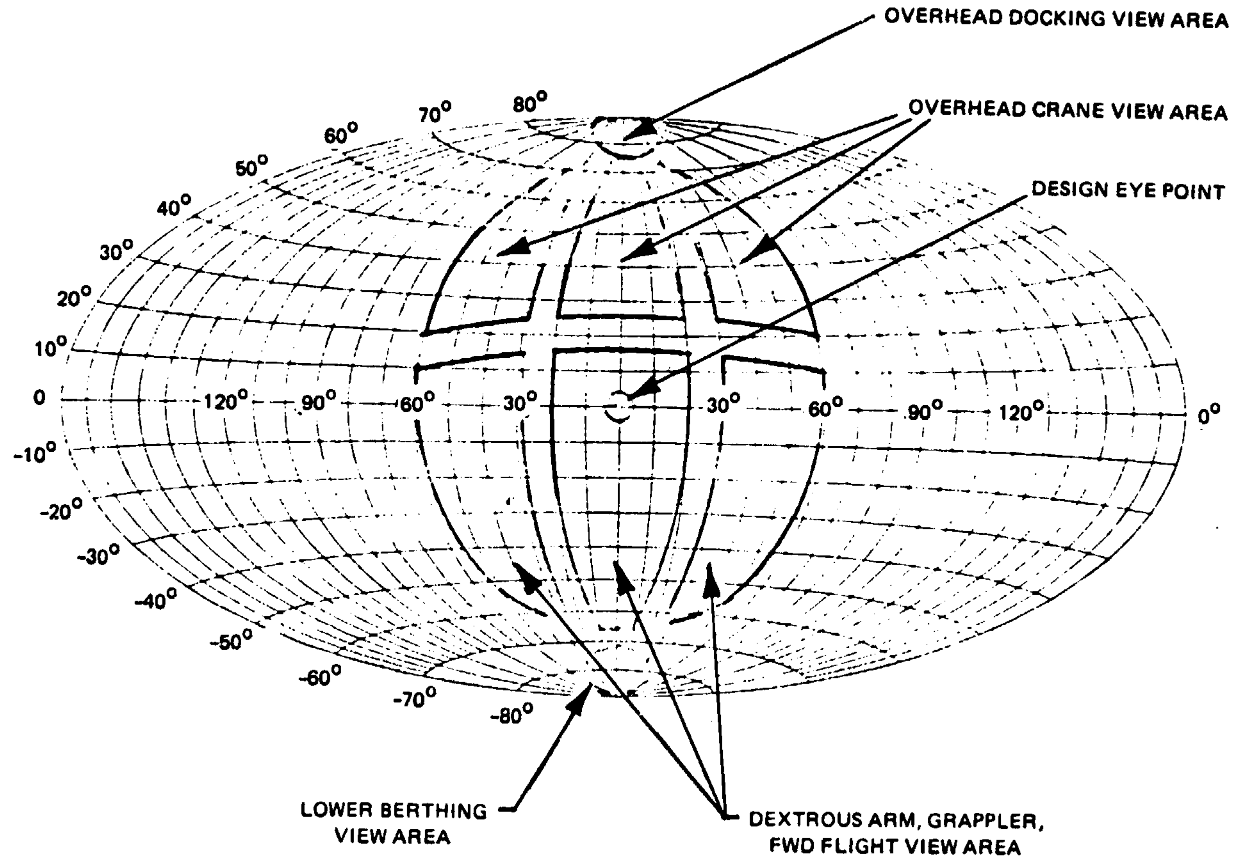

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Figure 15. MRWS Visibility Requirements on AITOFF's Equal Area Projection of the Sphere

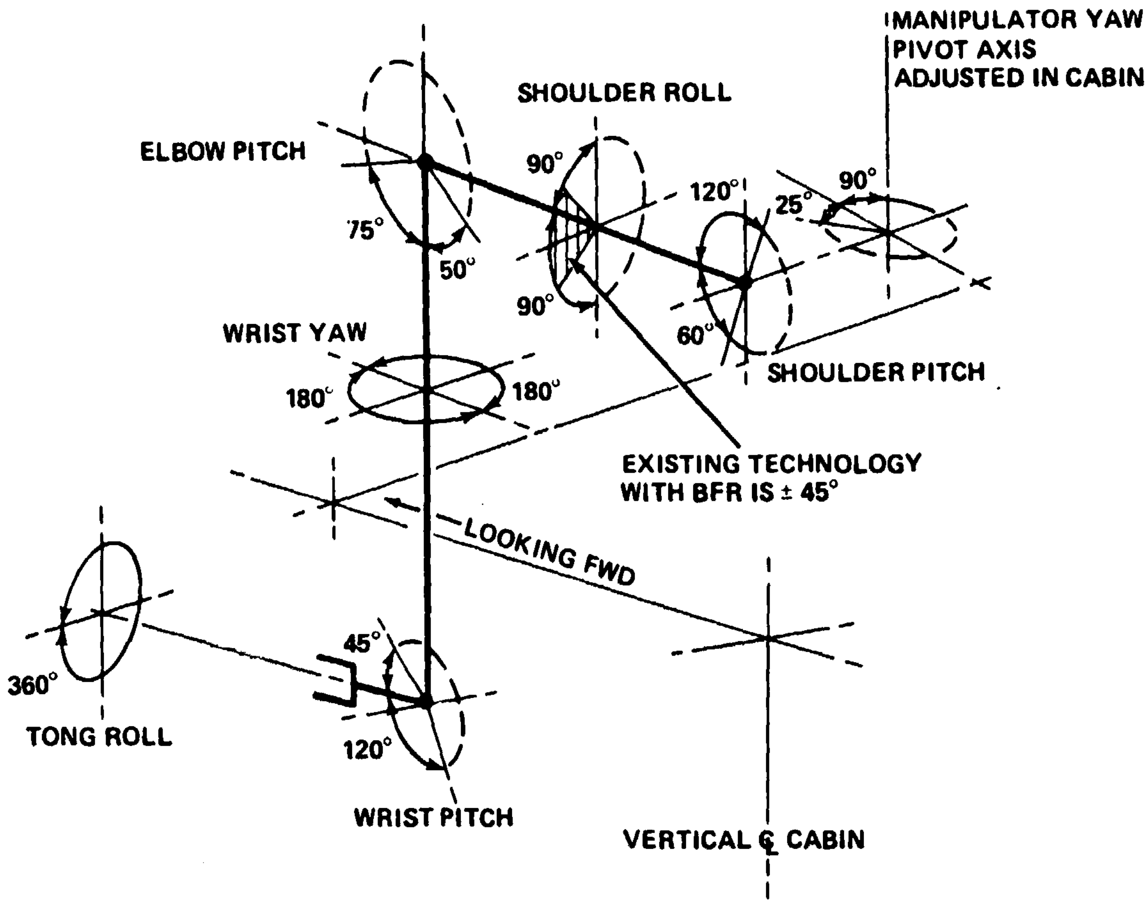

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Figure 16. Recommended Slave Arm Kinematics

- The manipulator characteristics are:
  - Reach 2 m
  - Tip force 67 N (1516 lb)
  - Velocity 0.75 m/sec (30 in./sec)
  - Accuracy ±5 mm (±.2 in.) for 457 mm (18 in.)
  - Resolution 1.5 mm (0.06 in.) x, y & z
- The manipulator master controllers, one for each manipulator, shall be 6 DOF replica bilateral force reflecting (BFR) with a ratio of 1:3.33 as illustrated in Figure 17
- The manipulator master shall be located in relation to the crew design eye as shown in Figure 18
- Shoulder you shall be controlled by a separate indexing switch
- The tip shall have mechanical and electrical interfaces to accept end effectors
- Provide controls to actuate end effector functions, e.g.:
  - Open/close jaws
  - Grasp/release beam
- The manipulator joints shall lock in existing position at power removal.

5.8 STABILIZER (CONTROLLER AND SLAVE)

- The closed cabin MRWS shall have one stabilizer located on the platform extending forward, and shall be capable of being installed/detached in orbit
- The stabilizer shall have 3 DOF as defined for the OCP in Figure 12
- The stabilizer characteristics are:

- Reach	1.3 m
- Tip force (locked)	40 lb
- Tip moment (locked)	4000 in lb
- Accuracy	±1 cm
- Resolution	±2 mm
- Velocity	1.1 cm/s

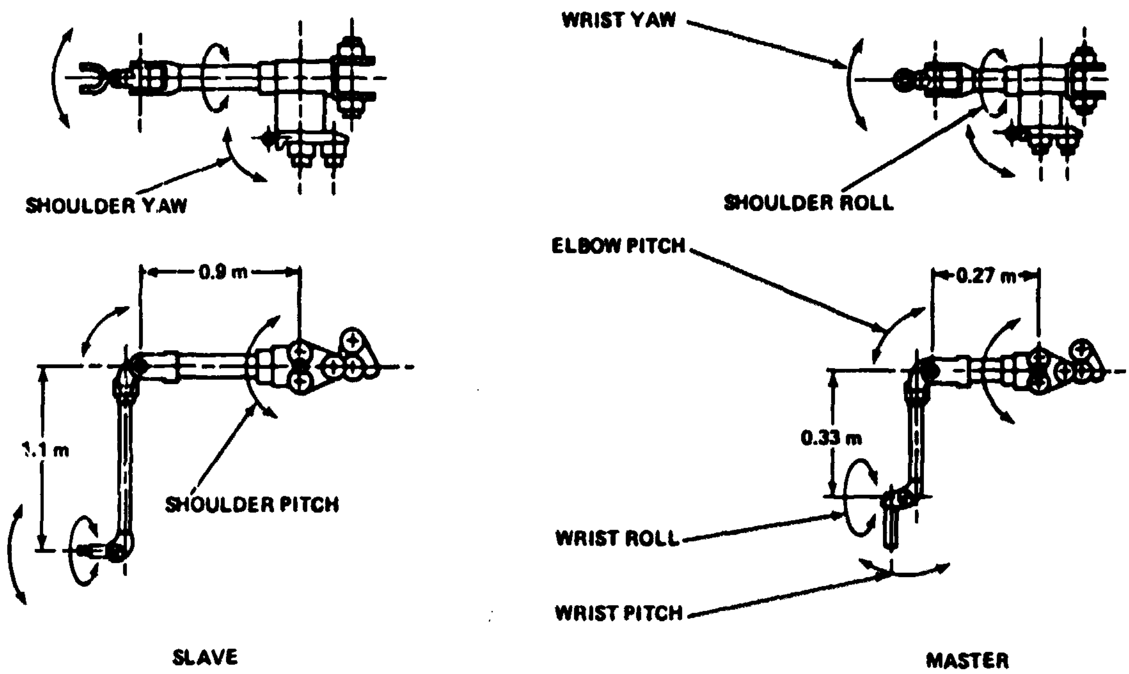

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Figure 17. Dextrous Manipulator Arrangement

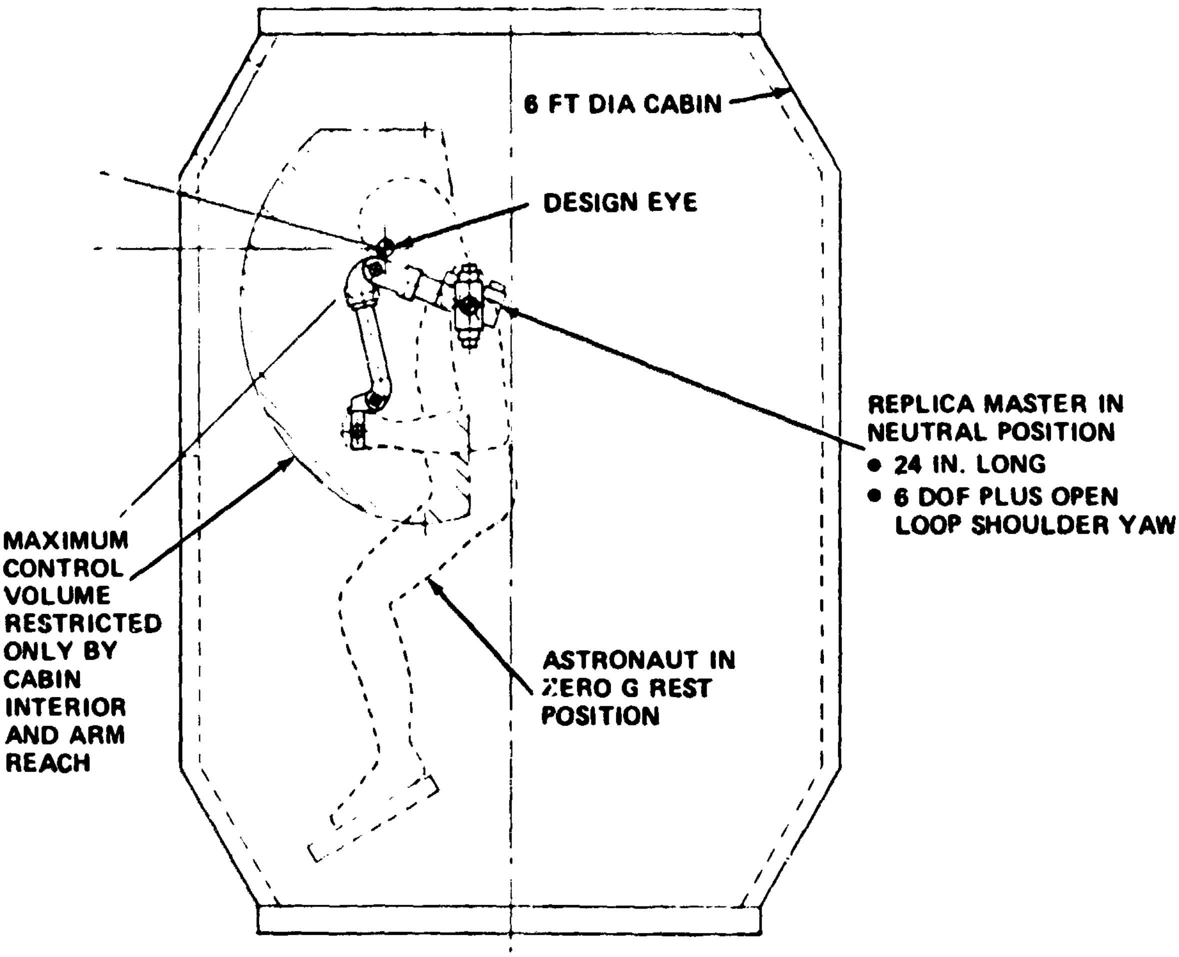


Figure 18. Master Control Configuration

- The stabilizer control shall be a resolved rate controller(s)
- The tip shall have mechanical and electrical interfaces to accept end effectors
- Provide controls to actuate end effector functions, e.g., open/close jaws
- The stabilizer joints shall lock in existing position at power removal
- The stabilizer joints shall be able to be backdriven.

5.9 CHERRY PICKER ARM CONTROL

- Provide crane cherry picker arm control from the closed cabin MRWS utilizing the same type of controllers used for the Orbiter RMS
- The capability shall be available to select control of an alternate crane arm
- Provide caution and warning to the cherry picker MRWS to avoid potential impact with assembled equipment/structure.

5.10 ILLUMINATION

- Lights shall be mounted on the cabin to provide 50 ft-c of luminous intensity within the reach of the manipulators
- Position lights shall be mounted on the exterior of the enclosed cabin in the X-Y plane, two top and two on the bottom, for determination of vehicle orientation. Each light shall have a luminous intensity of 2.5 candlepower.

5.11 DISPLAYS

- A closed circuit TV system shall be provided to aid construction. The camera shall permit views of assembly 90° to the normal cabin line-of-sight
- Cabin displays should minimize excursion into the manipulator controller working volume and crew line-of-sight to assembly tasks.

5.12 SOFTWARE

- TBD

Section 6

CRANE TURRET SUBSYSTEM REQUIREMENTS

6.1 STRUCTURE/MECHANICAL

Same as closed cherry picker.

6.2 COMMUNICATIONS

Same as closed cherry picker except that backup voice is hardwired to the orbital element (Space Construction Base).

6.3 ELECTRICAL POWER

Same as closed cabin cherry picker except that the electrical power shall be provided to the crane turret by an orbital element. Table 4 (closed cabin cherry picker) contains the electrical power requirements.

6.4 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Same as closed cherry picker.

6.5 THERMAL CONTROL

Same as closed cherry picker.

6.6 CREW ACCOMMODATIONS

Same as closed cherry picker except that unobstructed direct vision shall be provided for the crane turret operator with arms fully extended in any attitude.

6.7 CRANE (CONTROLLER AND SLAVE)

- The length of the crane arm shall be 35-m when fully extended
- Rotational and translation controllers shall be provided. Controls shall be configured for independent operation of each arm. Four operational modes shall be provided:
  - Remote control (manned or aided manual)
  - Automated

- Combined modes
- Cherry picker MRWS

- A universal interface will be provided for installation/exchange of various end effectors for parts and material handling operations. The range of end effectors shall consist of simple mechanical devices up to a cherry picker MRWS
- Each crane arm shall be capable of being installed/detached in orbit.

6.8 ILLUMINATION/CCTV

A lighting and CCTV subassembly shall be mounted on the crane arms and will consist of CCTV cameras with pan/tilt/zoom

6.9 DISPLAYS

Same as closed cherry picker.

6.10 SOFTWARE

Crane turret MRWS software shall accommodate the capability to handle the required degree-of-freedom (DOF). The DOF are: Turret assembly (azimuth), shoulder (pitch and yaw), upper arm (roll), elbow joint (pitch), and wrist joint (pitch, yaw, and roll). Collision avoidance software and/or maximum torque and/or energy override shall be provided.

Section 7

FREE FLYER SUBSYSTEM REQUIREMENTS

7.1 STRUCTURE/MECHANICAL

- Same as closed cherry picker
- Provide the capability to carry construction materials
- Thruster mounting and propellant tank support shall be provided
- Design structure to accommodate 80 lb force thruster loads
- Thruster plumes shall not adversely effect cabin operations. Avoid thruster plumes on manipulators and work area.

7.2 COMMUNICATIONS

Same as closed cherry picker except that hardline backup communications shall not apply.

7.3 ELECTRICAL POWER

- Same as closed cherry picker except that electrical power will be provided only by fuel cells and the emergency battery
- Table 4 (closed cabin cherry picker) contains the electrical power requirements.

7.4 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Same as closed cherry picker.

7.5 THERMAL CONTROL

Same as closed cherry picker.

7.6 CREW ACCOMMODATIONS

Same as closed cherry picker.

7.7 DEXTEROUS MANIPULATOR (MASTER AND SLAVE)

Same as closed cherry picker.

7.8 STABILIZER (CONTROLLER & SLAVE)

- Same as closed cherry picker
- The stabilizer shall meet the requirements of berthing the free flyer MRWS.

7.9 PROPULSION AND ATTITUDE CONTROL

Figure 19 summarizes the requirements.

- The free flyer shall have the capability of operating for 10 hr which includes:
  - Two traverses of 10-km each
  - One hour, 5-km out-of-plane
  - Twenty slews 180° each at 1 deg/sec
- Provide control authority:
  - Rotational acceleration $10°/sec^2$
  - Translation $0.3\ ft/sec^2$
- Rotation and translation shall be accomplished by the same thrusters:
  - Utilize six thruster clusters consisting of three bilevel thrusters in each cluster. Total = 36 thrusters
  - Propellant N_2H_4
  - Thrusters 5 lbf and 80 lbf
- Attitude deadband shall be ±0.1 deg
- Provide four 16-5 in. diameter propellant tanks to hold 283 lb of propellant.

7.10 ILLUMINATION

Same as closed cherry picker.

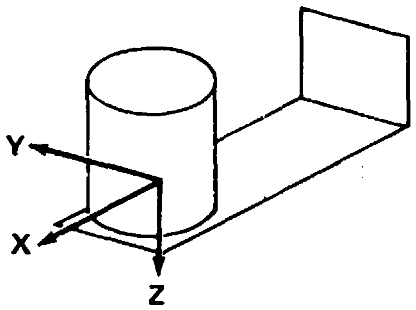
7.11 DISPLAYS

- Same as closed cherry picker
- Provide computer entry key board and read out displays for interface with the guidance and control subsystem.

7.12 GUIDANCE AND CONTROL

Provide tracking, guidance and control, and software necessary for free flyer rendezvous.

- OPERATING PERIOD: 10 h, 25% FREE FLYING
- TRANSLATION: TWO 10 km TRIPS ⟶ 40 m/s
- STATIONKEEPING: 5 km ABOVE OR BELOW FOR 1 h ⟶ 10.8 lbf
- ATTITUDE CONTROL DEADBAND: ±0.1°
- SLEWS: TWENTY, 18J° EACH @ 1 deg/s
- "GOOD" CONTROL AUTHORITY
  - ROTATIONAL 10 °/s^2
  - TRANSLATIONAL 0.3 ft/s^2
- NOMINAL CHARACTERISTICS – WEIGHT 8650 lb



I_X = 3900 SLUG·ft^2
I_Y = 6650 SLUG·ft^2
I_Z = 5900 SLUG·ft^2
L_X = 11 ft
L_Y = L_Z = 14 ft

ROTATIONAL CONTROL: F_X = 62 lbf F_Y = 83 lbf F_Z = 74 lbf

TRANSLATIONAL CONTROL: 80 lbf

- AVOID THRUSTER PLUMES ON MANIPULATORS & IN WORK VOLUMES
- MINIMIZE THRUSTER INTERFERENCE WITH CABIN ROTATION & PAYLOAD HANDLING
- MINIMIZE CG SHIFT SENSITIVITY

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Figure 19. Free Flyer Propulsion and Attitude Control Subsystem Requirements

APPENDIX A

MISSION REQUIREMENTS

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ILLUSTRATIONS (contd)

ILLUSTRATIONS (contd)

ILLUSTRATIONS (contd)

TABLES

Introduction

MRWS MISSION ANALYSIS

The introduction of the Space Transportation System (STS) has removed many of the constraints of payload volume and mass to orbit that have inhibited low-cost space operations. Most importantly, the STS transports up to seven astronauts to orbit, who can significantly enhance operations in terms of payload handling, satellite servicing, scientific observation, and structural assembly. Given the right tools, man-in-space can achieve goals never before imagined. The Manned Remote Work Station (MRWS) is one of these tools that can assist the astronaut in efficient and cost-effective orbital operations.

This appendix outlines a program scenario, broken down into the three time phases (Figure 1). Missions have been analyzed to derive MRWS flight article requirements and concepts, and to determine the requirements for a ground simulation program. The MRWS can operate from the end of the Shuttle Remote Manipulator System (SRMS) in the early 1980's and perform such operations as support of Spacelabs experiments, servicing and repair of satellites, and construction research and development (R&D). In the mid 1980's the MRWS will become an integral part of the Orbital Service Module (or Initial Space Construction Base) and perform the tasks of assembling large antenna and solar power technology satellites. The eventual use of the MRWS will be in support of constructing the Solar Power Satellite in the 1990's.

The MRWS is envisioned as a universal crew cabin that can support operations in the multiple roles (Figure 2). These roles include use as a crane turret, cherry picker, free flyer, railed work station, and personnel orbit transfer vehicle airlock. Each of these MRWS mission roles has been identified during the Orbital Construction Support Equipment Studies (NAS 9-15120) as being essential to the assembly of the Solar Power Satellite.

Table 1 is a mission matrix that relates the various MRWS operating roles to the missions they perform during the three time phases: near-term,

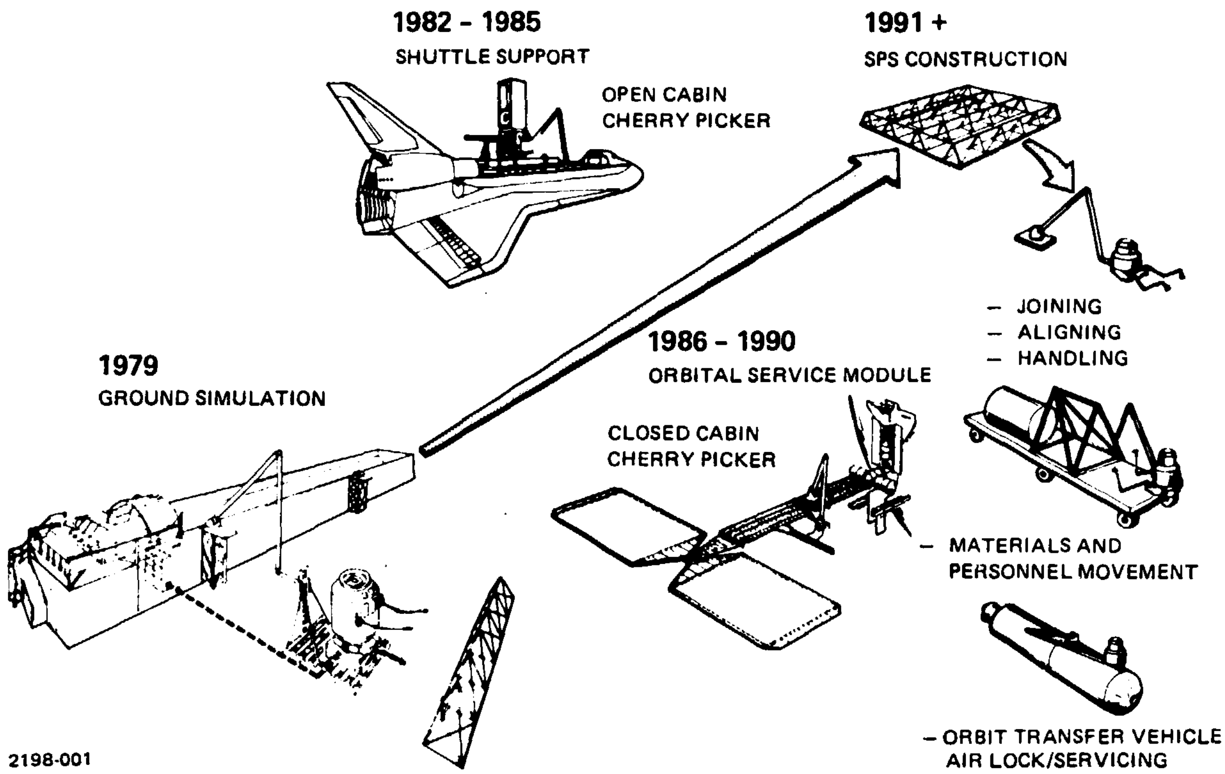

Figure 1. Orbital Construction Support Equipment Development – Universal Manned Remote Work Station

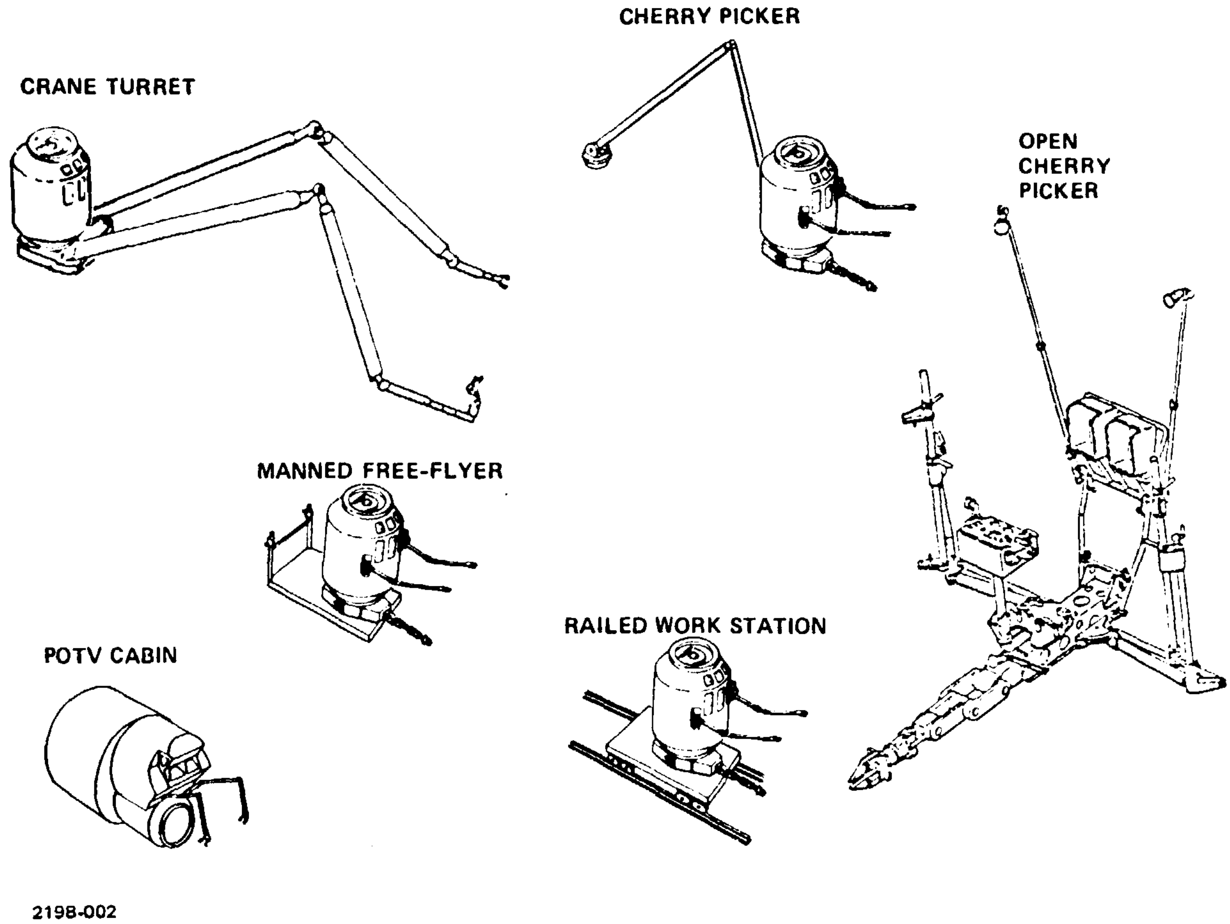

Figure 2. MRWS Multirole Concept in Support of Large Space Systems

1982 - 1985; mid-term, 1986 - 1990; and far-term, 1990 - 2000 +. The near-term operations can be performed with an open cabin version of the cherry picker. Requirements for this time phase have been derived from the mission descriptions for automated payloads and two studies (NAS 8-32390 and NAS 9-15310) related to construction R&D operations directly from the Orbiter. MRWS requirements for the mid-term have been derived from two studies related to the initial construction base operations, namely, the Orbital Construction Demonstration Study (NAS 9-14916) and the Space Station Systems Analysis Study (NAS 9-14958). These studies identified the need for a closed cabin cherry picker and the crane turret. The basis of far-term MRWS requirements are the results of the OCSE studies (NAS 9-15120) and the Solar Power Satellite Systems Definition Study (NAS 9-15196).

TABLE 1

MRWS MISSION MATRIX

MRWS ROLE	NEAR-TERM 1982-1985	MID-TERM 1986-1990	FAR-TERM 1991-2000+
• OPEN CHERRY PICKER–FIXED	SHUTTLE SUPPORT	SCB –STRONGBACK	
• CLOSED CHERRY PICKER–FIXED			
• RAILED CLOSED CHERRY PICKER			SPS CONSTRUCTION (PHOTOVOLTAIC)
• FIXED CRANE–TURRET			SPS CONSTRUCTION (THERMAL)
• RAILED CRANE			SPS CONSTRUCTION (PHOTOVOLTAIC)
• RAILED CABIN			
• FIXED CABIN			SPS CONSTRUCTION (THERMAL)
• FREE-FLYER		PSP CONSTRUCTION	SPS CONSTRUCTION
• OTV CABIN		GEO SERVICING	SPS CONSTRUCTION

[shaded box] AVAILABLE DATA

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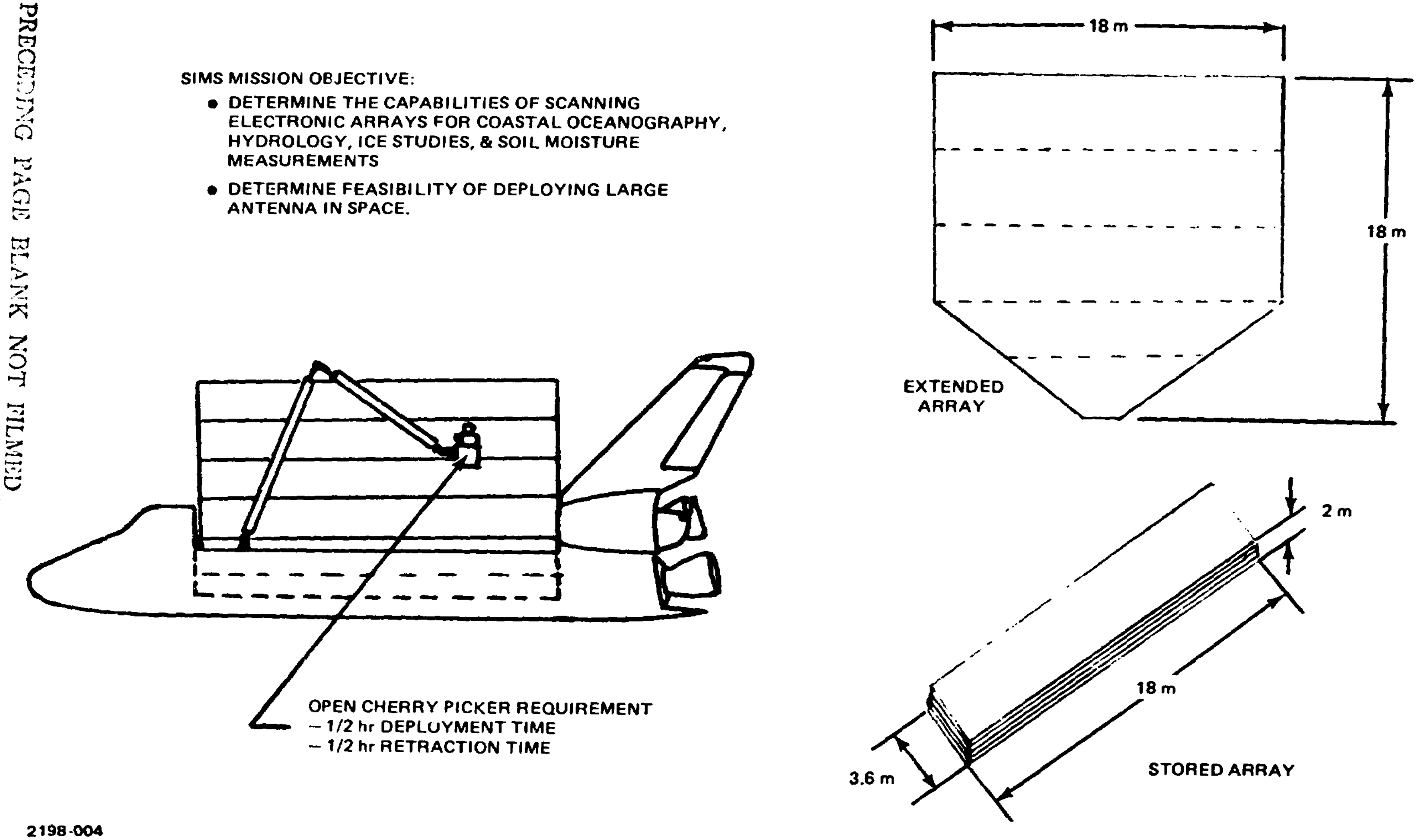


REF. PAYLOADS DESCRIPTIONS, VOL. II, BOOK 2 - SORTIE PAYLOADS, JULY 1975

Figure 2. Shuttle Imaging Microwave System (SIMS) Antenna Deployment

The reusable MMS offers several significant advantages over the conventional uniquely integrated spacecraft. Within its standard range of capabilities, it can be adapted to varied payload requirements, eliminating the need for costly and time-consuming design, development, production, and procurement activity.

The MMS with its payload can either be brought back from space or reserviced on orbit by the Space Shuttle, as desired by the user. This represents a major cost-saving capability unavailable with uniquely integrated spacecraft. In instances where on-orbit repair or refurbishment is not desired, the MMS can be retrieved by the Space Shuttle, returned to Earth for refurbishment or upgrading, and relaunched.

1.1.2 Spacecraft Description

The basic MMS consists of two major structural subassemblies and three major subsystem modules (Figure 4). The module support structure subassembly interfaces with the transition adapter subassembly, and is the central core structure of the MMS. It carries all structural loads imposed by, and all structural and functional interfaces with, the modules.

The transition adapter provides a standard payload interface to the MMS, provices the interface to the Space Shuttle Orbiter (through appropriate supporting hardware), and provides the capture point interface to the Shuttle remote manipulator system (RMS) for retrieval and on-orbit servicing or return to Earth.

The three major subsystem modules (see Figure 5 for dimensions and Figure 6 for retention scheme) each have a standard range of performance capabilities and provide communications and data handling, power, and attitude control services. Optional propulsion modules are available as required and a variety of mission-specific subsystem elements can be added to tailor the capabilities of the MMS to the user's requirements. Examples would include a tape recorder in the command and data-handling module, or additional batteries in the power module. Additional features such as antenna systems and solar arrays, also considered mission-specific, must be supplied by the user. Table 2 contains the mass of each MMS subassembly.

1.1.3 Support Functions and Mission Scenario

A one-man open cabin cherry picker MRWS configuration attached to the end of the Shuttle Remote Manipulator can be used to support on orbit servicing of the MMS. A concept and supporting functions for the open cabin cherry picker are shown in

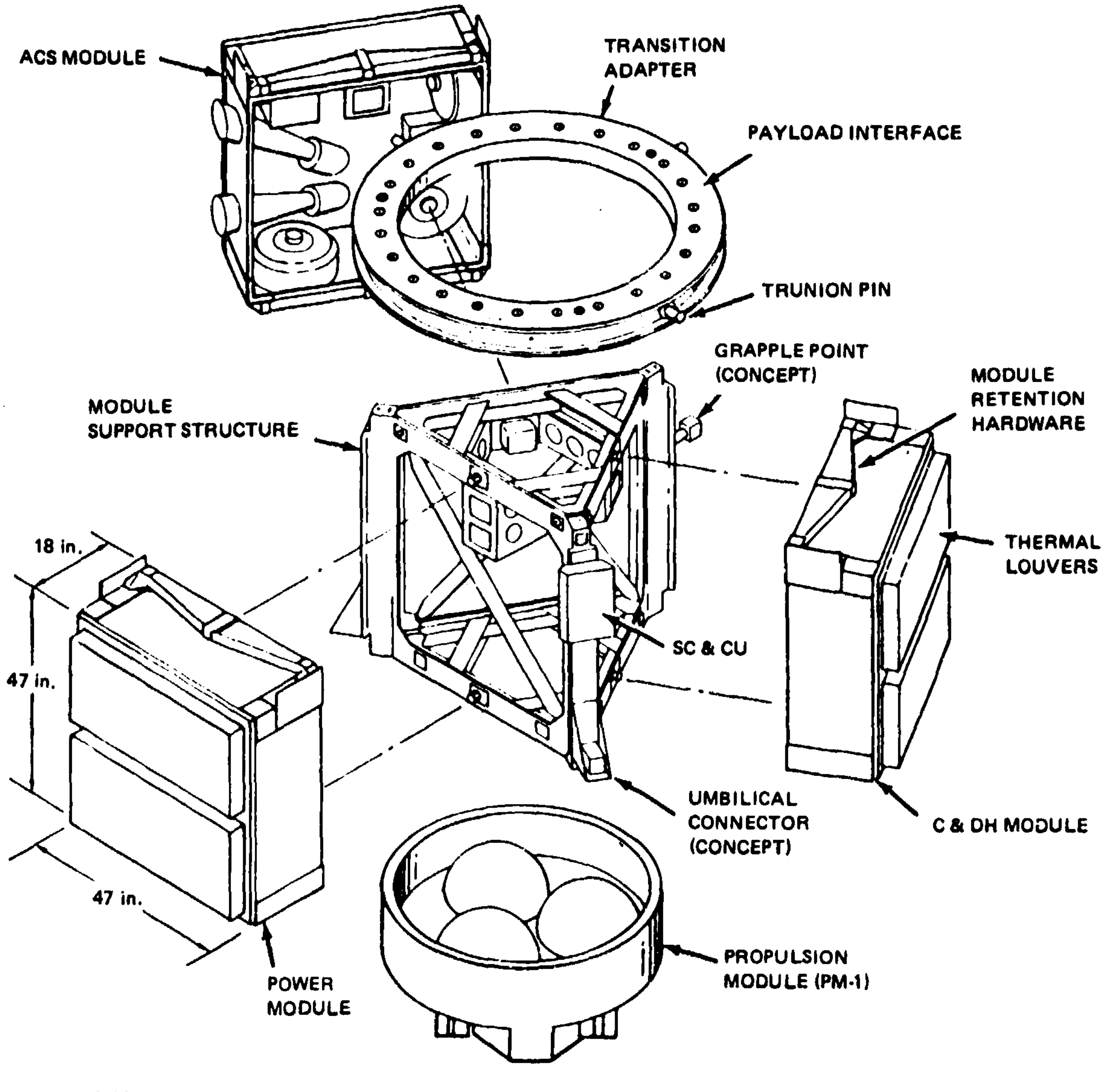
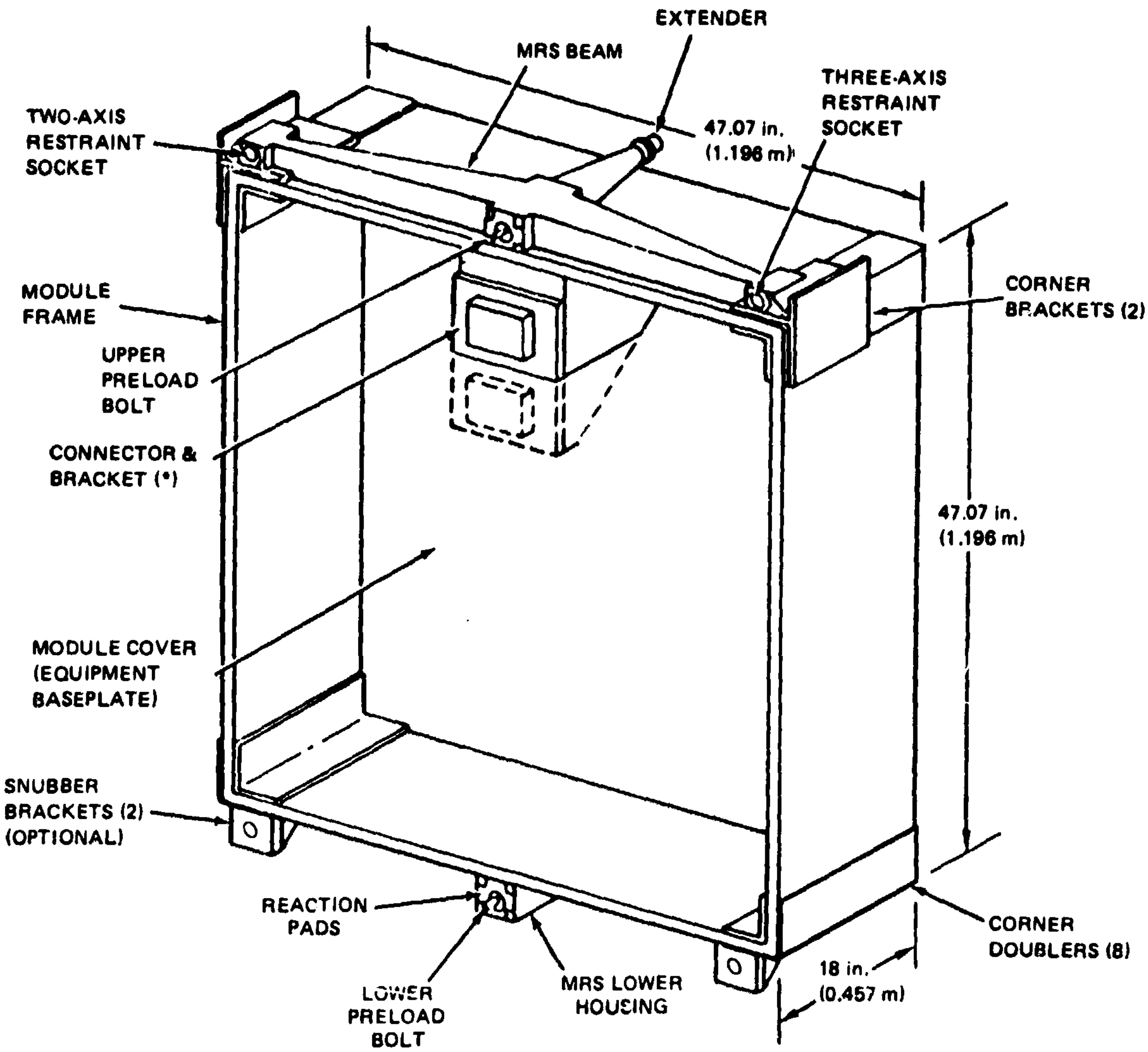


Figure 4. MMS Mechanical System Components



ALIGNMENT FOR
INSERTION

±2 in.

±3 deg

RELEASE TORQUE =

100 ft-lb

(*) DOUBLE CONNECTOR FOR POWER MODULE ONLY

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Figure 5. Standard Subsystem Module and Module Retention System

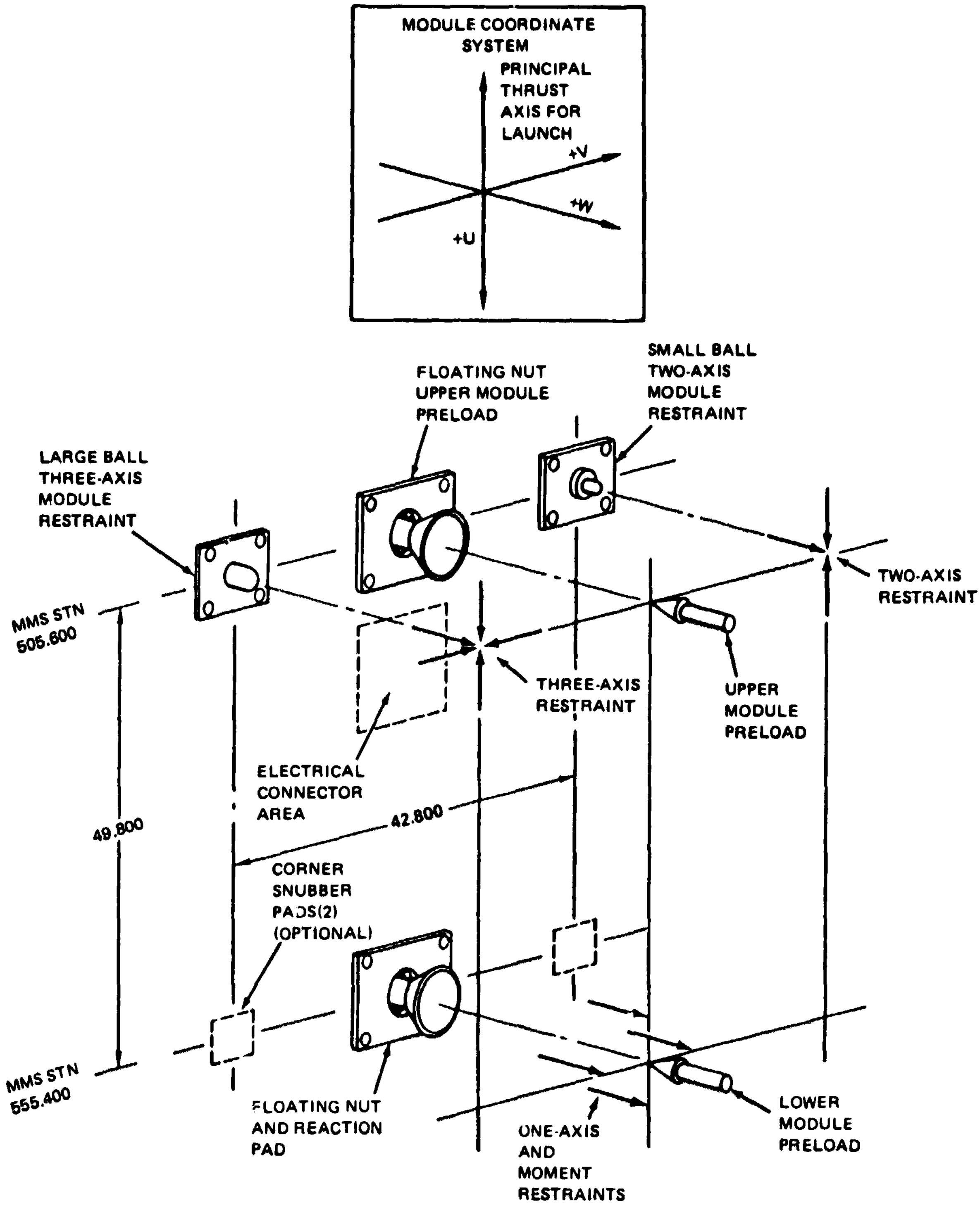

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Figure 6. Module Retention Interface

TABLE 2

MMS WEIGHT STATEMENT

	PRODUCTION MMS (lb)
BASIC SYSTEM	
• STRUCTURE (BASELINE-8 ATTACH POINTS)	
• SIGNAL CONDITIONING & CONTROL UNIT	
• ELECTRICAL HARNESS	384
MODULAR SUBSYSTEMS	
• POWER MODULE	
- COMPONENTS	260
- FRAME & THERMAL LOUVERS	87
• ACS MODULE	
- COMPONENTS	277
- FRAME & THERMAL LOUVERS	91
• C&DH MODULE	
- COMPONENTS	123
- FRAME & THERMAL LOUVERS	90
TOTAL MODULAR SUBSYSTEMS	928
TOTAL BASELINE MMS	1312
PROPULSION MODULE (OPTIONAL)	
• PM-I (CONTAINS 167 LB HYDRAZINE)	332
• PM-II (CONTAINS 1060 LB HYDRAZINE) THE PM-II MODULE IS DESIGNED FOR USE WITH THE STS AND ITS LATERAL LOADS ARE REACTED BY THE FSS, NOT THE MMS.	1353

2198-008

Figure 7. Control of the cherry picker is from the platform which also contains the supporting tools needed to perform the subsystem module installation and handling task.

The functional requirements for the open cherry picker are summarized in Figure 8. Functions 1.0 through 6.0 are common to all OCP near-term missions. The implications of these requirements are:

- Function 1.0 - The OCP should be mounted in the Shuttle cargo bay in a position that is accessible to the Shuttle Remote Manipulator System. The stowage arrangement should be minimum in size in an effort to keep user costs down. A preferred location for mounting would be on the forward payload bay bulkhead in a packaging arrangement that would not preclude addition of the docking module
- Function 2.0 - The OCP should utilize the existing SRMS power and signal lines allocated to payload use. SRMS power routing to the payload is limited to 250W. OCP power requirements over this limit would need an externally mounted cable. There are 14 signal lines available at the SRMS/payload interface. The OCP should utilize a multiplex system to stay within these signal line limits.
- Function 3.0 - The OCP should utilize the standard SRMS snare end effector grapple fixture (Figure 9)
- Function 4.0 - The OCP should be configured for remote checkout from the payload specialist station
- Function 5.0 - The OCP should be placed as close as possible to the extra vehicular activity (EVA) egress port. This feature would minimize the need to man-rate equipments in the payload bay, along the path of the EVA crewman
- Function 6.0 - The MRWS (OCP) retention device should be electromechanically released.

Functions 7.0 through 13.0 are peculiar to the MMS mission and are the basis of the task analysis in the following sections.

Figure 10 illustrates the MMS mission scenario. The SRMS is used to retrieve the free flying MMS and berths it to the payload retention device. The SRMS then

CHERRY PICKER REQUIREMENTS

- SERVICE/REPLACE SUBSYSTEM MODULE
- CALIBRATE/ADJUST/REPLACE INSTRUMENTATION
- REPLACE PROPULSION MODULE

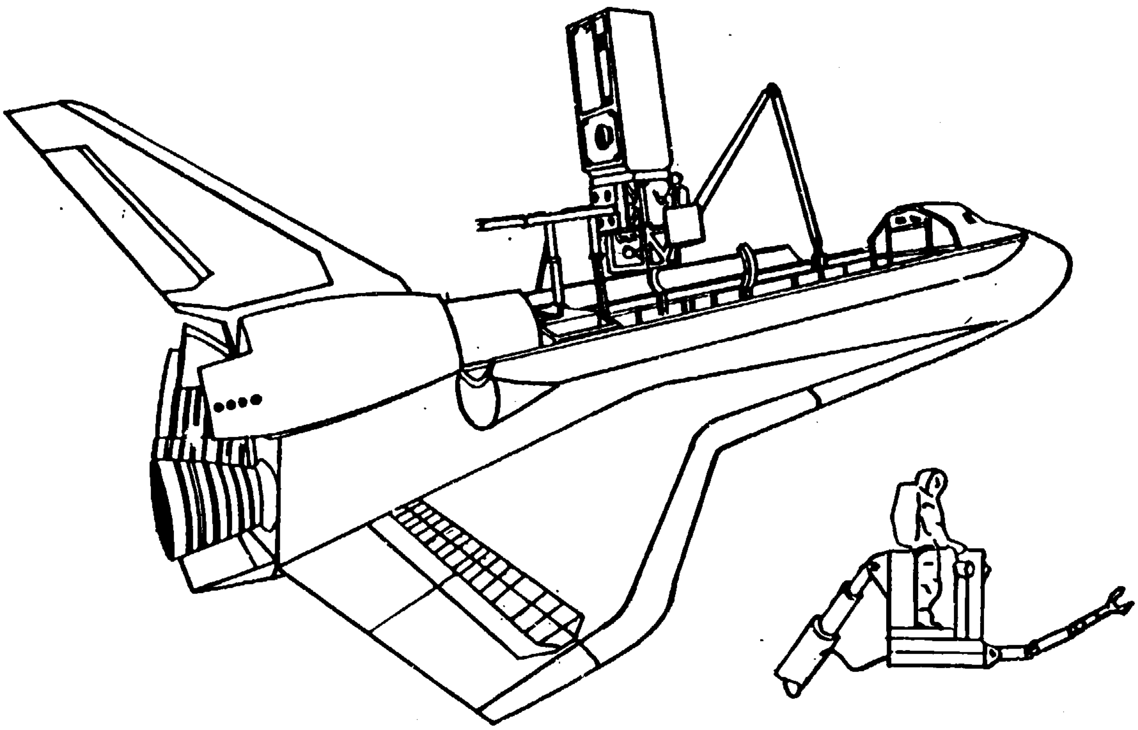

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Figure 7. Multimission Spacecraft Servicing

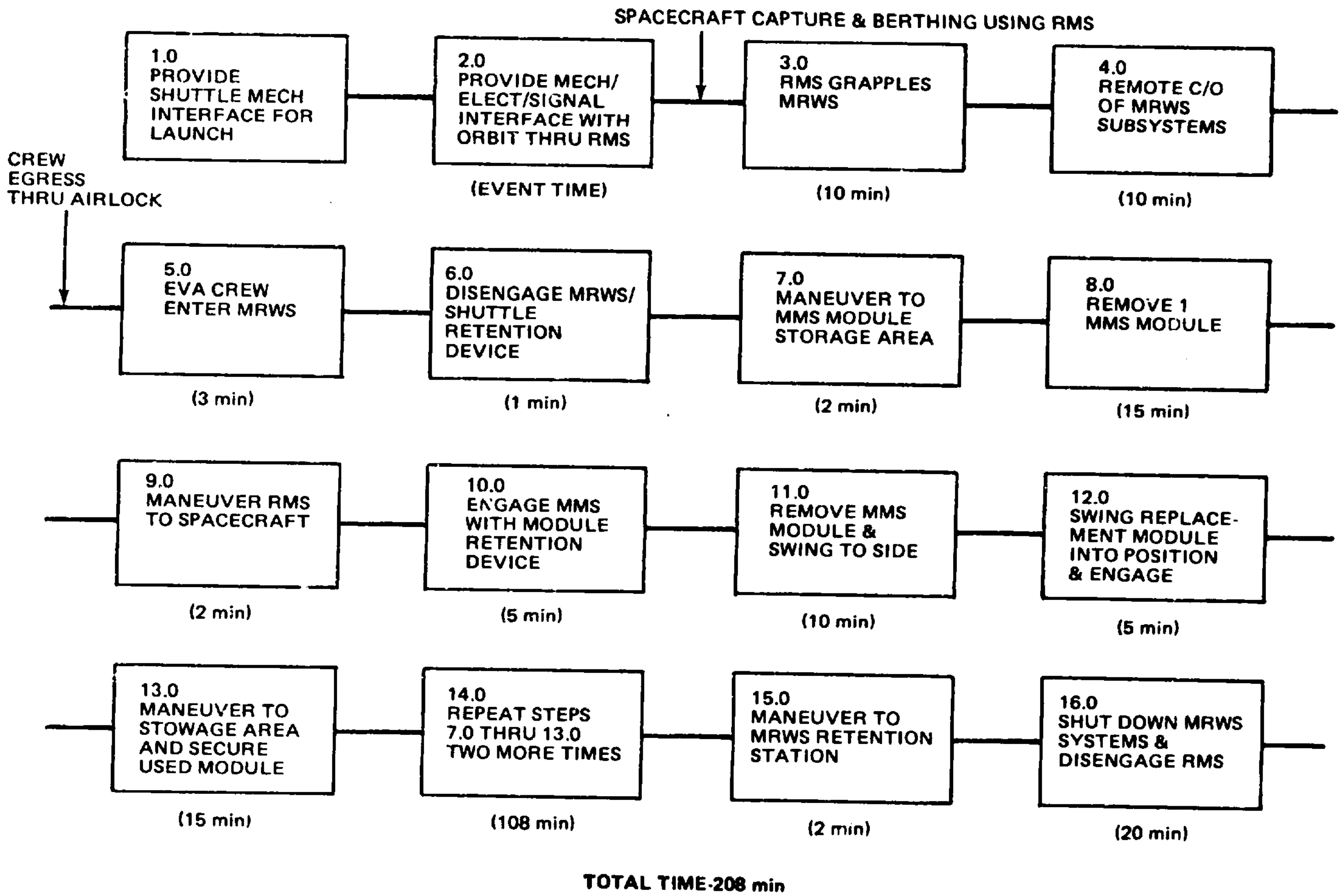

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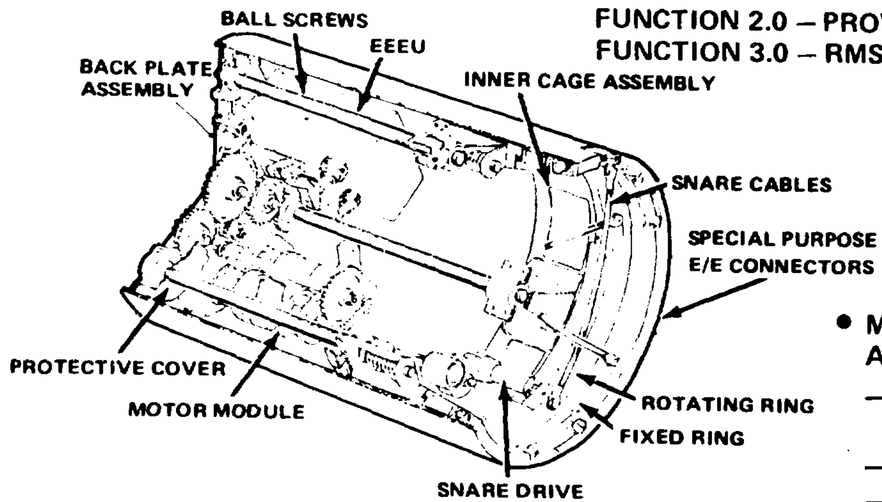
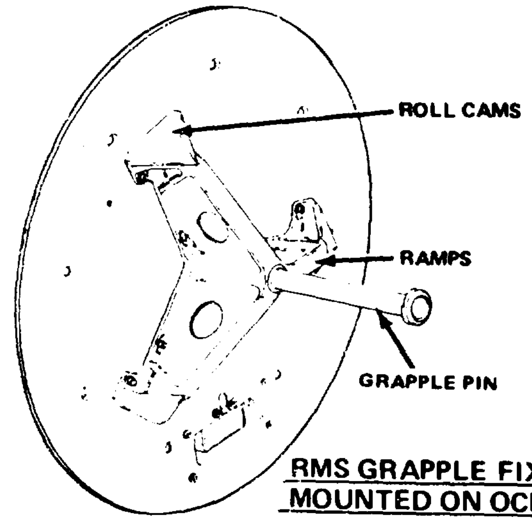
Figure 8. Open Cherry Picker Functions — MMS Servicing

FUNCTION 2.0 – PROVIDE MECH/ELECTRICAL/SIGNAL INTERFACE
FUNCTION 3.0 – RMS GRAPPLE MRWS



SNARE TYPE RMS END EFFECTOR



RMS GRAPPLE FIXTURE MOUNTED ON OCP

INTERFACE REQUIREMENT

- MECHANICAL – CANADIAN SNARE END EFFECTOR AND GRAPPLE FIXTURE
  - PRECAPTURE MISALIGN LIMITS – 4 in. $\pm 15°$
  - CAPTURE SPEED – 0.33 TO 0.95 ft/sec
  - RIGIDIZE SPEED – 8 TO 5.7 in./sec
  - TORQUE CAPABIL. – 350 ft-lb
  - RELEASE IMPULSE – 0.3 lbf-sec
- ELECTRICAL (100 WATTS AVAIL)
  - MRWS POWER =
    - D&C – 20 WATTS*
    - HAND CONT – 20 WATTS*

    TOTAL 40 WATTS
- SIGNAL
  - ATTITUDE AND TRANSLATION HAND CONTROLLER SIGNALS
  - RMS CONSOLE SIGNALS
  - ECLS SIGNALS

*ADDITIONAL POWER MAY BE NEEDED FOR HEATER

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Figure 9. Open Cherry Picker Requirements

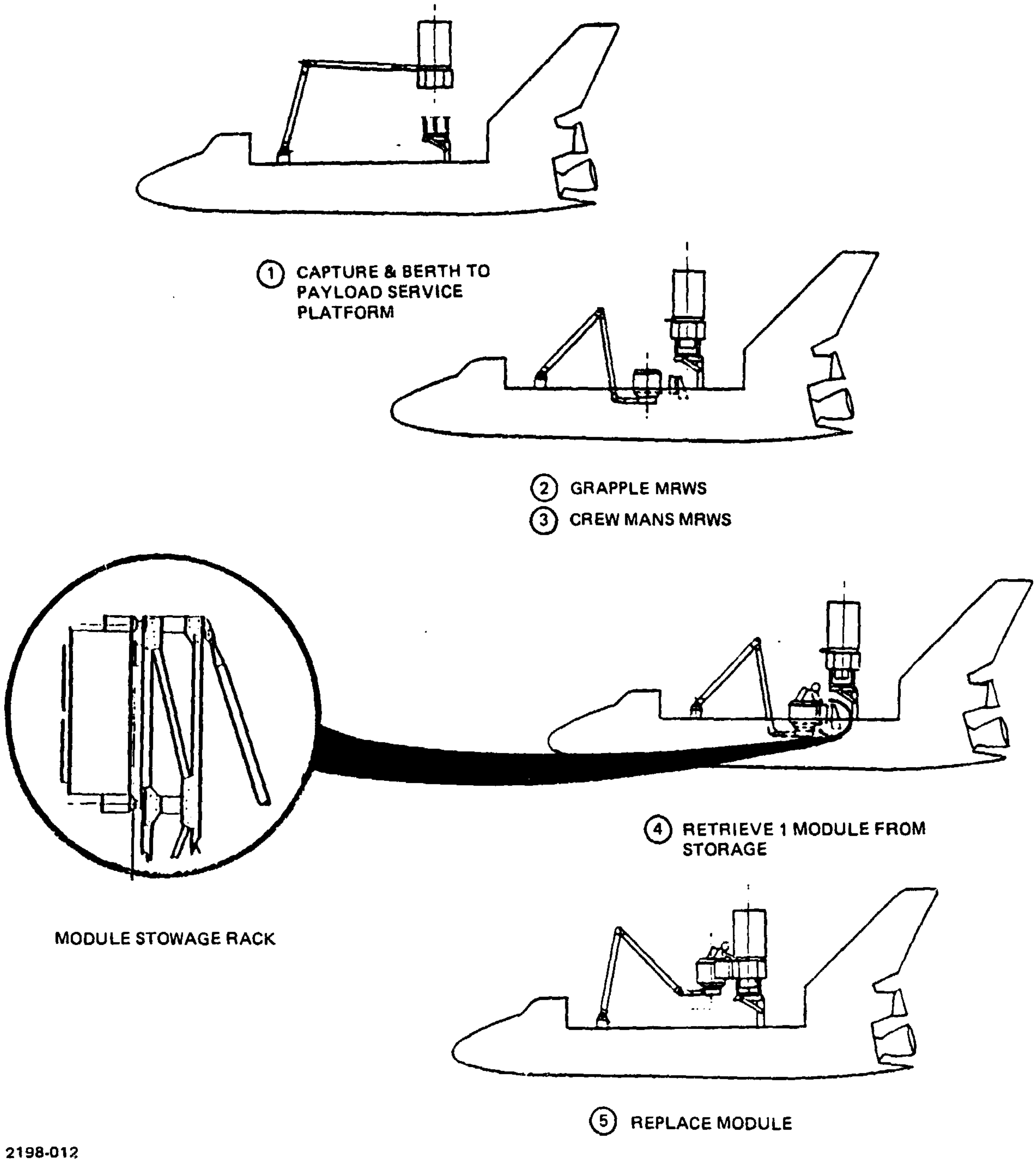


Figure 10. Modular Replacement Scenario

grapples the open cherry picker and maneuvers it to the EVA egress port where the crew enters the MRWS. The crew then controls the MRWS and maneuvers to the MMS subsystem module storage area to retrieve one module. The crewman then maneuvers to the spacecraft and replaces one module. This process is repeated until all three modules have been replaced.

1.1.4 Task Analysis - Replace Subsystem Module

1.1.4.1 Accessibility - The MMS is berthed to the payload positioning platform as shown in Figure 11. This platform is located in the forward part of the shuttle payload bay well within the reach envelope of the RMS. To enhance accessibility the platform rotates the spacecraft permitting the EVA astronaut access to all sides for subsystem module replacement, or sensor servicing. The standoff posts of the platform permit access to the underside of the spacecraft for power module servicing.

1.1.4.2 Items to be Handled - The crew and support equipment interface with the subsystem modules shown in Figure 3. These modules must be removed from the spacecraft and stowed in the payload bay where replacement modules are obtained. New modules are aligned and mechanically attached to the spacecraft by the crew. Similar operations are required for sensor replacement.

1.1.4.3 Operations - Replace Subsystem Module, three per spacecraft (Power, ACS, C&DH). The approximate time-line for replacing a single subsystem module is as follows:

ΔT (min)	Operations
13	Retrieve module from storage
21	Exchange module
12	Stow used module in payload bay
45	TOTAL

1.1.5 Open Cabin Cherry Picker Design Requirements

1.1.5.1 Size - A one-man crew is adequate for performing this mission. As a design goal the open platform should be of minimum size and weight to keep user costs down.

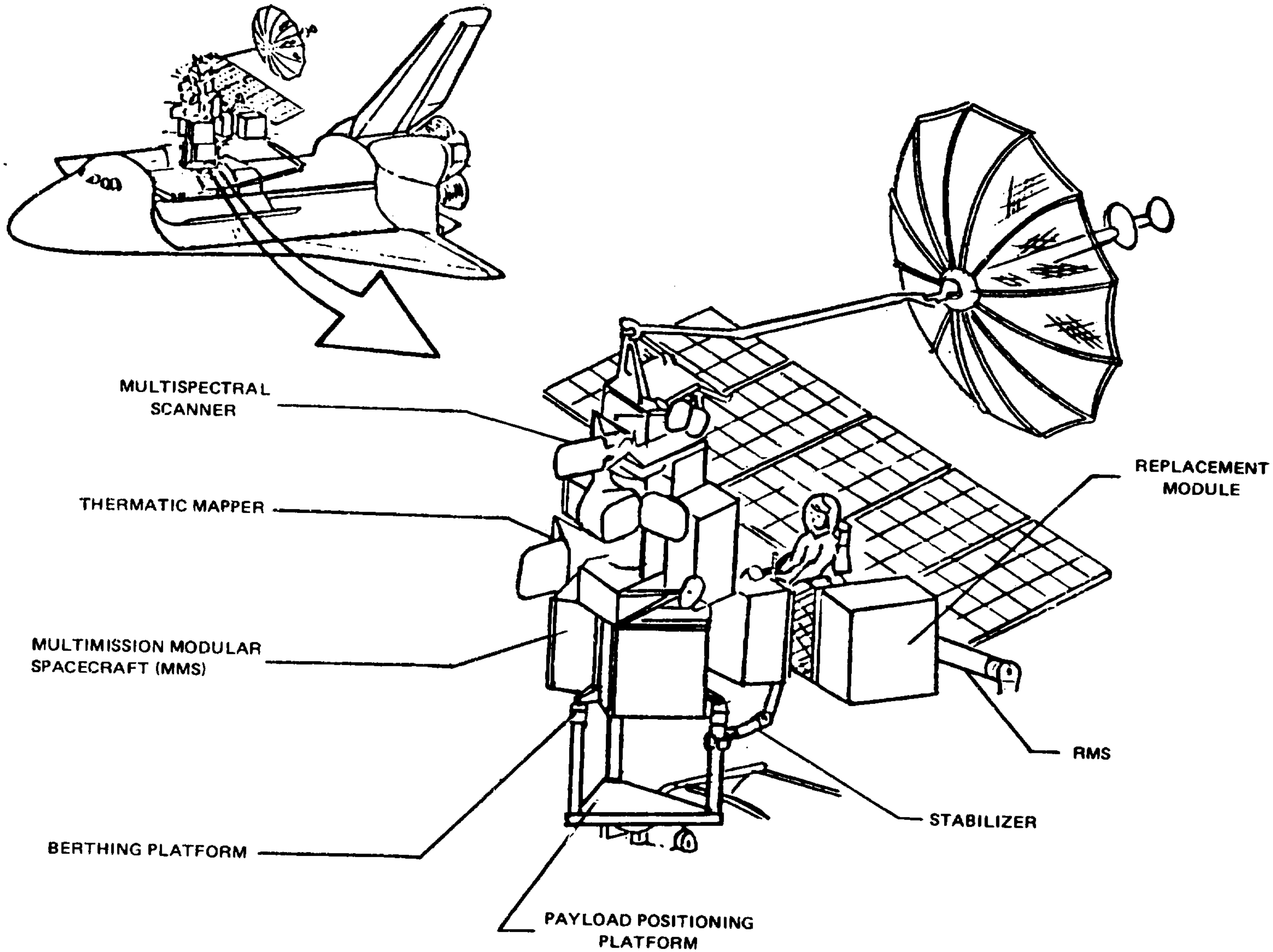


Figure 11. MRWS/MMS Servicing Configuration

1.1.5.2 Stabilizer - A stabilizer of approximately 5 ft in length is required at the work site to assist in resisting the loads that may be imparted by the astronaut or support equipment when performing servicing tasks (see Figure 11).

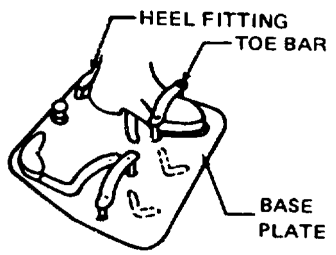
This device could be electromechanically driven or manually engaged and locked. If the device is electromechanical, the following characteristics based on current available systems appears adequate:

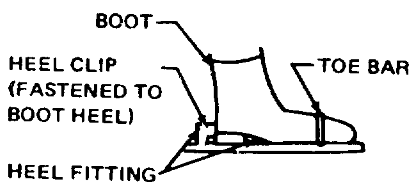
- Open-loop control is adequate (Resolved rate control using hand controllers should be considered)
- 5 ft reach is adequate
- System must retract to place OCP and work-site distance to within reach of astronaut. This feature may require an integrated control motion between SRMS and stabilizer
- The design load conditions for the foot restraint system (Figure 12) are also the design load conditions for the stabilizer
- Tip speeds of 7 in./sec should be adequate
- A 6-DOF system should provide adequate dexterity and reach around capability for this mission.

1.1.5.3 Controls and Displays - The MRWS open cabin cherry picker should provide a control console similar to that located at the Shuttle payload handling station, that permits axis-by-axis control of the cherry picker SRMS as well as candidate hand controllers (Figure 13). In addition, the following are required:

- Electric Power Control Panel - Switched to turn power on and off, and circuit breakers to protect all circuits
- ICS Communication Panel - Controls to permit communication with Shuttle and other EVA crew men
- Elapsed Time Clock - To indicate time elapsed on any sequence of operations and total time spent EVA by crew
- Lighting Control Panel - Switches to control external flood lights on platform.

1.1.5.4 Life Support - The MRWS should provide stowage for an oxygen, power, and sublimator makeup kit to enhance and extend EVA operations. This ECLS makeup kit weighs approximately 102 lb and requires a volume of 1.5 ft^3.





DESIGN PARAMETER	DESIGN REQUIREMENTS/REMARKS
MOBILITY	EVA FOOT RESTRAINTS SHALL MAINTAIN FOOT POSITION TO ALLOW THE CREWMAN A COMPLETE RANGE OF MOTION (ROLL, PITCH, YAW) WITHIN THE CONSTRAINTS OF THE SPACESUIT
RESTRAINT SPACING	• CENTER-TO-CENTER DISTANCE = 25.4 TO 43.2 cm (10.0 TO 17.0 in.) • CENTER DIMENSION SHALL BE DETERMINED FROM ANALYSIS OF THE TASKS TO BE PERFORMED
LOAD CAPACITY	• ULTIMATE DESIGN LOAD = 623 N (140 lb) MINIMUM IN TENSION AND SHEAR • TORSION = 203 N-m (1800 in.-lb) MIN
TEMPERATURE	MAXIMUM ALLOWABLE TEMPERATURE FOR EVA FOOT RESTRAINTS SHALL BE COMPATIBLE WITH THE SPACE SUIT BEING USED
LOCATION	FOOT RESTRAINTS SHALL BE LOCATED AT ALL EVA WORKSITES REQUIRING PERFORMANCE OF THE FOLLOWING TASKS: • REPETITIVE TASKS REQUIRING THE USE OF ONE OR BOTH HANDS • LONG-TERM MONITORING TASKS • TASKS REQUIRING CLOSE CONTROL OF BODY POSITION

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Figure 12. Open Cherry Picker Requirements – EVA Foot Restraint General Specifications

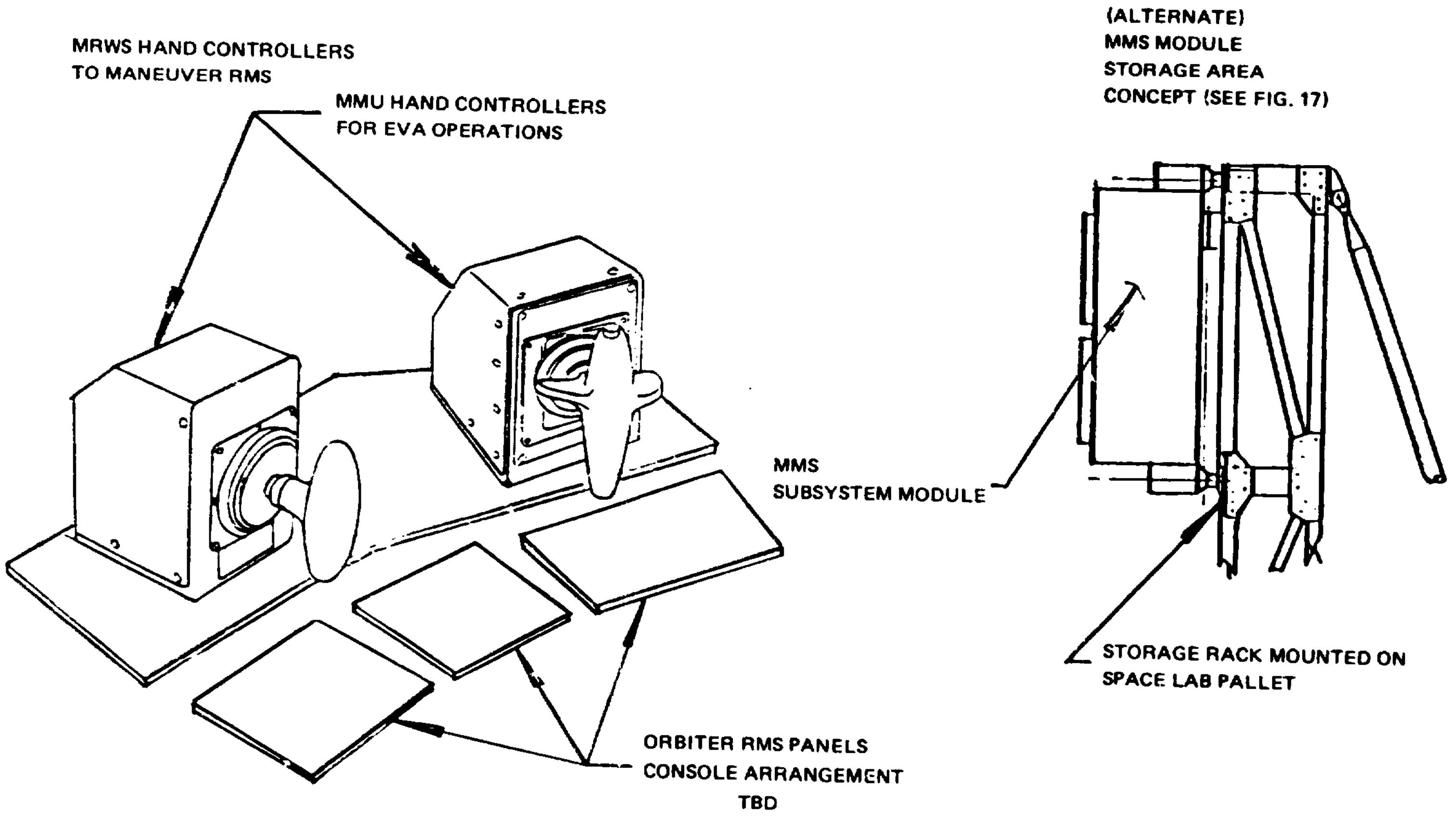

Figure 13. Open Cherry Picker Requirements – Function 7.0 – Maneuver to MMS Module Storage Area

SRMS Interface

The cherry picker platform should provide a stabilizer fixture to interface with the RMS snare type and effector shown in Figure 9.

Restraint Provisions

To assist the EVA crewman in tasks requiring the use of one or both of his hands and for those tasks requiring moderate force/torque applications foot restraints (see Figure 12) should be provided. These loads design the structural/mechanical characteristics of the grappler. In addition, a tether is required.

Mission Peculiar Support Equipment

Several items of equipment which require storage provisions are needed to support orbital operations.

Subsystem Module Removal/Installation Tool - To assist the EVA astronaut in removing and handling the subsystem module, a tool (Figure 14) should be provided. With the cherry picker located at the work area and stabilized by the grappler attachment to the payload positioning platform, the astronaut removes the module removal/installation tool from the cherry picker tool storage area. The tool is then inserted into a guide track mounted on the module. This guides the tool to the module preloaded installation bolt. When engagement is made, the astronaut activates a lever which locks the tool in place. The astronaut then applies a scissor action to the two lower handles of the tool, this action breaks the 100-ft-lb installation torque of the bolt. Using the crank handle of the tool, the bolt is backed out of the bolt retention fitting; approximately six turns of the crank is needed to free the bolt. The tool retention lever is then actuated releasing the tool from the module. The tool is then removed and inserted at the second bolt guide track. The tasks are then repeated until the bolt is released. With the tool still locked to the module, the astronaut using the tool as a handle removes the module from the spacecraft and places it in the cherry picker module retention/stow device.

Module Retention/Stow Device - The open cherry picker must provide a stowage area and support for two MMS subsystem modules. A module retention/stow device concept is shown in Figure 15. The cherry picker would be equipped with two of these devices, one to handle the replacement module retrieved from the payload bay module magazine, and the other for the module removed from the spacecraft. With the cherry picker positioned at the spacecraft, the astronaut removes the spacecraft subsystem module with the module removal/installation tool previously described. He then places the module on the pedestal of the retention device and secures the

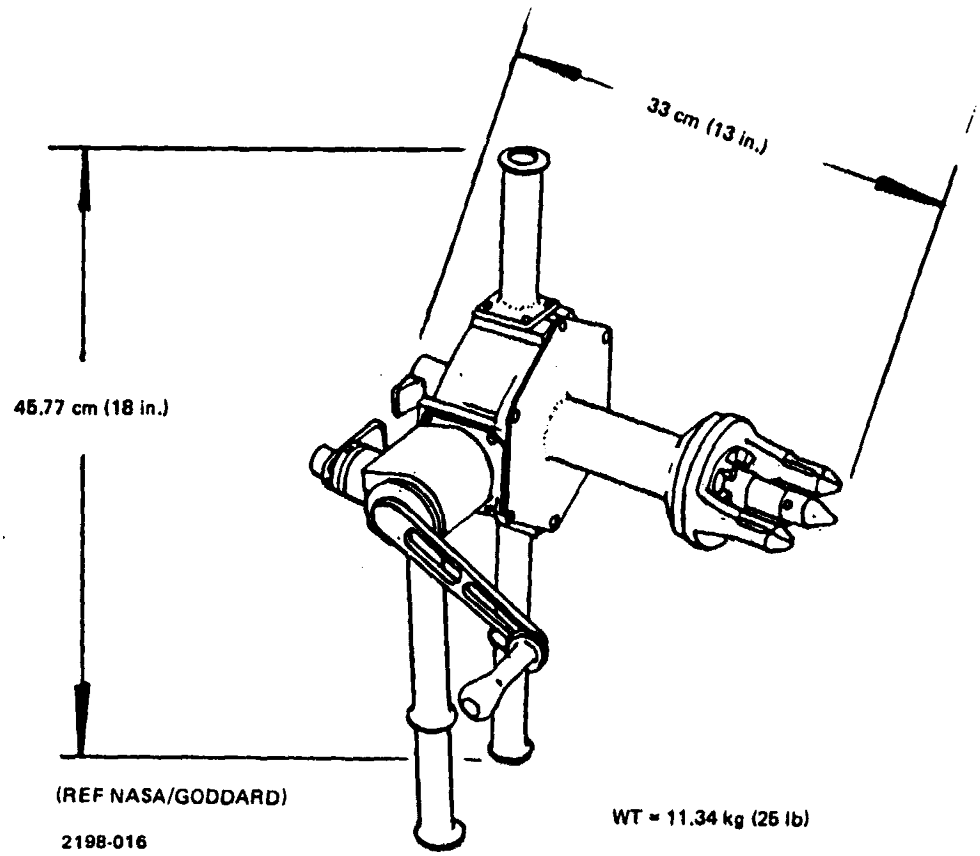

Figure 14. EVA Tool – MMS Subsystem Module Replacement

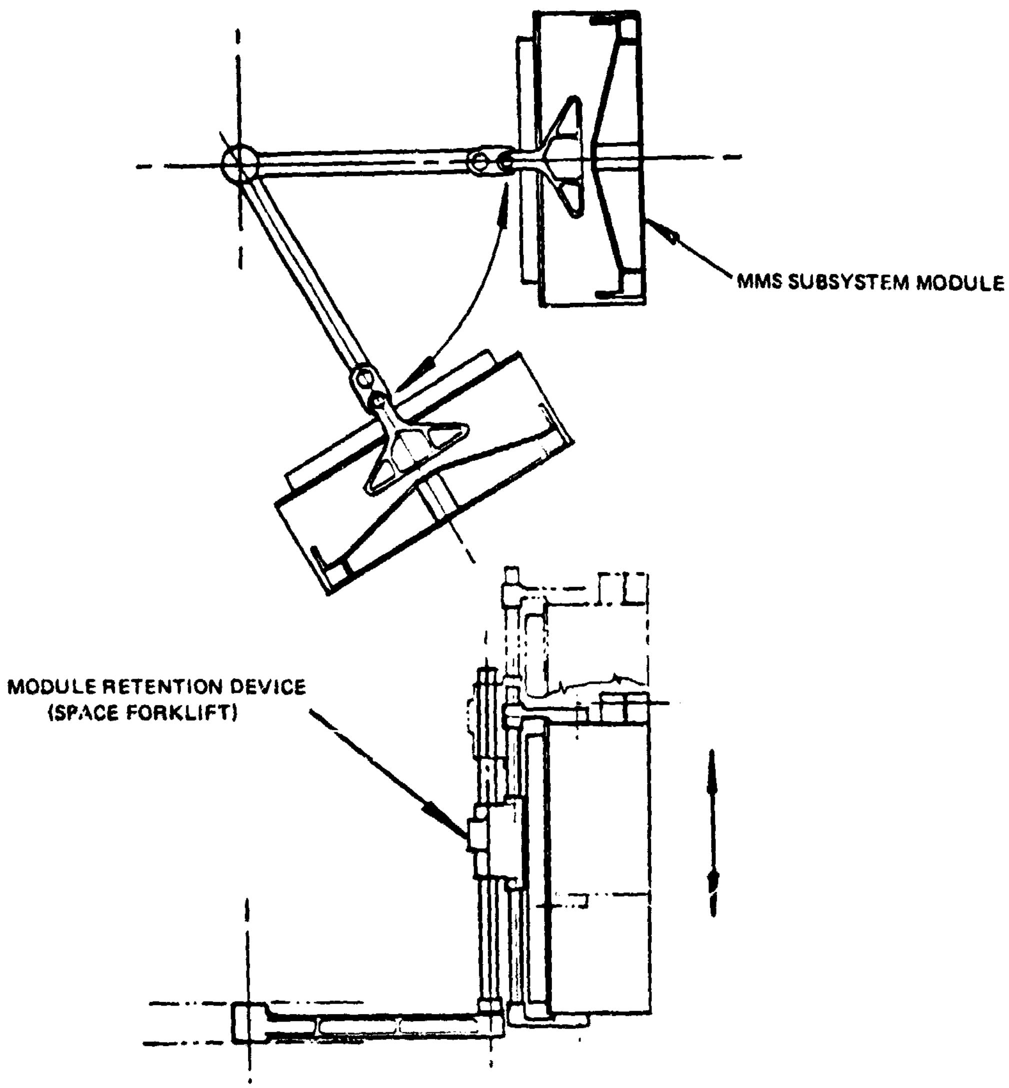

Figure 15. Module Retention Device — Open Cherry Picker Requirements — Function 8.0 — Remove One MMS Subsystem Module

upper clamp to the module. The module removal/installation tool is then unlocked from the module and stowed and the module is moved to its stowage area by means of the retention/stow device swing arm. The replacement module is then brought into place and the reverse procedure is performed to install the new module.

MRWS Payload Bay Retention/Stow Device - The MRWS should be stowed in the payload bay as near to the Shuttle cabin egress hatch as possible to provide the EVA astronaut with the shortest route to the MRWS. This would reduce the amount of hardware located along the EVA route that would be required to be man-rated. A stowage concept for the MRWS is illustrated in Figure 16.

Subsystem Module Rack - Stowage and support provisions for MMS replacement and retrieved subsystem modules must be provided. The Module Magazine of the MMS flight Support System (Figure 17) should be used.

1.1.6 Issues to be Resolved

- Definition of loads on SMRS during servicing operations
- Size and geometry of MRWS cab
- Definition of module retention device
- Power and signal interface with SRMS
- Lighting configuration
- Stabilizer configuration and number required.

1.1.7 References

- Multimission Modular Spacecraft System Specification. S-700-10, May 1977.
- Internal Interface Specification and User's Guide. S-700-11, February 1978.

1.2 LONG DURATION EXPOSURE FACILITY

1.2.1 Mission Description

The Long Duration Exposure Facility (LDEF) is a reusable, unmanned gravity-gradient-stabilized, free-flying structure. It can accommodate many technological, scientific, and applications experiments, both passive and active, that require

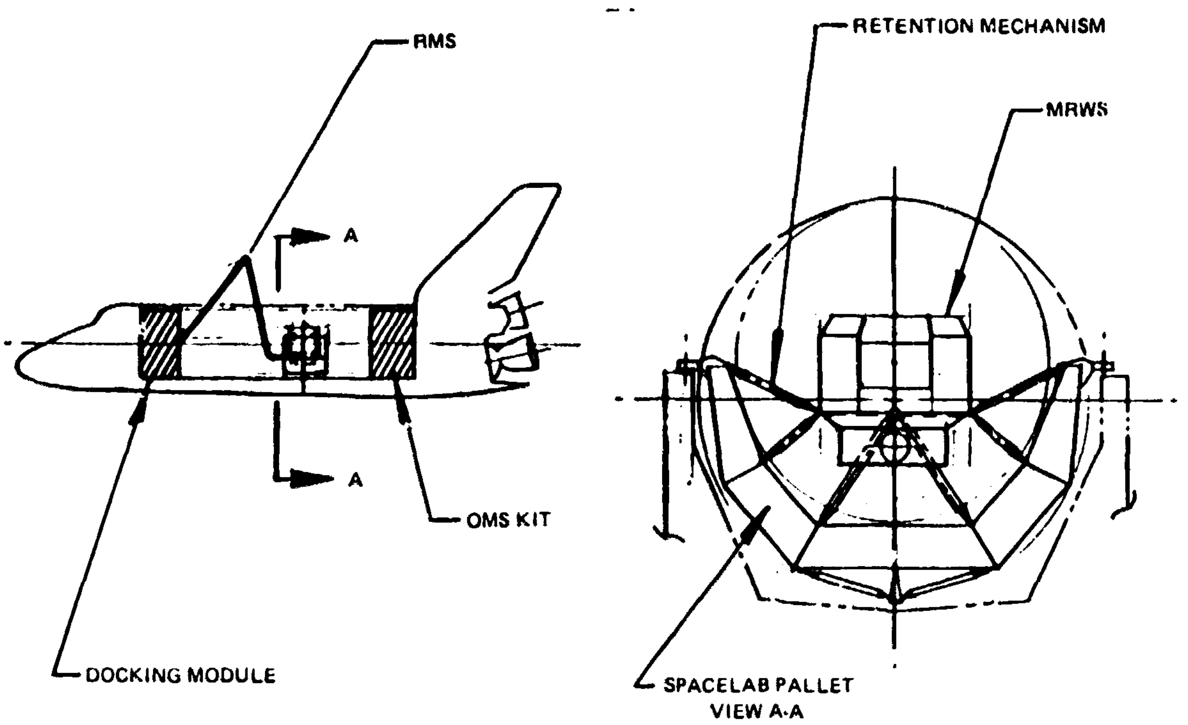

Figure 16. Open Cherry Picker Requirements – Function 1.0 – Provide Shuttle Mechanical Interface for Launch

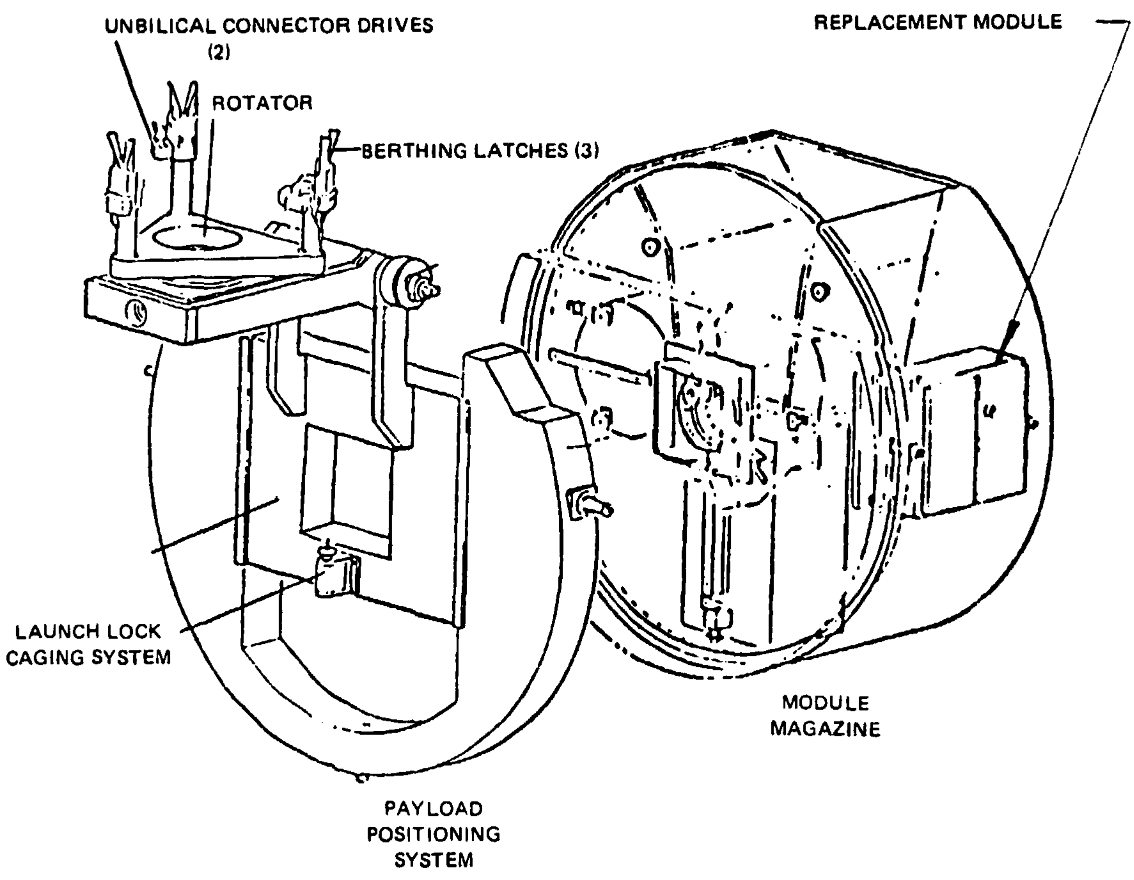

Figure 17. Mission Peculiar Support Equipment

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exposure to space. The LDEF provides an easy and economical means for conducting these experiments. Users are expected to include governments, universities, and industries in both the United States and other countries.

The Space Shuttle Orbiter places the LDEF in Earth orbit at an altitude of 300 n mi in inclinations ranging from 28.5° to 57°. Gravity-gradient stabilization is used in combination with a viscous magnetic damper to null transients. Initial versions of LDEF will remain in orbit for 6 months or more until another Shuttle flight retrieves it and returns to Earth. The concept of in-orbit replacement of experiment trays rather than retrieval of the entire satellite is now being evaluated. The analysis of MRWS requirements for the open cherry picker (OCP) utilizes this mission function to derive flight article requirements.

Figure 18 presents a concept in which the Shuttle RMS has retrieved the LDEF and berthed the Satellite to a holding fixture. The OCP is then used to perform the experiment tray replacement function.

1.2.2 Spacecraft Description

The LDEF is a 30-ft (9.14-m) long structural framework as shown in the figure, with room for 72 experiment trays on the periphery and two trays on each end. The LDEF cross section is a 12-sided regular polygon of bolted aluminum I-beam construction with a diameter of 14 ft (4.27 m). The primary framework consists of 7 ring frames and 12 longerons fabricated from aluminum extrusions. Trays containing experiments are mounted into the bays formed by the ring frames and longerons. Each tray is approximately 50-in. long and 38-in. wide (127 by 97 cm). Trays are 3, 6, or 12 in. deep (8, 15, or 30 cm), see Table 3. Trays are provided by NASA, and individual experiments are bolted to the trays. Standard experiments are sized to fill a full tray or 1/6, 1/3, or 2/3 of a tray. The total mass allowable in a single tray is 175 lb (79 kg). Experiment sizes are not necessarily limited to the dimensions of trays; heavier or larger experiments and different mounting locations or arrangements will be considered on an individual basis. However, no experiment can protrude beyond the planes defining the 12-sided polygon of the LDEF.

Figure 19 presents a layout of the fastening arrangement for the current LDEF experiment tray. Twenty-four bolts secure the tray flange to the LDEF structure. Though this fastening arrangement could be designed for easier on-orbit servicing, this arrangement, needing a high degree of dexterity, has been used for mission analysis.

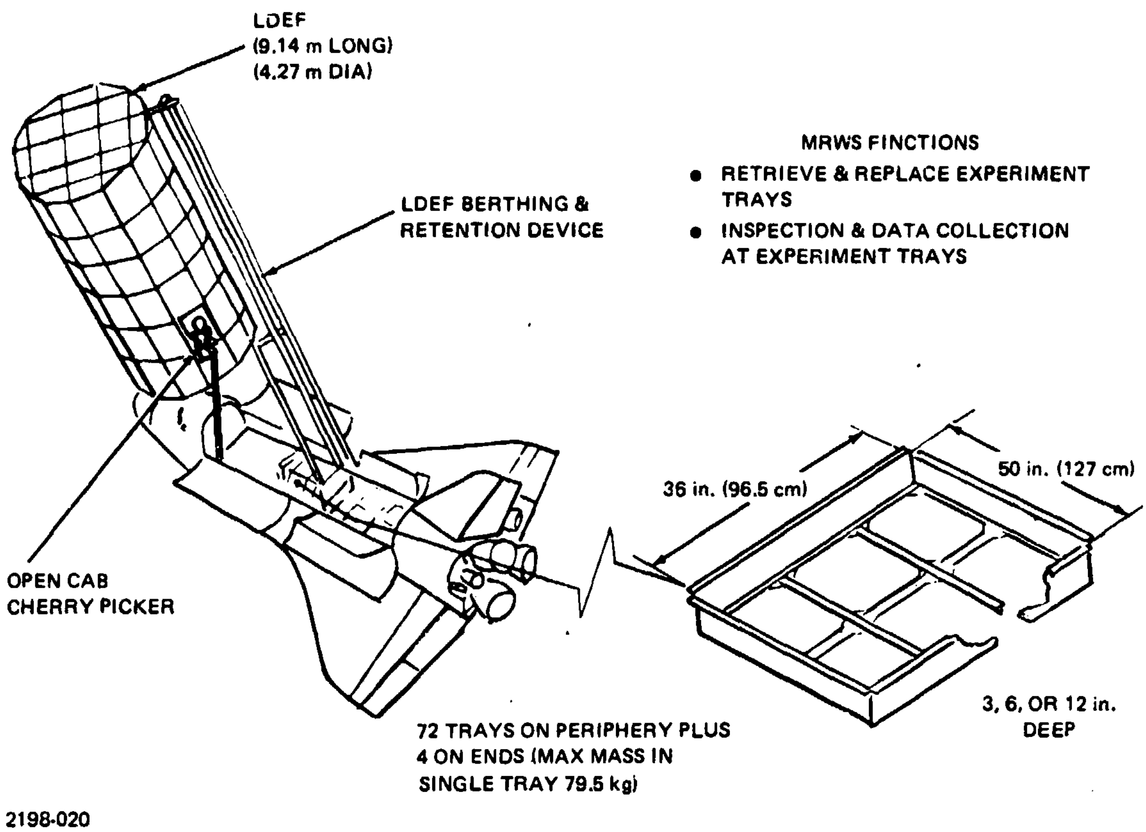
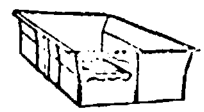
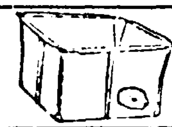


Figure 18. Long Duration Exposure Facility Support

TABLE 3

TRAY ACCOMMODATIONS

LOCATION	DEPTH (in.)	SPACE (in. x in.)	CONFIGURATION
PERIPHERAL NO. OF TRAYS – 72 WEIGHT ALLOWANCE – 180 lb	3	37.5 x 49.5	
	6	33.0 x 48.75	
	12	33.0 x 48.75	
END CORNER NO. OF TRAYS – 8 WEIGHT ALLOWANCE – 200 lb	6	28.5 x 28.5	
	12	28.5 x 28.5	
END CENTER NO. OF TRAYS – 6 WEIGHT ALLOWANCE – 200 lb	6 or 12	30.75 x 33.50	

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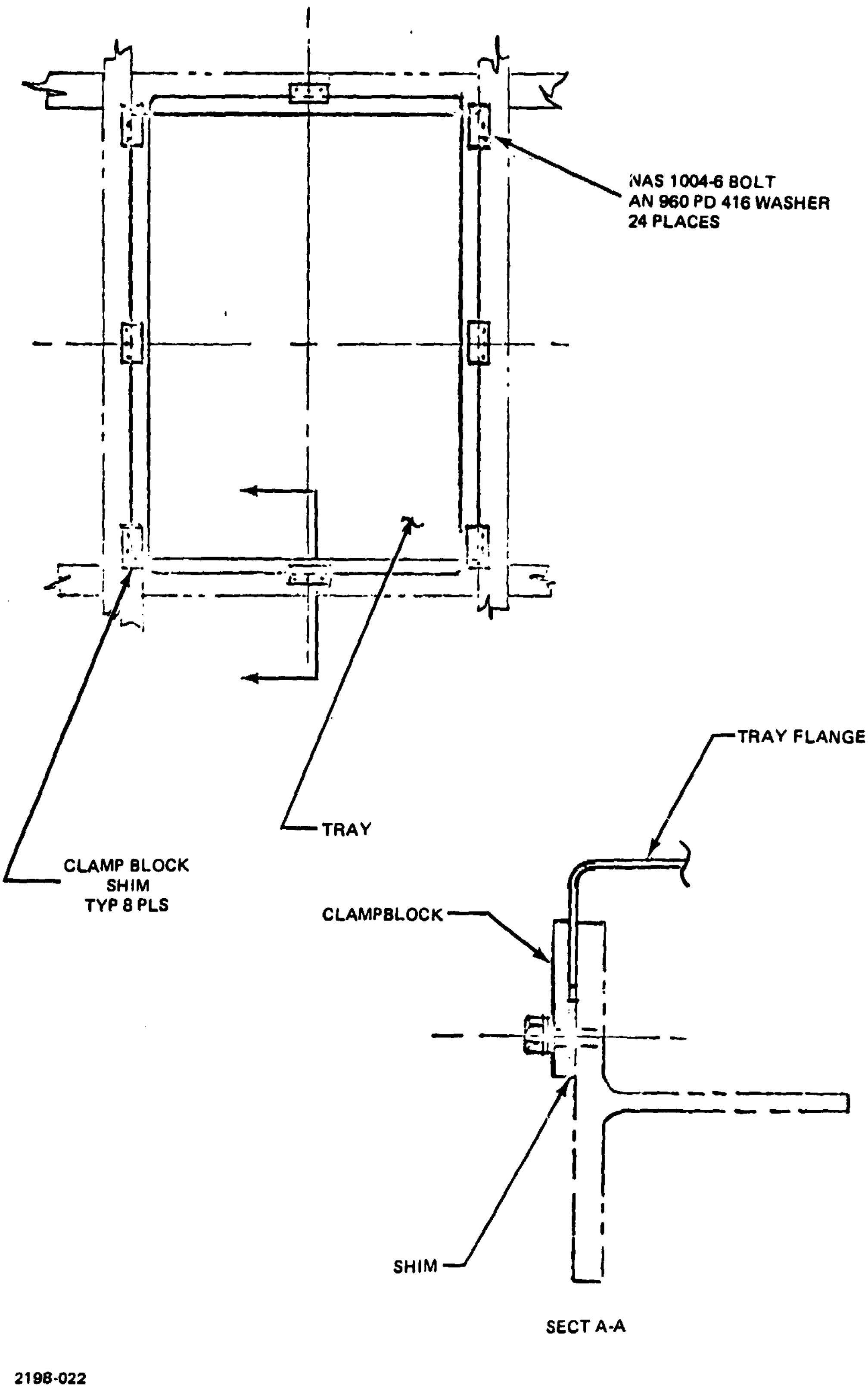

Figure 19. Typical LDEF Tray Installation

1.2.3 Support Functions and Mission Scenario

The MRWS, in an open cherry picker configuration mounted to the end of the Shuttle Remote Manipulator, can be used to retrieve and replace the experiment trays of the Long Duration Exposure Facility. A concept and supporting function for the open platform cherry picker are shown in Figure 20. This one-man platform is controlled from the platform and contains the supporting tools required to perform the experiment retrieval and replacement tasks.

The support functions for the open cherry picker are summarized in Figure 20. Functions 1.0 through 6.0 are similar to those discussed previously for the MMS servicing mission. The mission scenario is illustrated in Figure 21.

1.2.4 Task Analysis - Replace Experiment Tray

1.2.4.1 Accessibility - The LDEF is captured and berthed to the payload platform shown in Figure 21. The platform is centrally located in the payload bay and is capable of rotating the spacecraft permitting the astronaut in the cherry picker access to all of the 72 periphery mounted trays. The cherry picker stabilizer is engaged to the grappler fittings mounted along the LDEF longerons, the stabilizer is then rigidized placing the astronaut within 0.4 m of the spacecraft.

1.2.4.2 Items to be Handled - The crew and support equipment interface with the trays identified in Figure 21. The trays must be removed from the spacecraft and stowed in the payload bay where replacement trays are obtained. The replacement trays are aligned and mechanically attached to the spacecraft by the astronaut.

1.2.4.3 Operations - The approximate time-line for replacement of experiment tray is given in Table 4.

TABLE 4

EXPERIMENT TRAY REPLACEMENT TIME-LINE

ΔT (min)	OPERATION
15	RETRIEVE EXPERIMENT TRAY FROM PAYLOAD BAY STORAGE RACK
30	REMOVE TRAY FROM SPACECRAFT
30	INSTALL REPLACEMENT TRAY
15	STOW RETRIEVED TRAY IN PAYLOAD BAY STORAGE RACK
90	TOTAL

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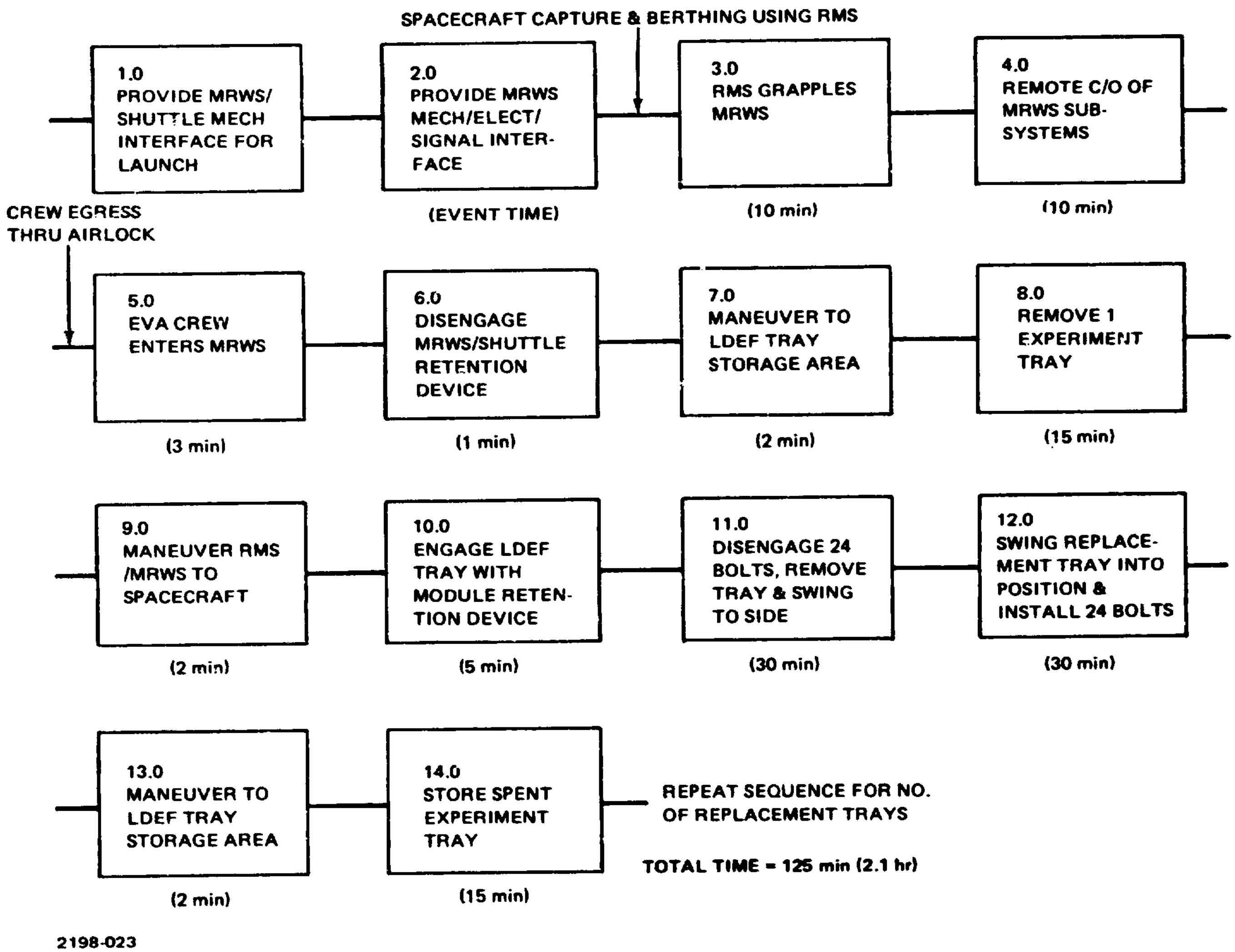

Figure 20. Open Cherry Picker Functions – LDEF Servicing

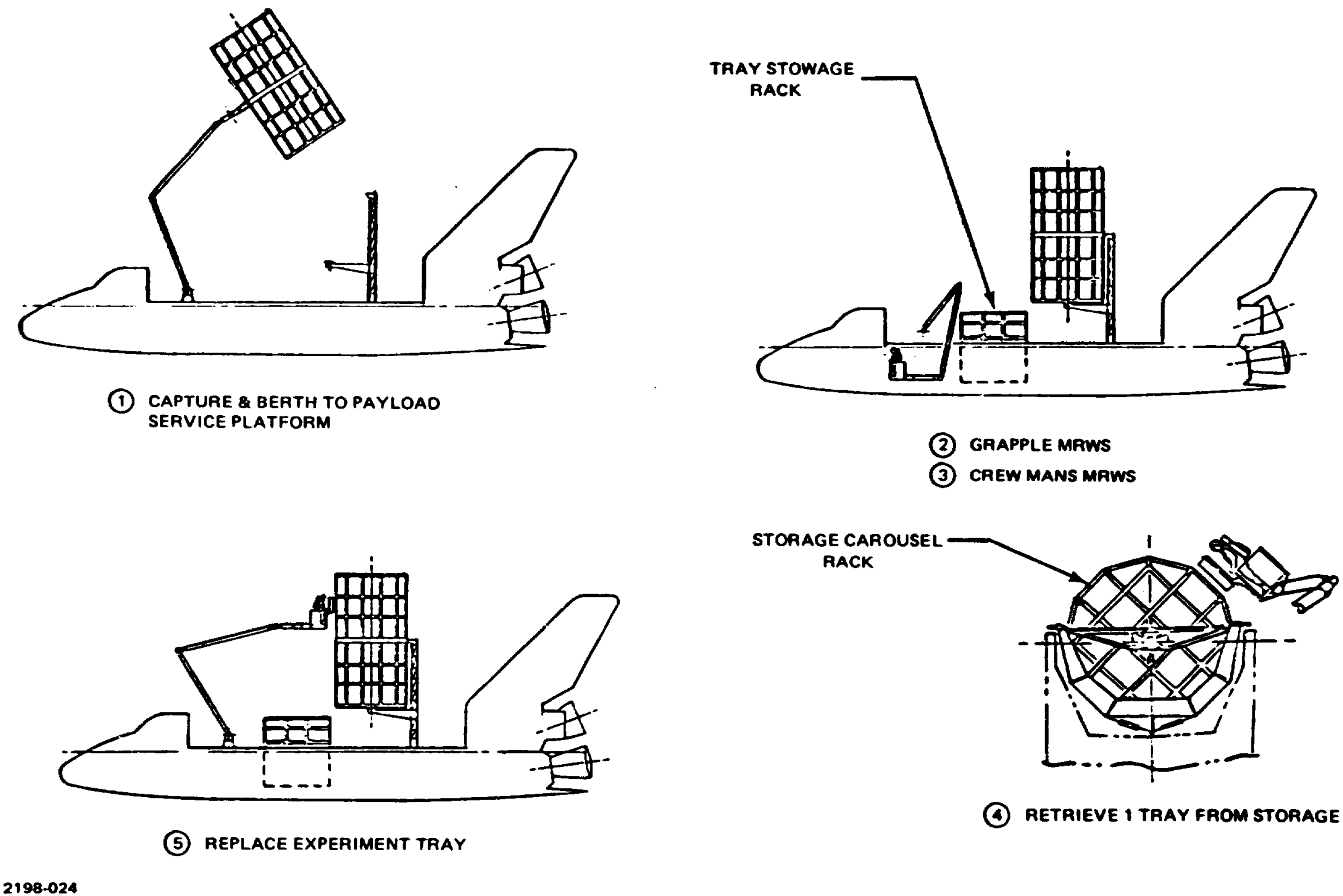

Figure 21. LDEF Experiment Tray Replacement Scenario

1.2.5 Additional Open Cherry Picker Design Requirements Derived from the LDEF Mission

Several items of equipment are needed to support orbital operations and payload bay storage provisions are required for the following:

- Payload platform and turntable
- Experiment trays
- Experiment tray hardware removal/install tool
- MRWS retention device.

The conceptual configurations for the payload platform, experiment tray rack, and MRWS retention device are similar to those described and illustrated in Paragraph 1.1.5 MMS servicing.

1.2.6 Issues to be Resolved

Number of experiment trays to be replaced on one mission.

1.2.7 References

- NASA - Space Transportation System User Handbook. April 1977.
- LDEF Experiment Tray Installation. NASA Drawing LE 155639 (Preliminary), July, 1977.

1.3 LARGE SPACE STRUCTURE PLATFORM

1.3.1 Mission Description

The Large Space Structure (LSS) platform is a concept for a space constructed structure that is used for earth pointing observation sensors. The goals of the mission are to: verify the operation and technical feasibility of automatic beam builders; measure the on-orbit properties of typical beam fabricated elements; verify that a large space structure can be assembled from the Shuttle cargo bay; measure the structural properties of a space assembled structure; and to provide a useful platform for earth pointing sensors.

The LSS is assembled in one Shuttle flight at an orbit altitude of 300 km at an inclination of 57°. This large, relatively stiff structure is used as a gravity gradient stabilized platform for the sensors listed in Table 5. These sensors, with the

TABLE 5

SENSOR REQUIREMENTS FOR LSS DEMO CONCEPT

NAME/ACRONYM	MEASURED PHENOMENA	ORBIT (ALT/INCL)	MASS (kg)	SIZE (m) (L X W X H)	POWER (W)
LARGE FORMAT CAMERA (LGC)	VISIBLE & NEAR IR FOR LAND RESOURCES	343 km/ 57 deg	181	2.9 X 0.91 X 1.7	120 (OPER)
SHUTTLE IMAGING RADAR-A (SIR-A)	IMAGING RADAR FOR GEOLOGICAL MAPPING	200 km/ 40 deg	90 135 55	2.2 X 0.15 X 9.4 1 X 0.25 X 1.5 0.5 X 0.6 X 0.6	900 (OPER)
SHUTTLE MULTI-SPECTRAL IR RADIOMETER (SMIRR)	0.6 TO 2.5μm RADIOMETRY FOR GEOLOGICAL MAPPING, RADIANCE, REFLECTANCE	200 km/ 57 deg	70	0.8 X 0.7 X 0.85	150 (OPER) 150 (PEAK)
OCEAN COLOR EXPERIMENT (OCE)	MARINE ALGAE MAPPING WITH SCANNING RADIOMETER/TELESCOPE	260 km/ 57 deg	94	0.79 X 0.27 X 0.24 0.43 X 0.30 X 0.53 0.48 X 0.17 X 0.22	550 (OPER) AT 440 Hz 550 (PEAK) AT 440 Hz
STANDARD OZONE SOUNDING UNIT (SOSU)	150 & 400 m RADIOMETRY FOR OZONE DISTR	ANY	20 20	0.33 X 0.15 X 0.2 0.33 X 0.15 X 0.2	20 (OPER)
MEASUREMENT OF AIR POLLUTION FROM SATELLITE EXPERIMENT (MAPS)	GLOBAL DIST OF TROPOSHERIC CO & AIR MASS TRANSPORT	ANY	63 1	0.75 X 0.75 X 0.45 0.1 X 0.15 X 0.1	110 (PEAK) 110 (PEAK)
MATERIAL EXPERIMENTS ASSEMBLY (MEA)	FURNACES, LEVITATOR, LATEX REACTION CHAMBER TO PROCESS MATERIALS	ANY	685	1.9 X 0.96 X 1.1	N/A

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characteristics indicated, provide a wide variety of scientific measurements in the field of land resource observation, pollution control, and oceanography.

1.3.2 Spacecraft Description

The LSS spacecraft consists of a large triangular girder structure that is 9 m in depth and 31.5 m long. The structure is assembled from space fabricated beams that have a depth of 1 m. The sensors and supporting subsystems are mounted to the structure in the positions indicated in Figure 22. A docking/subsystem module is mounted at the other end along with the KU band antenna used for telemetry data. Solar arrays (5kW) are located at a mid-body point as are the magnetic dampers for gravity gradient stability.

The general arrangement of the spacecraft along with the supporting construction equipment are shown in Figure 23. The system utilizes a beam fabrication machine and tripod dispension machine for automated assembly of the basic structural building block. The structure is assembled on a supporting jig located at the mid-point in the Shuttle cargo bay. Structural assemble is performed by EVA astronauts utilizing the RMS for handling components and an open cabin cherry picker for locating the assembly worker.

The overall weight breakdown for the spacecraft and supporting elements is shown in Table 6.

1.3.3 Support Functions and Mission Scenario

The MRWS, in an open cherry picker configuration mounted to the end of a second SRMS, can be used to support the assembly operations of the Large Space Structure Platform. A concept and supporting function for the open cabin cherry picker are shown in Figure 24. This one-man platform is controlled from the platform and contains the supporting tools to perform the structural fastening, a subsystem installation and payload handling tasks. The cherry picker works in series with the SRMS used for component handling and positioning.

The top level functional requirements for the open cherry picker are summarized in Figure 25 for the structural assembly tasks. Functions 1.0 through 6.0 are similar to those discussed previously for the MMS and LDEF servicing missions. As indicated in those discussions, the open cherry picker should be of minimum size and weight to keep user costs down and be located as near to the Shuttle egress hatch

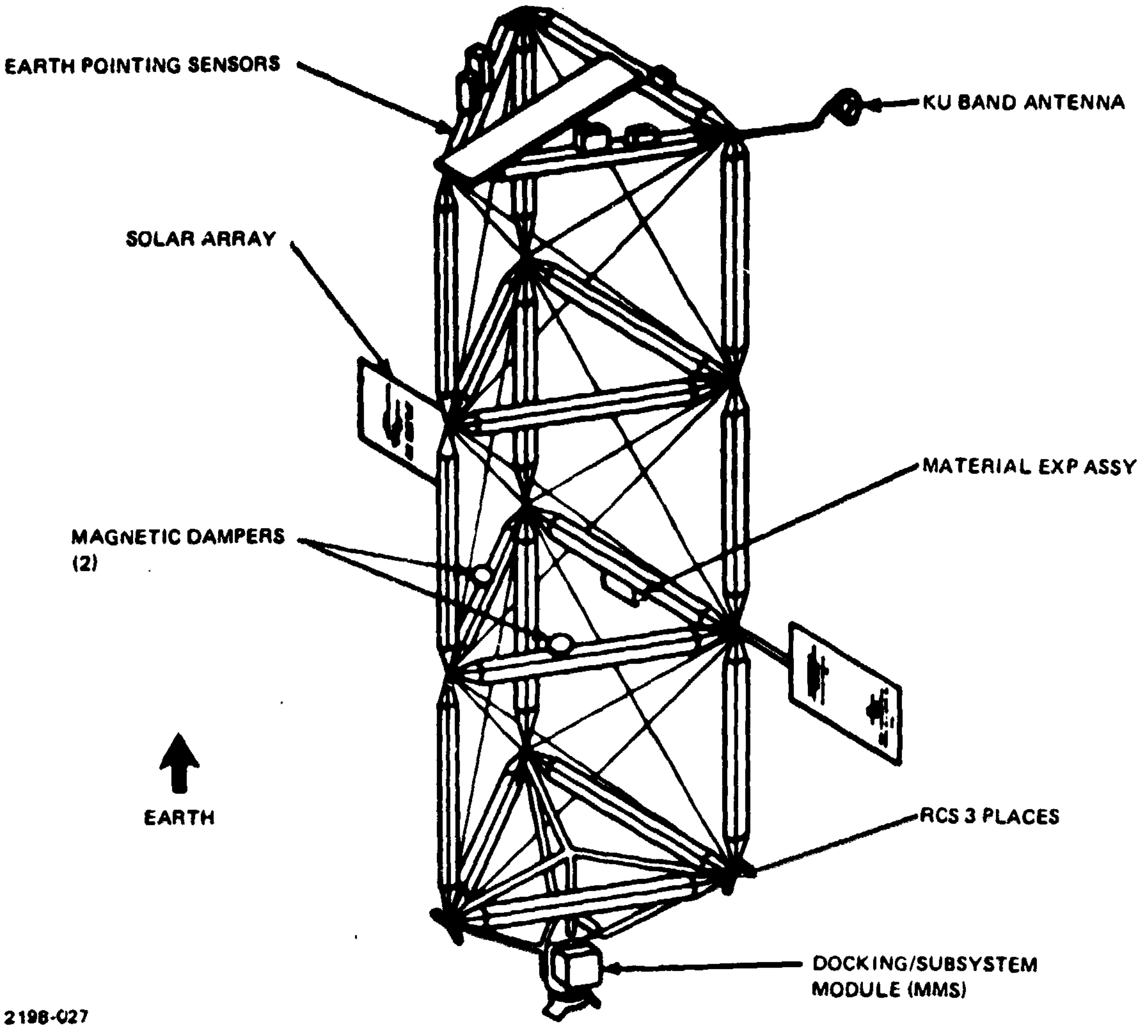
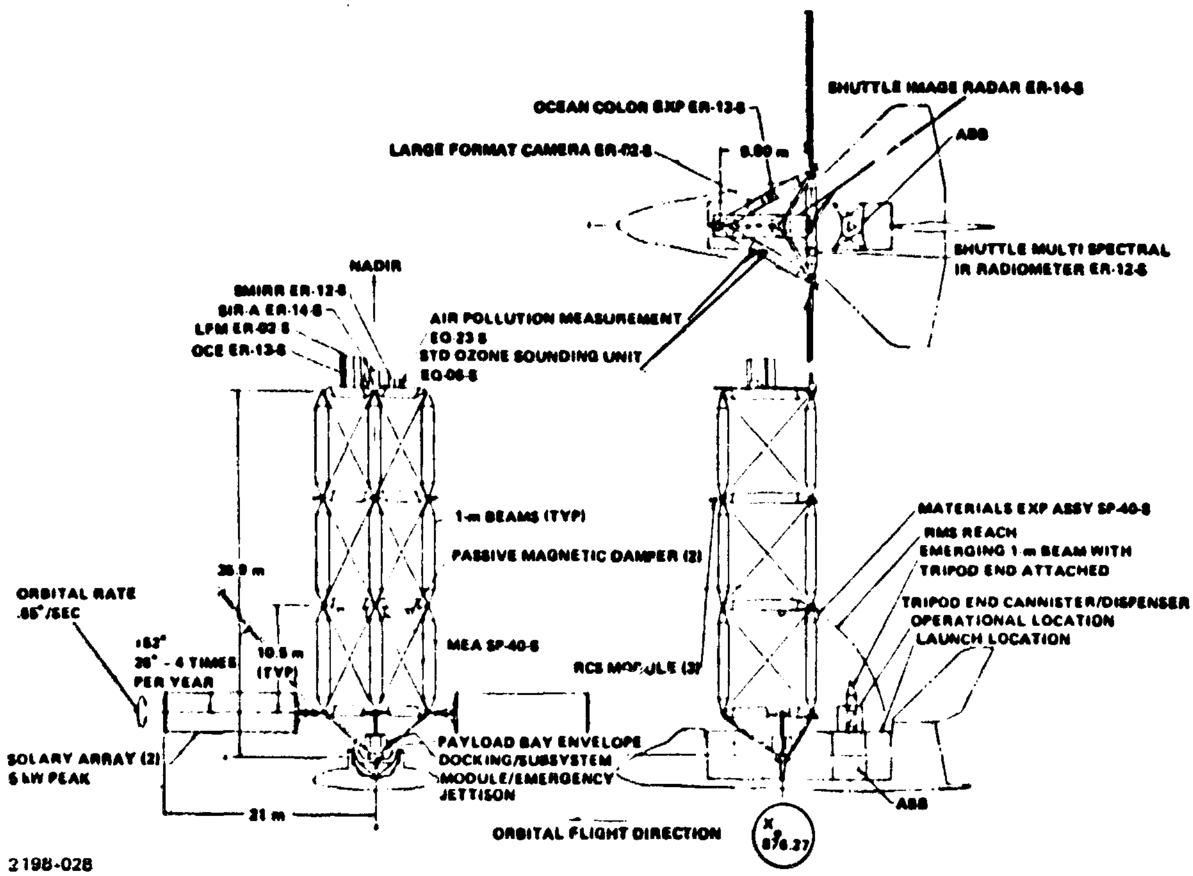


Figure 22. Large Space Structure Platform – Free Flyer Configuration



2198-028

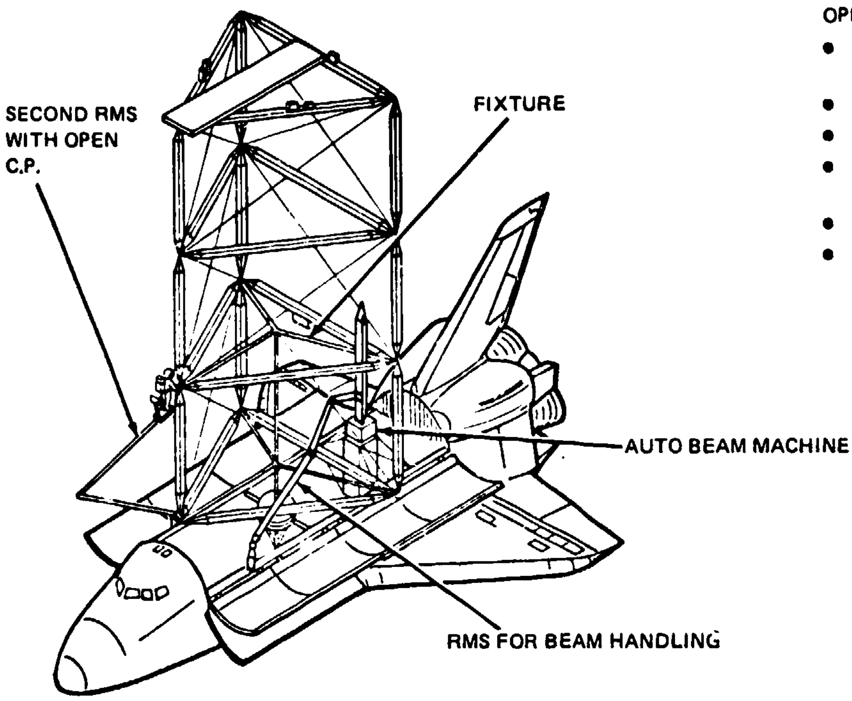
Figure 23. LSS Platform General Arrangement

TABLE 6

LSS PLATFORM MASS ELEMENTS

	LAUNCH		LANDING	
	WT (kg)	CG (m)	WT (kg)	CG (m)
DEMO ARTICLE STRUCTURE	500	28.23		
CONSTR JIGS	746	22.25	228	22.25
EXPERIMENTS	1414	18.00	1414	18.00
BEAM MACHINE	7256	28.23	7256	28.23
TRIPOD END FITTING MACHINE	2500	31.25	2500	31.25
BEAM BUILDER DEMO ARTICLES	187	28.23	187	20.93
DOCKING ADAPTER(S)				
SUBSYSTEMS				
TOOLS, SPARES, ETC	450	17.50	450	17.50
SPACE LAB PALLET				
PAYLOAD TIEDOWNS, ATTACH.	1305	29.00	1305	29.00
LSS PAYLOAD	14,358	27.17	13,340	27.22

2198-029



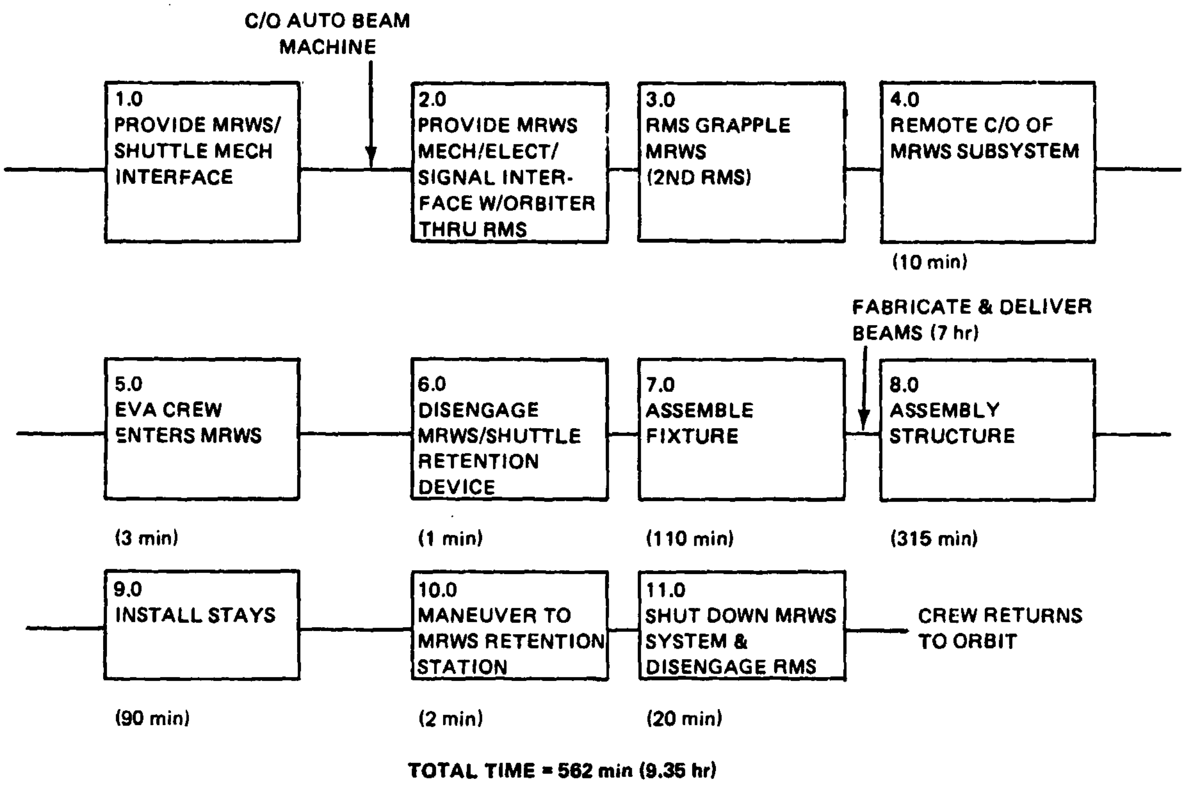
OPEN CHERRY PICKER FUNCTIONS

- TRANSPORT & HANDLE STRUCTURAL ELEMENTS
- DEPLOY FIXTURES
- RESUPPLY FAB MACHINE
- PERFORM JOINING AND ALIGN OPERATIONS
- C/O ASSEMBLED STRUCTURE
- INSTALL SUBSYSTEMS & EXPERIMENTS

(REF SYSTEMS DEFINITION STUDY FOR SHUTTLE DEMO FLIGHTS OF LARGE SPACE STRUCTURES)

2198-030

Figure 24. Support Construction of LSS Platform



NOTE: SECOND SHIFT REQUIRED

2198-031

Figure 25. Open Cherry Picker Functions — LSS Platform Construction Support

as possible to minimize the EVA travel distance from hatch to MRWS. This latter requirement would minimize the need to man-rate all hardware in the path of the astronaut.

Figures 26 and 27 delineate the mission scenario for MRWS operations during assembly of the fixture (Function 7.0, Figure 25) and during assembly of the structure (Function 8.0). In both of these assembly operations there is a significant interplay between cherry picker operations and SRMS operations. A control system concept that gives control of the SRMS to the cherry picker operator during close-in SRMS positioning tasks could improve overall system efficiency.

Three open cherry picker tasks have been analyzed for determining MRWS requirements; namely, installation of the assembly fixture, joining of structural beams, and path control of the SRMS arm. Other functions of this mission, namely, subsystem and instrument installation, are similar to those covered under analysis of the MMS and LDEF mission.

1.3.4 Task Analysis

1.3.4.1 Assembly Fixture Installation -

Accessibility

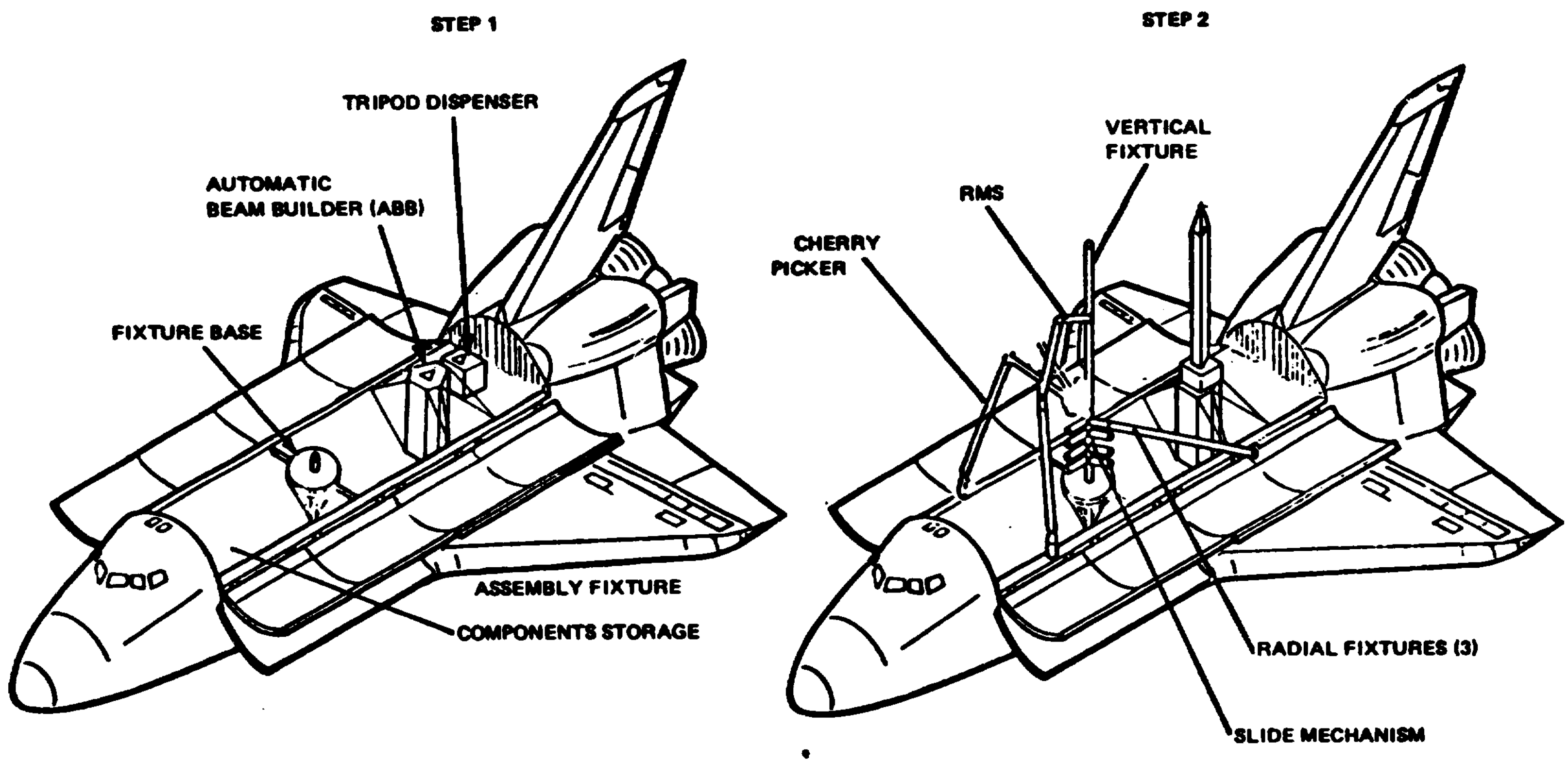
Insertion of the assembly fixture vertical post and slip mechanism is within the reach of the astronaut in a cherry picker (Figure 28). The cherry picker stabilizer is engaged to the keel mounted fixture base and rigidized, placing the astronaut within 0.3 m of the base to slip fixture joint. The installation operation of the vertical post is similar to the cherry picker stabilizer engaged to the slip mechanism.

The joining of both the slip mechanism and the vertical post requires a coordinated operation between the cherry picker operator and the SRMS. The payload handling specialist can readily coarse align the slip mechanism or vertical post within a few inches of the insertion hole. The fine alignment would require control of the SRMS by the cherry picker operator. The natural compliance of the SRMS would also help in this fine align and insertion task, providing the astronaut did not overload the arm.

Items to be Handled

The elements to be handled in this operation are:

- Slip Mechanism
  - 1-m long by 2-m wide, 46 kg



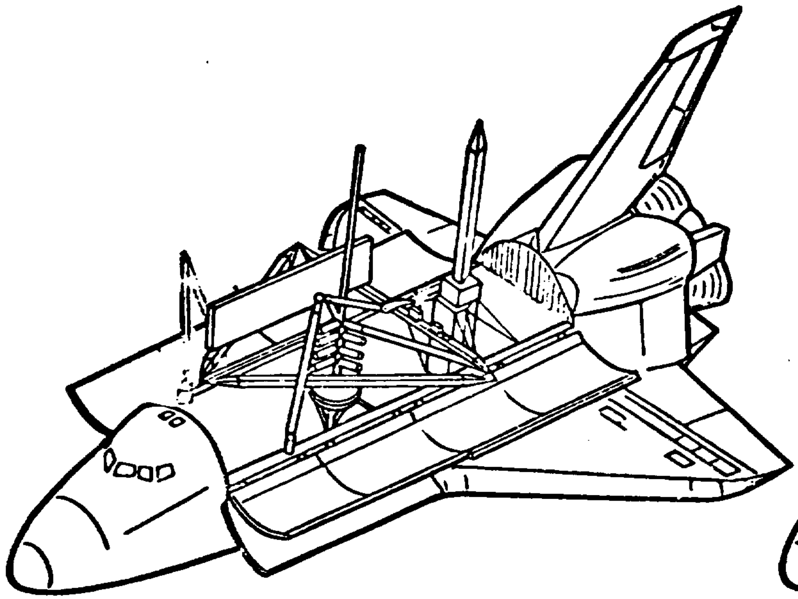
FUNCTIONAL REQUIREMENTS

7.1 RMS RETRIEVE SLIDE MECHANISM FOR COMPONENT STORAGE
7.2 RMS MANEUVERS SLIDE MECHANISM TO FIXTURE BASE
7.3 CHERRY PICKER JOINS SLIDE MECHANISM TO FIXTURE BASE
7.4 RMS RETRIEVES VERTICAL FIXTURE
7.5 RMS MANEUVERS VF TO SLIDE MECHANISM
7.6 CHERRY PICKER JOINS VF TO SLIDE MECHANISM
7.7 RMS RETRIEVES RADIAL FIXTURES & MANEUVERS
7.8 CHERRY PICKER JOINS TO SLIDE MECHANISM

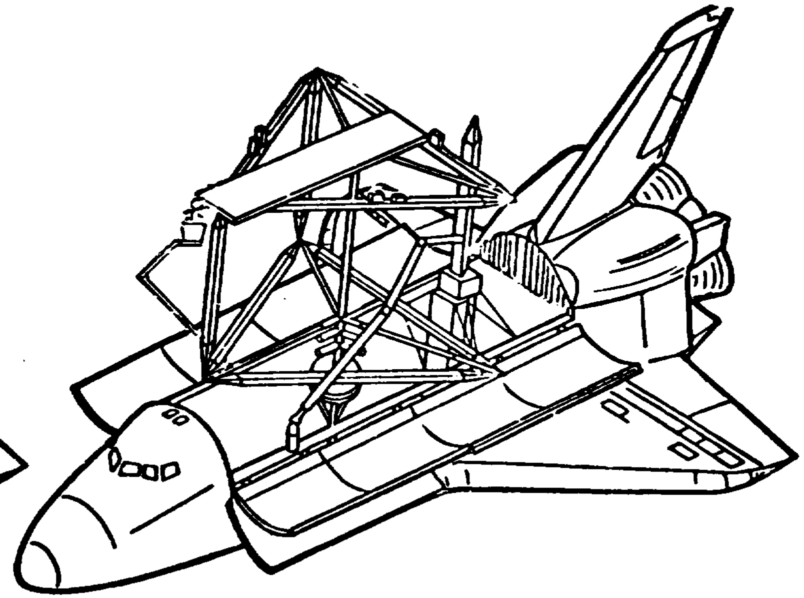
2198-032

Figure 26. Open Cherry Picker Requirements – Function 7.0 – Assemble Fixture

STEP 3



STEP 4



FUNCTIONAL REQUIREMENTS

8.1 – RMS TRANSPORTS BEAMS TO ASSIGNED ASSEMBLY POSITION (9 BEAMS)

8.2 – CHERRY PICKER PERFORMS JOINING OPERATIONS (9 JOINTS)

8.3 – INSTALL EXPERIMENTS

2198-033

Figure 27. Open Cherry Picker Requirements – Function 8.0 – Assemble Structure

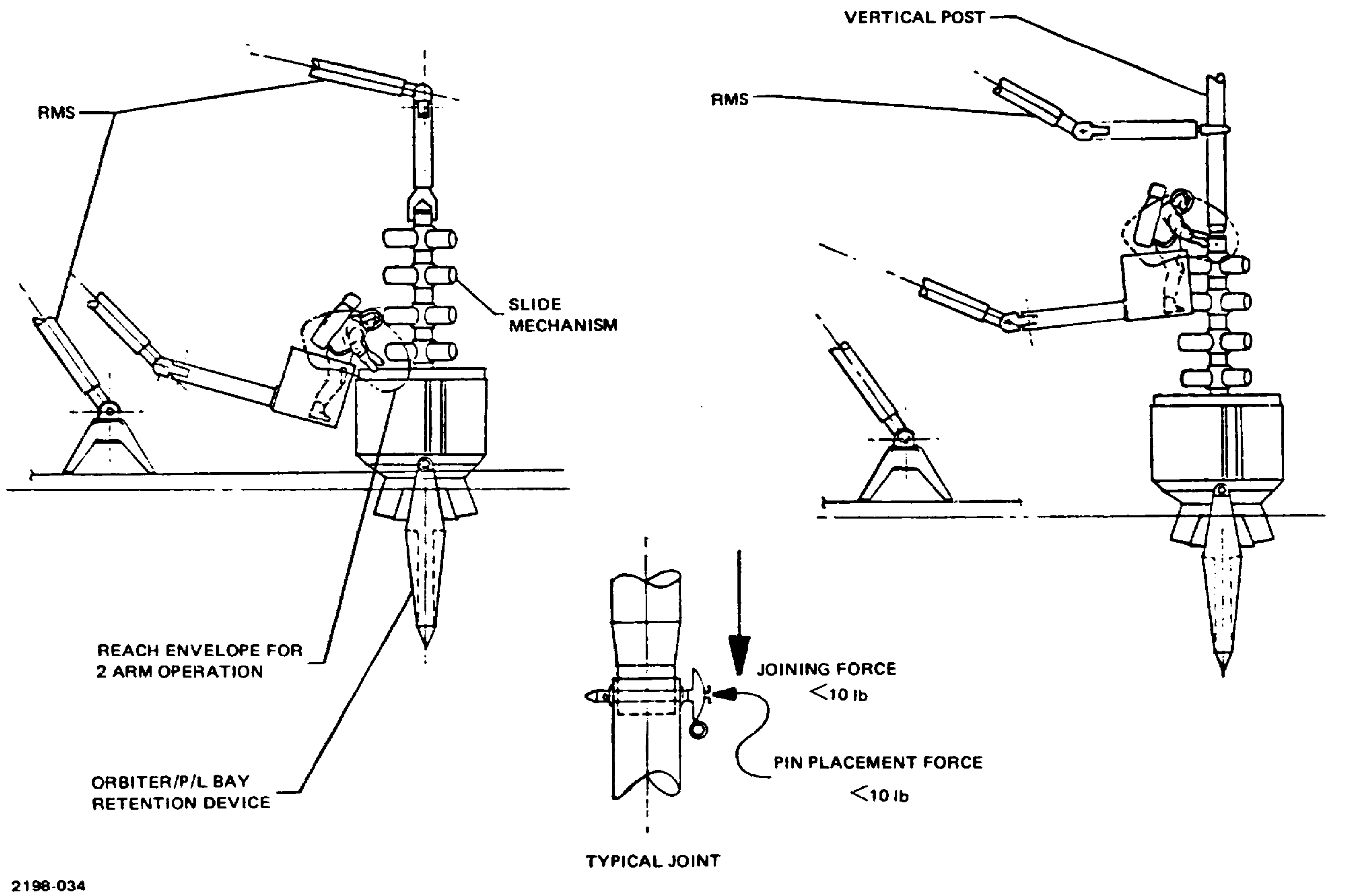


Figure 28. Open Cherry Picker Requirements – Function 7.0 – Assemble Fixture

- Vertical Post
  - 9.6-m long by 0.3-m wide, 80 kg
- Tool for pin insertion and lock.

Operations

The installation of the assembly fixture can be performed within the approximate time-line as shown in Table 7.

1.3.4.2 Beam Assembly -

Accessibility

The cherry picker bucket can be placed within the reach of an EVA astronaut (Figure 29). The stabilizer is engaged at a point on the assembly fixture and draws the platform to within 0.6 m of the structural joint before it is rigidized. The long distance (0.6 m) requires the astronaut to fully extend himself while performing the fastening operation.

The fastening concept used in the LSS assembly is a mechanical crimping technique. A simple probe/drogue arrangement that allows up to 7° misalignment is utilized. Once the probe/drogue is engaged, the astronaut crimps the drogue for a permanent joint.

Items to be Handled

The major element handled by the MRWS is a joint crimping tool with the characteristics summarized in Figure 29.

Operations

The approximate time-line for the beam joining operation is shown in Table 8.

TABLE 7

ASSEMBLY FIXTURE INSTALLATION TIME-LINE

ΔT (min)	OPERATION
5	RETRIEVE SLIP MECHANISM FROM STORAGE WITH SRMS
3	SRMS COARSE ALIGN RELATIVE TO FIXTURE CASE
5	CHERRY PICKER ASTRONAUT FINE ALIGNS, INSERTS & FASTENS
5	SRMS RETRIEVES VERTICAL POST FROM STORAGE
3	SRMS COARSE ALIGN RELATIVE TO SLOP MECHANISM
5	CHERRY PICKER ASTRONAUT FINE ALIGNS, INSERTS & FASTENS
26	TOTAL

2198-035

TABLE 8

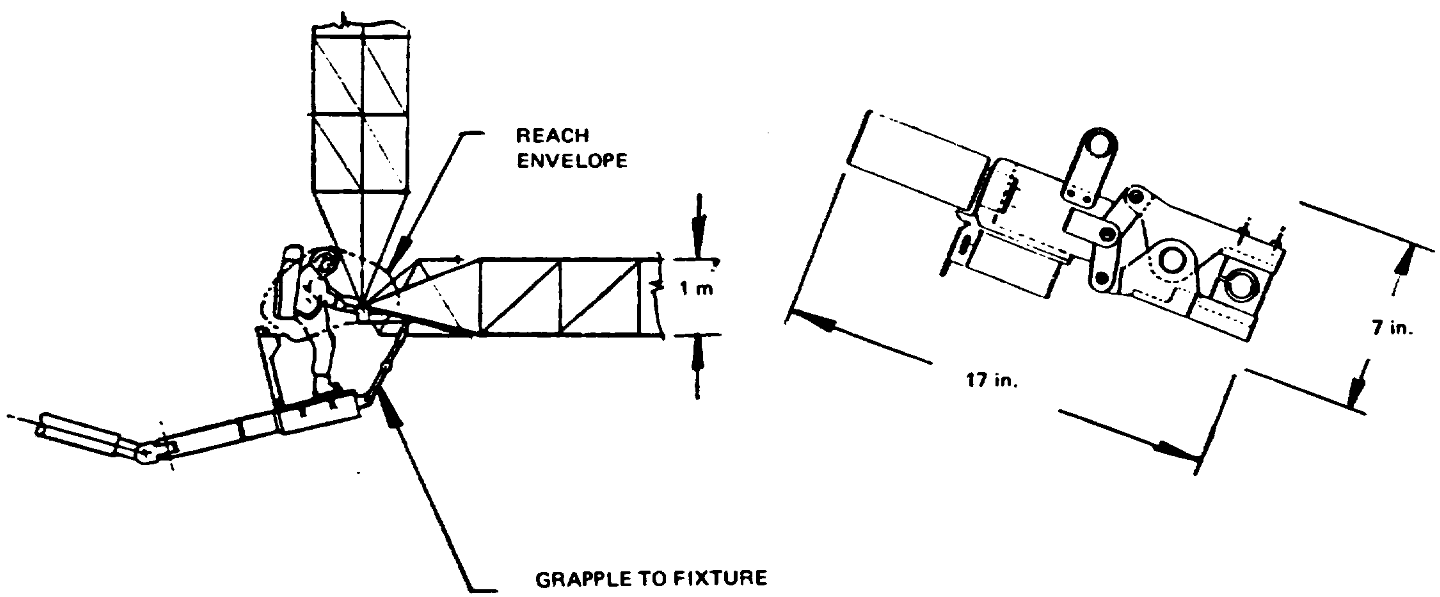
BEAM JOINING OPERATION TIME-LINE

ΔT (min)	OPERATION
5	CHERRY PICKER POSITIONS NEXT TO ASSEMBLE JOINING & GRAPPLES ASSEMBLY FIXTURE
5	SRMS RETRIEVE BEAM FROM AUTO BEAM FABRICATOR
5	CHERRY PICKER FINE POSITIONS BEGIN, INSERTS PROBE INTO DROGUE AND CRIMPS
15	TOTAL

2198-037

SPECIAL TOOLS

- CRIMPER



2198-036

WT = 25 lb

Figure 29. Open Cherry Picker Requirements – Function 8.0 – Assemble Structure

1.3.4.3 Obstacle Avoidance - The large size of the LSS platform relative to the Shuttle cargo bay introduces conditions where the cherry picker must weave through the structure to get at a worksite. Figure 30 illustrates such a condition and lists three approaches to obstacle avoidance. The first approach is to automate the entire procedure through the Shuttle computer. The second approach, in which the computer provides a series of coordinate target points, will have as big an impact on software as the first approach, but puts the man-in-the-loop for safety. The third approach provides an open loop axis-by-axis control panel in the MRWS and relies on the judgement and training of the astronaut to select the proper sequence of SRMS motions to weave through the structure. The last approach is the lowest-cost technique and would not impact an already tight Shuttle computer software package.

1.3.5 Additional Open Cherry Picker Design Requirements

This mission is best performed with two SRMS's. The second should be controlled from the cherry picker platform, and operated in series with the payload handling SRMS. If parallel operation is needed, it will require modifications to the current SRMS system.

Mission Peculiar Support Equipment

Several items of equipment over and above that already identified to support the MSS and LDEF missions were identified. Storage provisions are needed for the following:

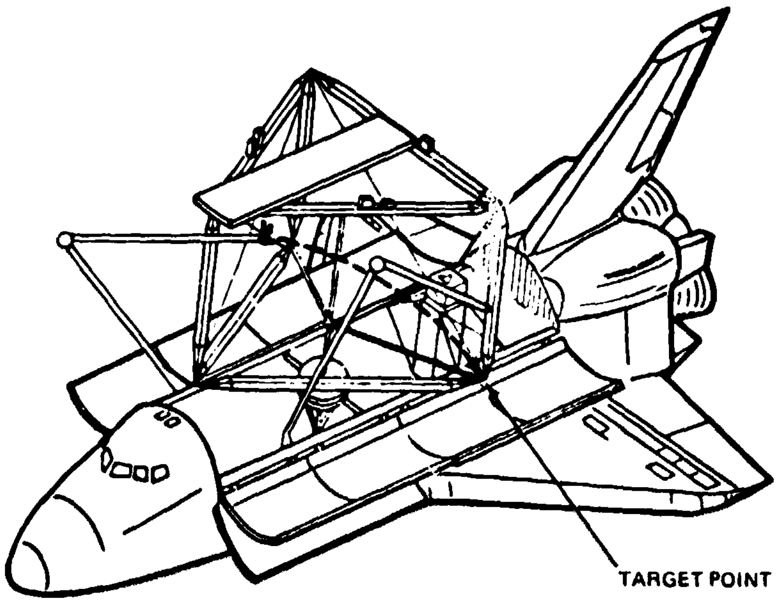
- Joint crimping device
- T-section joint probes
- Pins for assembly fixture installation.

1.3.6 Issues to be Resolved

- Feasibility of utilizing the SRMS natural compliance during joining operations
- Feasibility of operating two SRMS in parallel.

1.3.7 References

System Definition Study for Shuttle Demonstration Flights of large Space Structures. Grumman Report NSS-LS-RP008, NAS 8-32390, January 1978.



CANDIDATE APPROACHES

1 – PROVIDE SOFTWARE FOR AUTOMATED OPERATION

2 – PROVIDE SOFTWARE TO DISPLAY SERIES OF TARGET POINTS TO MRWS OPERATOR

3 – PROVIDE AXIS BY AXIS CONTROL (RMS PANEL) AND DEPEND ON JUDGEMENT AND TRAINING OF MRWS OPERATOR

2198-038

Figure 30. Open Cherry Picker Requirements – Obstacle Avoidance

1.4 SPACE CONSTRUCTION AUTOMATED FABRICATION EXPERIMENT (SCAFE)

1.4.1 Mission Description

The purpose of the SCAFE spacecraft is to demonstrate the techniques, processes, and equipment required for automatic fabrication and assembly of structural elements in space using the Shuttle as a launch vehicle and construction base. The fabrication and construction techniques demonstrated by the spacecraft will be applicable to future programs such as Orbital Construction Base and Solar Power Satellites.

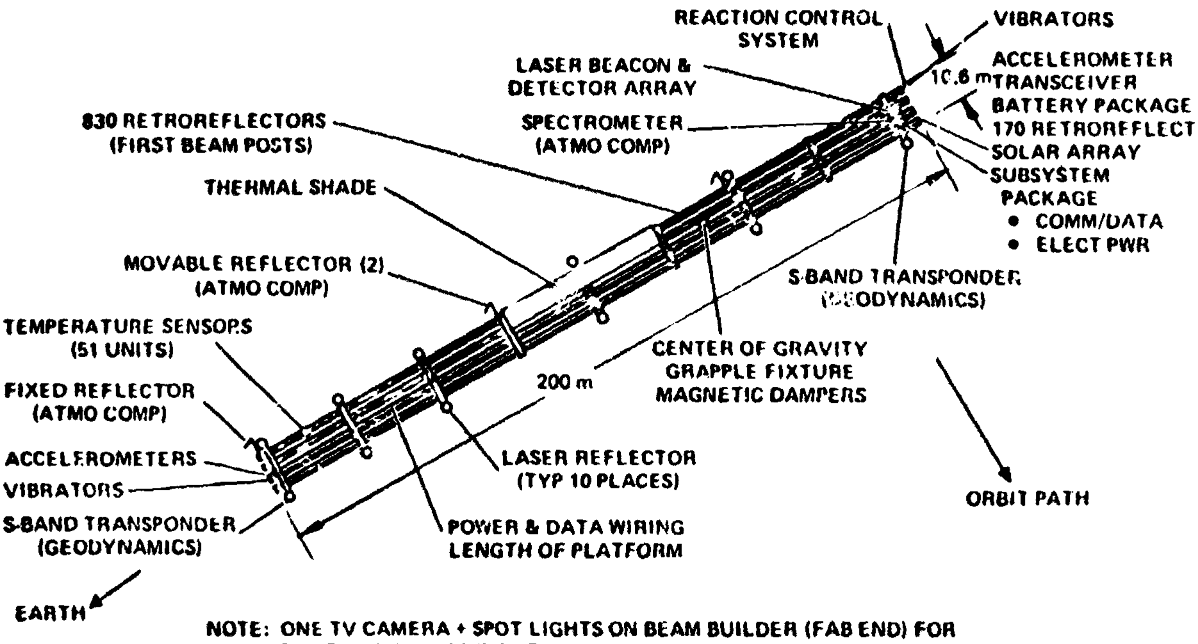
The spacecraft will also be used as a structural test platform to measure dynamic responses of the structural elements and thermal induced deformations of the platform. These experimental results will be compared with math model predictions. The spacecraft platform is also used to mount equipment for geodynamics and atmospheric composition experiments. The geodynamic experiment will map anomalies in the earth's gravity field and obtain data on the internal mass distribution of the earth. The atmospheric composition experiment will measure composition and density of the atmosphere at platform altitudes.

The spacecraft could also be used to evaluate the capabilities of man's ability, using an open MRWS attached to the Shuttle RMS, to aid in the various construction and maintenance tasks necessary to build, operate, and maintain the spacecraft.

1.4.2 Spacecraft Description

The spacecraft general arrangement is shown in Figure 31. The structure consists of four longitudinal beams, 200-m long, and nine cross beams, 10.6-m long. The beams are triangular in shape, the legs of which are 1.362-m long and are made of laminated graphite/glass fibers. The longitudinal and cross beams are joined together at the four cap-to-cap joints by ultrasonic spot welding. Mounted to the platform are the various packages, sensors, and wiring necessary to perform the various structural and experimental tests.

The SCAFE assembly concept is shown in Figures 32 and 33. Fabrication/assembly systems and prepackaged raw materials are delivered by Shuttle to a 556 km circular orbit. Upon system deployment from the stowed position, the beam builder, moving to successive positions along the shuttle-attached assembly jib, automatically fabricates four triangular beams, each 200-m long, in the first two days on orbit. Retention of the completed beams is provided by the assembly jig.



NOTE: ONE TV CAMERA + SPOT LIGHTS ON BEAM BUILDER (FAB END) FOR FIRST BEAM EXPERIMENT

2198-039

Figure 31. Platform Equipment General Arrangement (Experiment plus Subsystems)

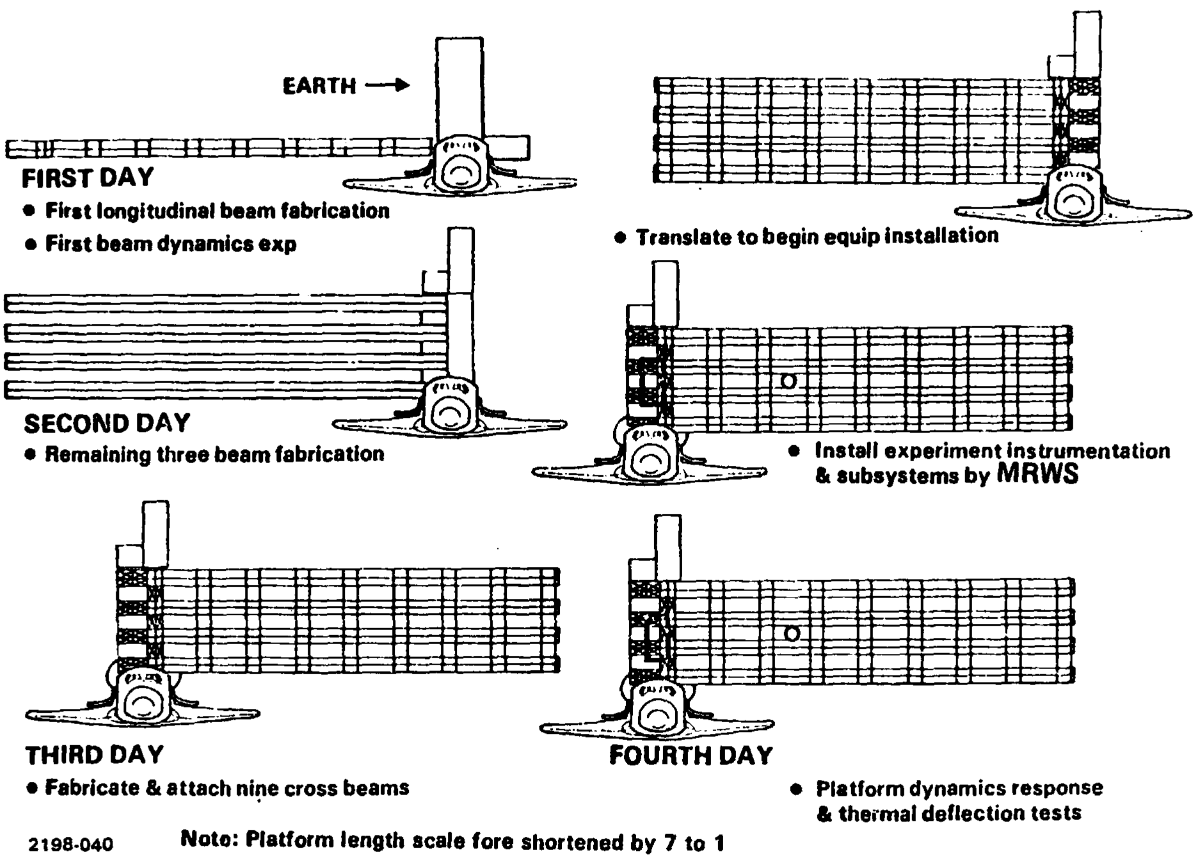


Figure 32. Operational Sequence No. 1

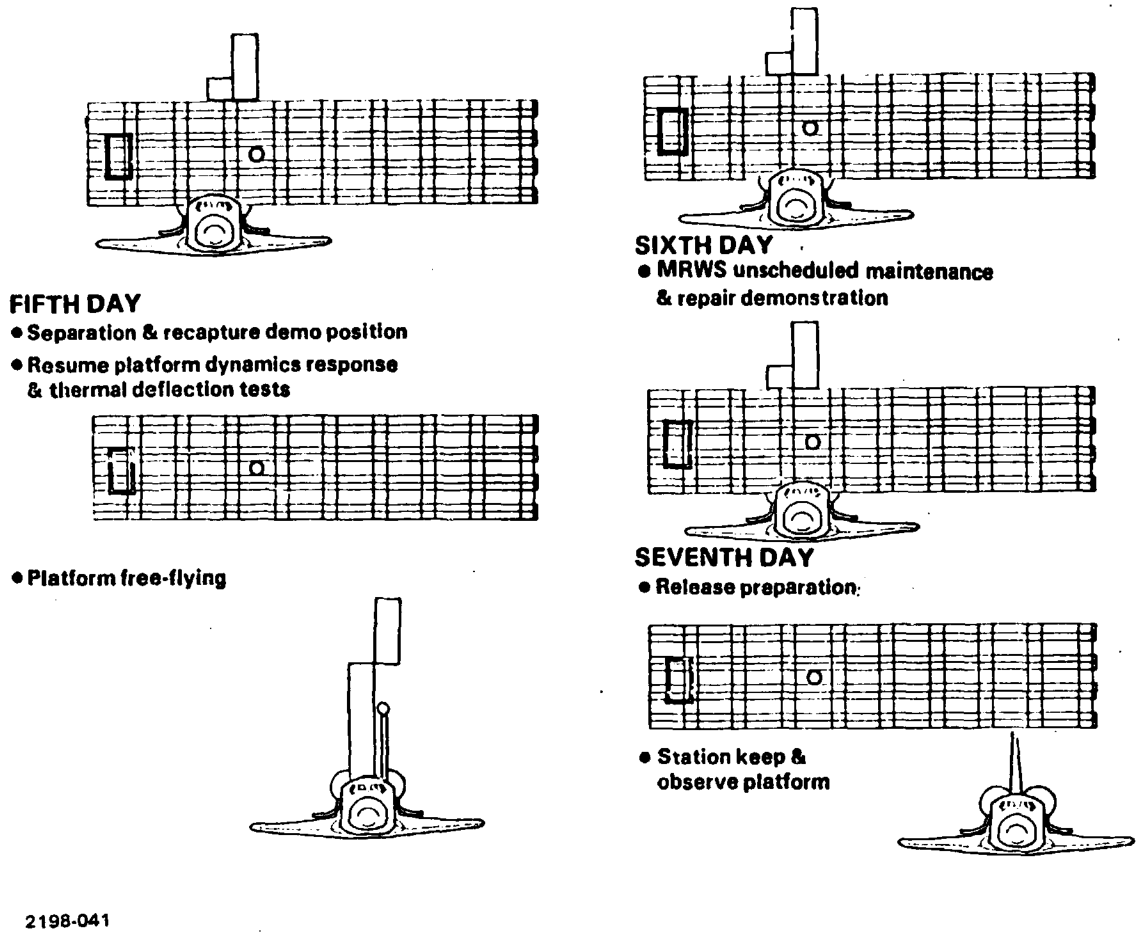


Figure 33. Operational Sequence No. 2

The beam builder then moves to the position shown for the third day and fabricates the first nine shorter, but otherwise identical, cross beams. After cross beam attachment, the partially completed assembly is automatically transported across the face of the assembly jig to the next cross beam location, where another cross beam is fabricated and installed. This process repeats until the "ladder" platform assembly is complete. The completed platform is then translated back across the assembly jig so that the experiment instrumentation and subsystems can be installed by MRWS.

On the fourth day, the dynamics response and thermal deflection tests are performed in the configuration shown.

On the fifth day, a separation and recapture demonstration takes place. The platform assembly will be translated to a position where the center of gravity is directly above the RMS. The RMS will attach itself to the grapple fitting on the platform and will pull the platform away from the assembly jig. The RMS will then detach itself from the platform, leaving it in a free-flying mode. The orbiter will be positioned a short distance away from the platform in preparation to re-acquire the platform. The RMS will be used to attach to the grapple fitting and place the platform back in the assembly jig in a manner so that it can be translated across the assembly jig again to the same position as on the fourth day so that the response tests can be resumed in the afternoon of the fifth day.

On the sixth day, the platform assembly will be translated back to the position where the center of gravity is over the RMS, and an unscheduled maintenance and repair demonstration will be performed by the MRWS.

On the seventh day, preparation will be made to release the platform for the free-flying portion of the mission. The RMS will be used as previously described with the platform center of gravity directly over the RMS. After observing the platform for a short time after release, the orbiter will return to earth.

Table 9 shows a mass summary of the spacecraft.

1.4.3 Support Functions and Mission Scenario

MRWS support functions were established for an open cherry picker utilizing the Shuttle Remote Manipulator System as the crane component as shown in Figure 34. Figure 35 contains the MRWS functional requirements. Functions 1.0 through 6.0 were discussed in previous sections and Functions 11.0, 12.0, and 13.0 are discussed in the following task analyses.

TABLE 9

SCAFE MASS SUMMARY

	MASS (kg)
STRUCTURE	(997)
• CROSSBEAMS	108
• LONGITUDINAL BEAMS	889
SUBSYSTEM/COMPONENT	(838)
• COMMUNICATIONS	73
• ELECTRIC POWER	441
• ATTITUDE CONTROL	154
• GRAPPLING FIXTURE	50
• WIRING	120
TOTAL	1835

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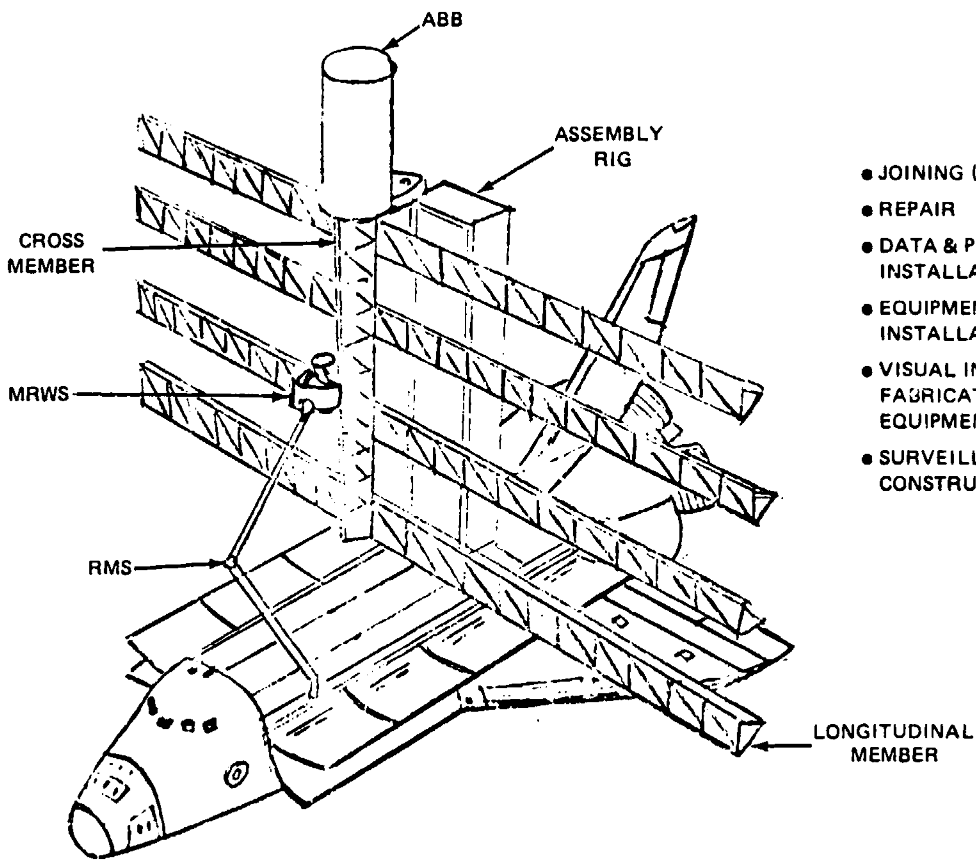


- JOINING (ULTRA SONIC WELD)
- REPAIR
- DATA & POWER WIRING INSTALLATION & HOOKUP
- EQUIPMENT HANDLING & INSTALLATION
- VISUAL INSPECTION OF FABRICATION DEPLOYMENT EQUIPMENT
- SURVEILLANCE OF BEAM CONSTRUCTION

2198-043

Figure 34. Space Construction Automated Fabrication Experiment (SCAFE) Support

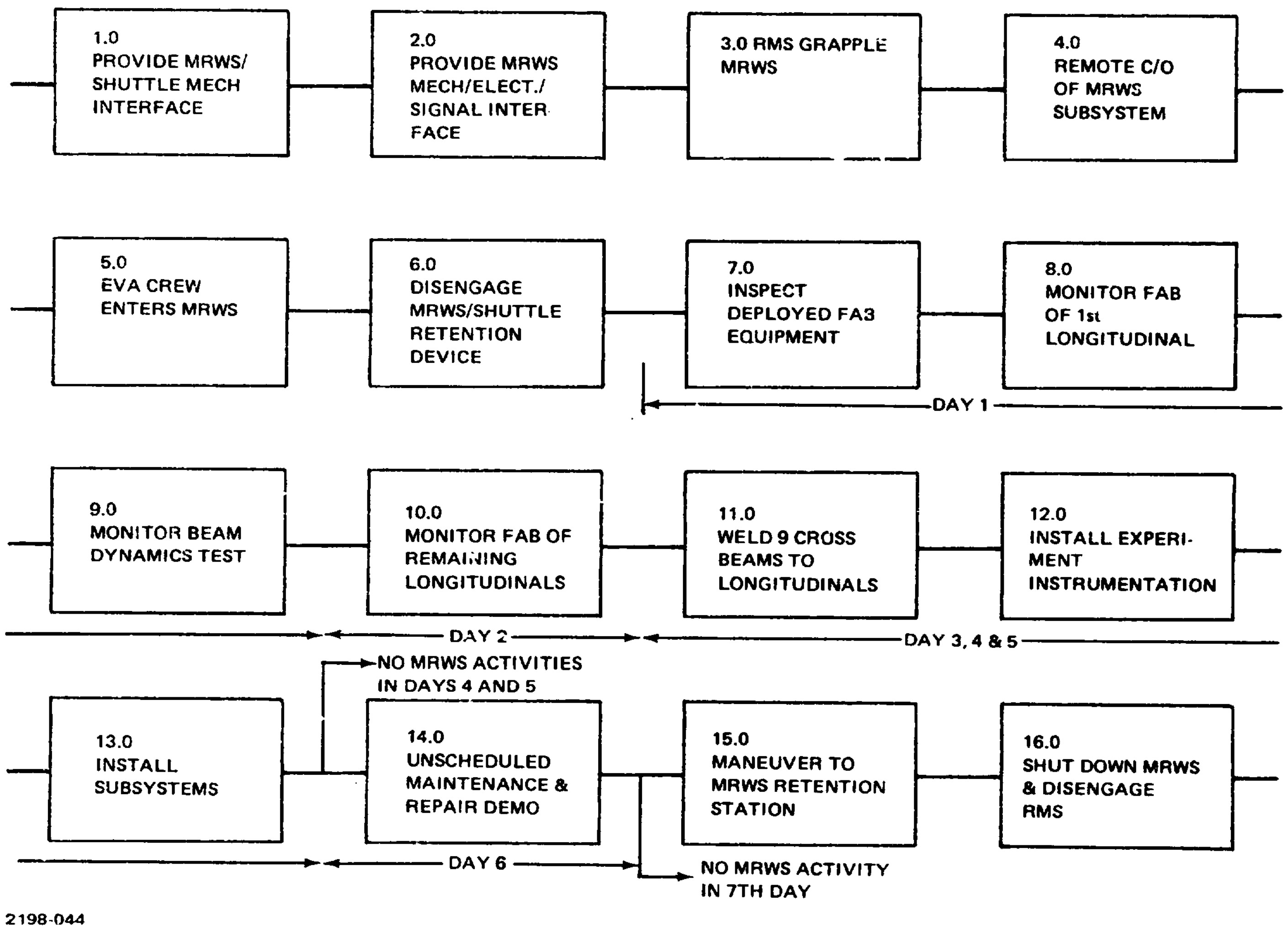


Figure 35. Open Cherry Picker Functions - SCAFE Support

1.4.4 Task Analysis

1.4.4.1 Weld Joints -

Accessibility

The longitudinal beams are held in position in the assembly jig and the beam builder fabricates a cross beam 10.6-m long at right angles to the longitudinal beams. The astronaut must be able to maneuver the MRWS to reach the beam to beam intersection consisting of cap to cap joints with an ultrasonic welding tool (Figure 36). The weld horn must be inserted under one cap member and the anvil around the other. Pressure is then applied to the joint by the welding tool automatic clamp up device, power applied and spot weld made. See Figure 37 for details of beam intersection joints.

Items to be Handled

Figure 36 shows the welding tool that must be positioned and inserted between the caps. The cross beams must be positioned and aligned before welding. If a gap exists between caps due to manufacturing tolerances, shims must be added between caps before welding. The power requirements for the wleding tool may impose the need to carry batteries on the MRWS for the welding operations characterized by high current pulses.

Operations

Weld cross beams to longitudinal beams: 8 welds per intersection joint (2 welds per joint), 32 welds per cross beam connection. There are 288 welds per spacecraft to join nine cross beams.

The operations listed in Table 10 are repeated 35 times to complete the platform.

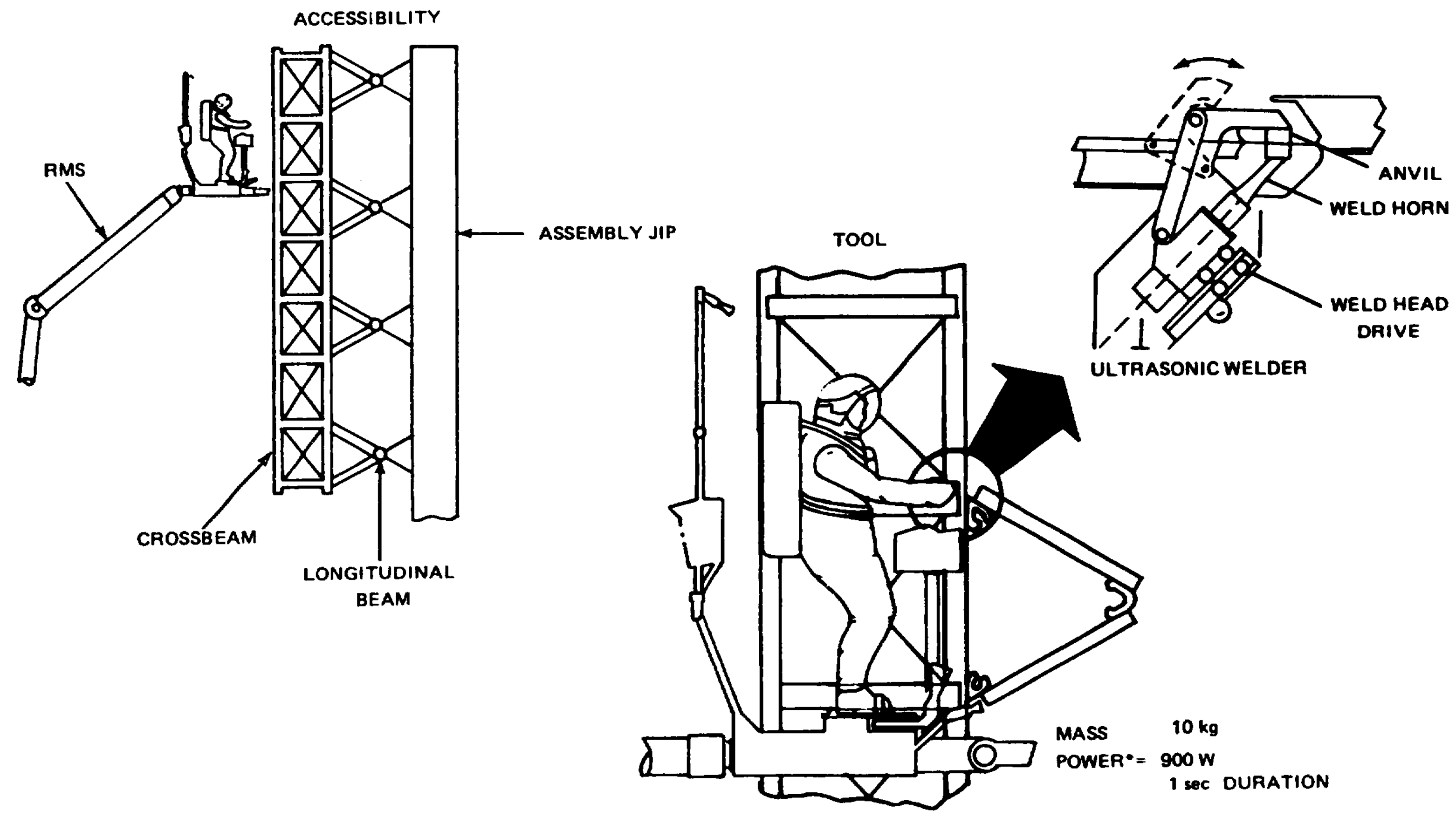
1.4.4.2 Install Subsystems and Sensors -

Accessibility

The complete platform is automatically transported across the face of the assembly jig so that the experiment instrumentation and subsystems can be installed by the MRWS. The platform equipment locations are shown in Figure 31 and the installations shown in Figures 38 and 39.

Items to be Handled

The solar array (approximately 10 sq m) is placed on the end of the platform. The batteries and other electrical power systems components are contained within



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*NOTE: POWER FED THRU RMS/MRWS POWER LINE

Figure 36. MRWS Open Cherry Picker Functions – Function 11.0 – Weld 9 Crossbeams to Longitudinals

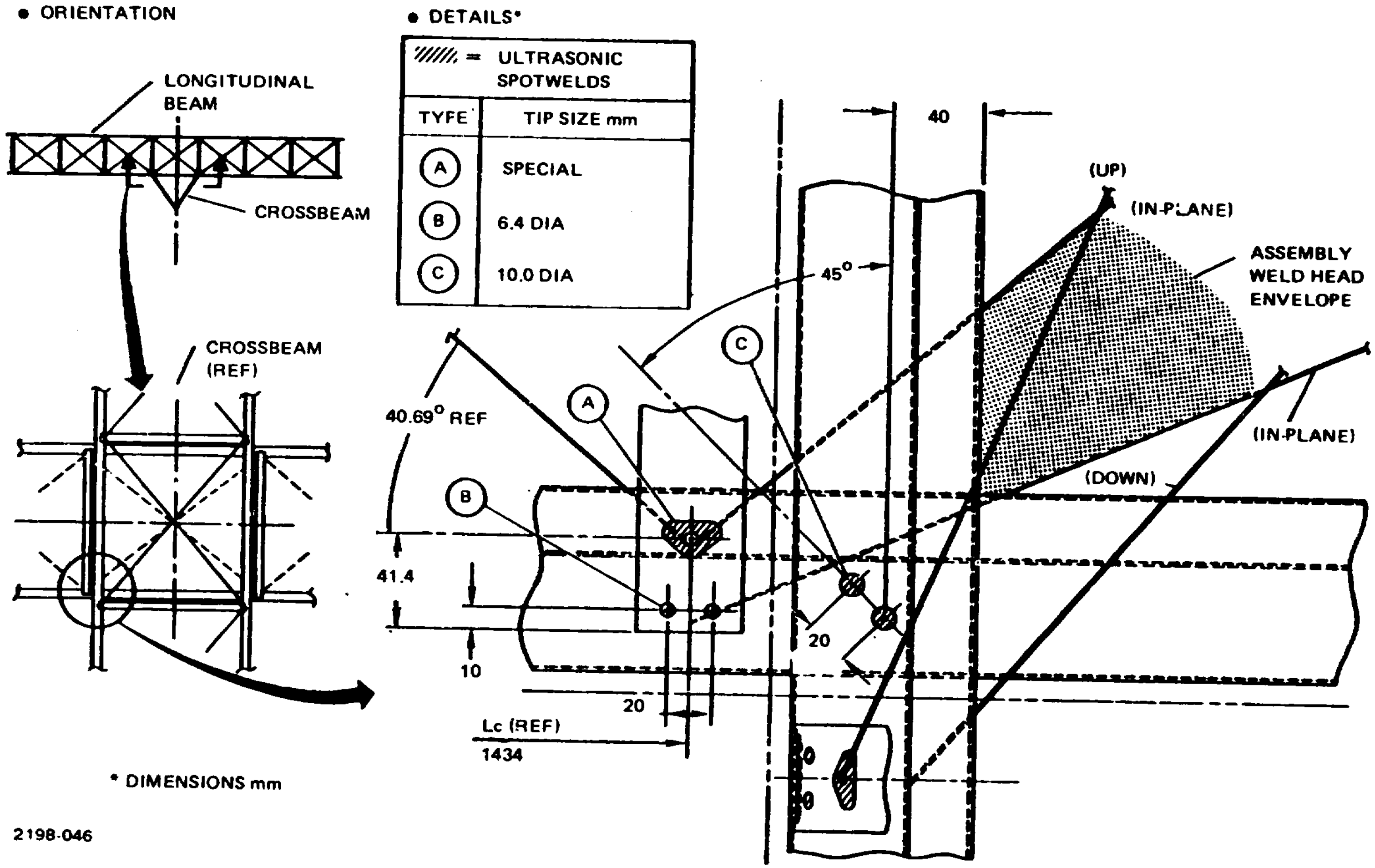

Figure 37. Beam Intersection Joints

TABLE 10

WELDING OF CROSSBEAMS TO LONGITUDINAL BEAMS TIME-LINE

ΔT (hr : min)	OPERATION
:05	MANEUVER MRWS TO INTERSECTION WITH TOP LONG BEAM
:02	POSITION & ALIGN BEAM CAPS
:02	ADD SHIM(S) IF REQUIRED
:05	INSERT WELDING TOOL BETWEEN CAPS OF BEAMS
:01	CLAMP & WELD
:02	UNCLAMP TOOL & MOVE 20mm
:01	CLAMP & WELD
:02	UNCLAMP WELD TOOL, REMOVE FROM BETWEEN CAPS
1:00	MANEUVER TO OTHER 3 JOINTS & REPEAT OPERATION
1:20	TOTAL

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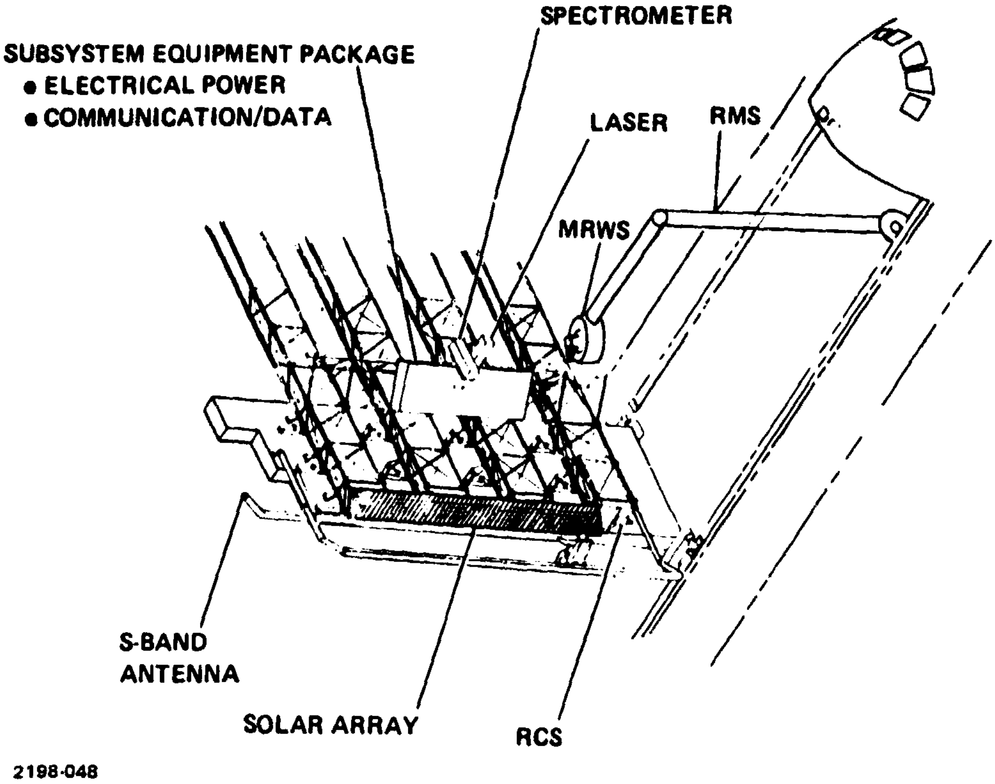

Figure 38. Subsystem Installation

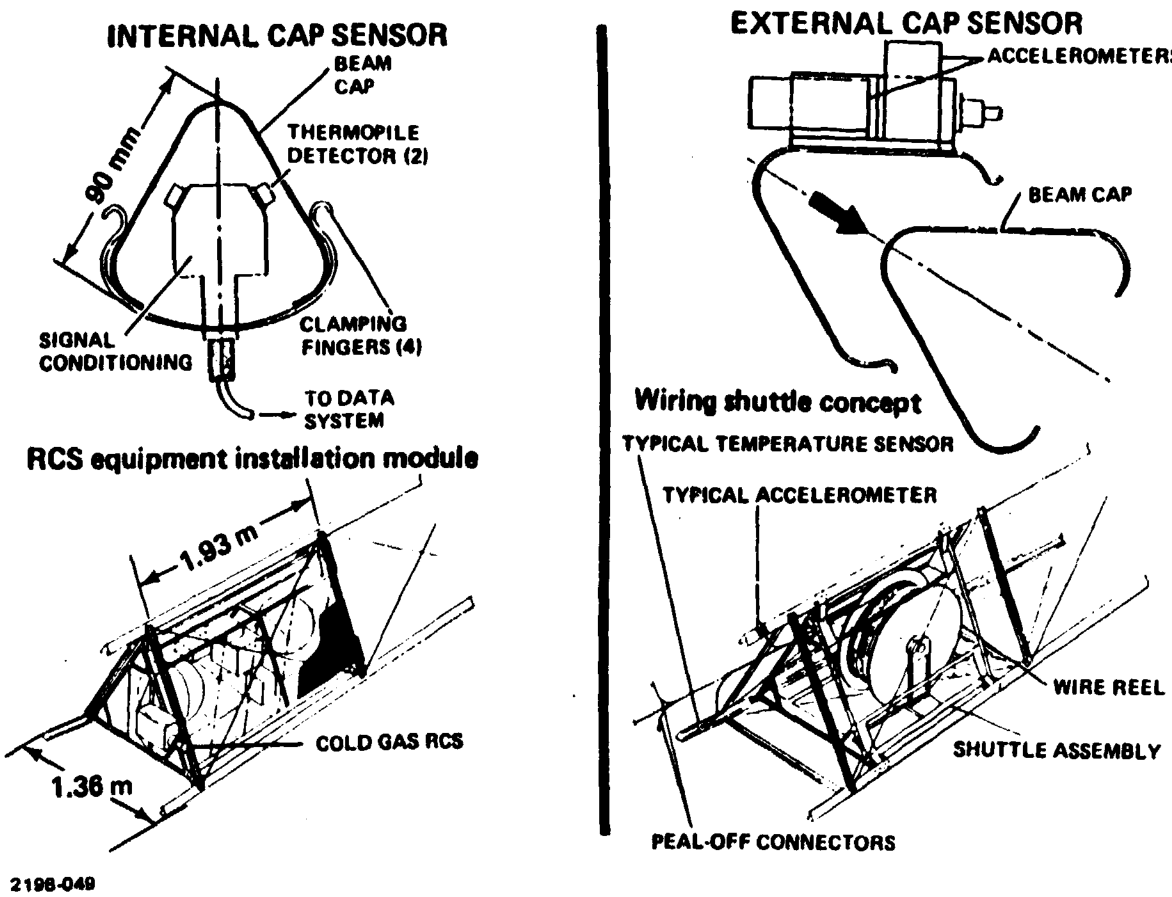

Figure 39. Instrument and Subsystem Installation

the subsystem equipment package. The platform avionics is also contained within the subsystem package. The altitude control system is placed in the end of one of the longitudinal beams. The spectrometer, laser beacon and detector array are mounted on subsystem package. The temperature probes are installed internally to the cap beam by a spring clamp and the data wires hooked up to wiring shuttle. The accelerometers will be attached external to beam caps by spring clamps and the data wires hooked up to the wiring shuttle. Figure 39 shows the wire shuttle which is translated along the longitudinal beam. The wires on the reel contain the leads and connectors to be connected to the instruments as they are installed. The following chart is a mass summary of installed equipment.

Equipment	Mass (kg)
Attitude Control System	154
Spectrometer	135
Laser	10
Subsystem Package	421
Wiring Shuttle	120
Solar Cell Blanket	93
Grappling Fixture	50

Operations

Install RCS module in end of longitudinal beam. The operations listed in Table 11 are repeated for other equipment installations.

1.4.5 Open Cherry Picker Design Requirements

See Subsection 1.1

Support Equipment

Several items of equipment are needed to support orbital operations. Mounting fixtures are required for storing the OCP in the payload bay. RMS end effector and grapple fixture which attaches the OCP to the RMS are needed (Figure 9). Ultrasonic Spot Welding tool and power supply (Figure 36) is required. Lights (30 - 100 ft-c illumination) are required mounted to the OCP.

TABLE 11

RCS MODULE INSTALLATION TIME-LINE

ΔT (min)	OPERATIONS
:03	MANEUVER MRWS TO SHUTTLE CARGO BAY
:05	UNCLAMP RCS MODULE TIE DOWN
:02	GRAPPLE MODULE & LIFT OUT OF SHUTTLE CARGO BAY
:02	TRANSIENT MODULE TO END OF PLATFORM
:05	POSITION & INSERT MODULE IN END OF LONGITUDINAL
:03	CLAMP MODULE TO LONGITUDINAL BEAM
:05	HOOK UP WIRES
25	TOTAL

2198-050

1.4.6 Issues to be Resolved

- Need for stabilizer to aid in welding operation or second astronaut in cabin
- Welding tool configuration and power requirements
- Storage areas in open cabin for tool/parts
- Retention device design for subsystem and sensor handling.

1.4.7 References

- Space Construction Automated Fabrication Experiment Definition Study. General Dynamics, Part II Mid-Term Briefing, CASD-ASP-77-011; Part II Final Briefing, CASD-ASP-77-016.
- Proposed Construction Experiment for Shuttle. JSC Spacecraft Design Division.

1.5 INITIAL CONSTRUCTION BASE

1.5.1 Mission Description

The initial Space Construction Base (SCB) module delivered to orbit is a small 38 kW power module. After the solar arrays and radiator systems are deployed and operational integrity of the module has been verified by the Orbiter crew, the power module is released. The module is left in a nominally quiescent state until scheduled launch of the Space Construction Module (SCM). Following the Orbiter rendezvous and docking operation with the power module, the SCM can be deployed from the Orbiter cargo bay by means of the combined operation of the SRMS and Open Cherry Picker (OCP). During verification of subsystems, the SRMS removes the space crane components from their launch position and the OCP assembles them in the operational configuration. The SRMS then berths the SCM to the X-axis of the Power Module (PM) (Figure 40). The SCB is now configured to initiate routine construction activity.

1.5.2 Spacecraft Description

The resulting orbital configuration of the Shuttle-tended SCB (Figure 40) consists of the Orbiter, Power Module, and the Space Construction Module. The SCM incorporates four radial berthing ports for attaching assembly jigs, material canisters,

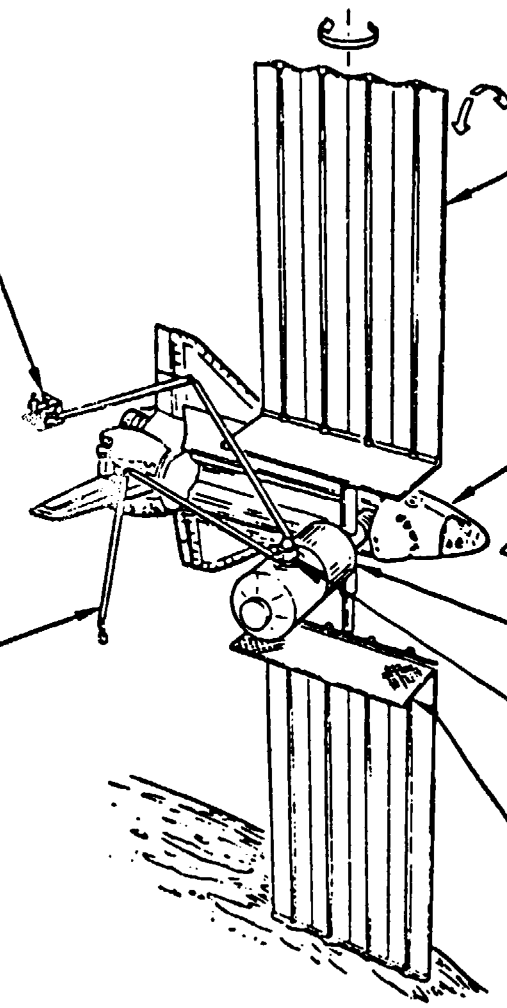

Figure 40. Shuttle Tended Space Construction Base

or pallets to the side of the module. Thus, the crane can transport material directly from the pallet to the assembly fixture or it can supply raw material directly to fabrication machines.

1.5.2.1 Power Module - The function of the Power Module is to provide required quantities of electrical power, initially to Shuttle/Spacelab combinations, and, subsequently, to the SCB in its early years.

The Power Module characteristics are:

- Bus power - 38 kW continuous at the bus
- Heat rejection - internal and excess over Orbiter capability of approximately 24 kW

- Communication/data management-telemetry in free-flying mode
- Attitude control.

The Power Module (Figure 41) consists of: (1) a 15.5-m long cylindrical shell with a 5.5-m long telescoping cylinder at either end with the two axis gimbals at the solar array juncture; (2) two solar array wings, each consisting of four SEPS units, and (3) deployable radiators. The weights of this system can be found in Table 12.

The Power Module contains a limited communication and navigation system and an RCS, which permits it to free-fly between Orbiter visits. A 4.4-m wide, 16-m long radiator panel is mounted along each of the two array support beams. The radiator panels are hinged so that they fit within the cargo bay clearance envelope. Mounted as they are, outboard of the gimbals and normal to the plane of the arrays as shown in Figure 41, the radiator panel surfaces are always parallel to the sun line and their heat-rejection capacity is maximized.

1.5.2.2 Space Construction Module - The functions of the space construction module are:

- Supervision and scheduling of construction projects and resources
- Material handling and module/pallet berthing
- Testing of components and complete assemblies

TABLE 12

POWER MODULE MASS

ITEM	MASS (kg)
SOLAR ARRAYS (SEPS WINGS, 8 @ 192)	1540
BATTERY (16 @ 370.5)	5928
BATTERY CHARGERS	104
LOAD REGULATORS	177
WIRE	400
SUPPORT STRUCTURE & GIMBALS	1701
RADIATOR/THERMAL CONTROL	957
ATTITUDE CONTROL & ORBIT KEEPING	429
AVIONICS	59
TOTAL	11,295

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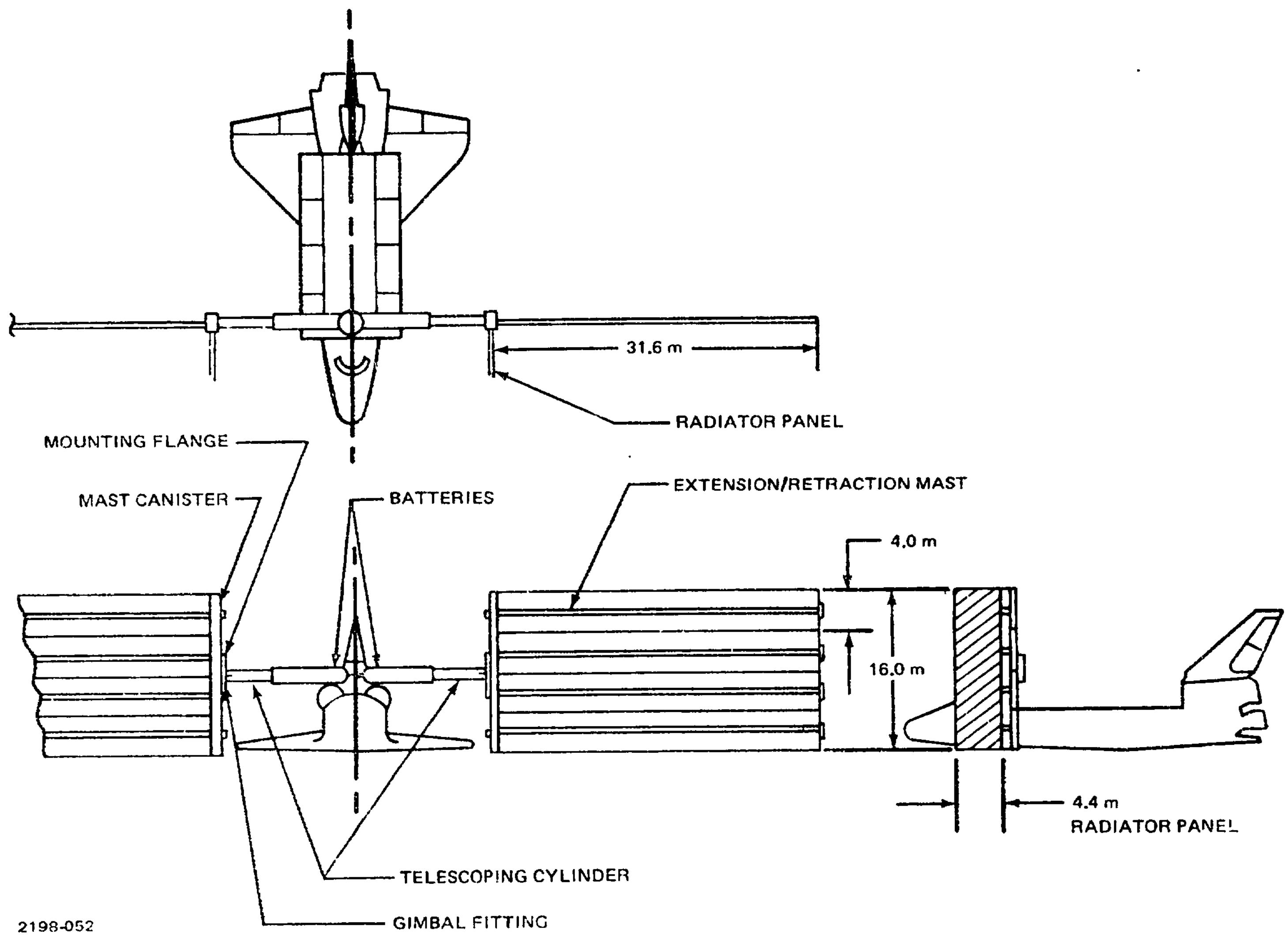


Figure 41. Power Module Configuration

- Maintenance and storage of EVA crew equipment and construction tools
- Secondary emergency refuge area.

The SCM (Figure 42) is configured to support construction. The module is 9.5 m (31.25 ft) long with a maximum external diameter of 4.42 m (174 in.) and an internal pressure shell diameter of 4.26 m (168 in.). The module depends entirely on external sources for the operational subsystems support and resources necessary for its operation. These resources may be supplied from either the Orbiter, or Power Module. The SCM is configured to provide adequate but not excessive facilities for construction and test support.

The module contains five basic facilities:

- Construction control
- Test control
- EVA equipment support
- Module subsystems
- Tools and part storage.

The internal arrangement is dominated by the four radial berthing ports. Each port is passive, containing only the structural ring and alignment guides used to berth construction material pallets. Also incorporated are two axial berthing ports, one active and one passive, to provide appropriate interface with other SCB elements such as the strongback. The addition of a kit to the passive port will make it compatible with the active port, making universal berthing possible. The launch mass of the SCM is 13,518 kg (29,800 lb).

1.5.3 Support Functions and Mission Scenario

For both Shuttle launches, two SRM's are required, one to move the payload to their required interfaces, and one to support an open cab Cherry Picker. On Flight No. 1, the MRWS, in the open configuration, can be used to support the assembly of the Power Module (PM). A concept for using the OCP in the assembly of the PM while berthed to the Shuttle docking module is shown in Figure 43. The one-man platform is controlled from the platform and contains the support tools for performing

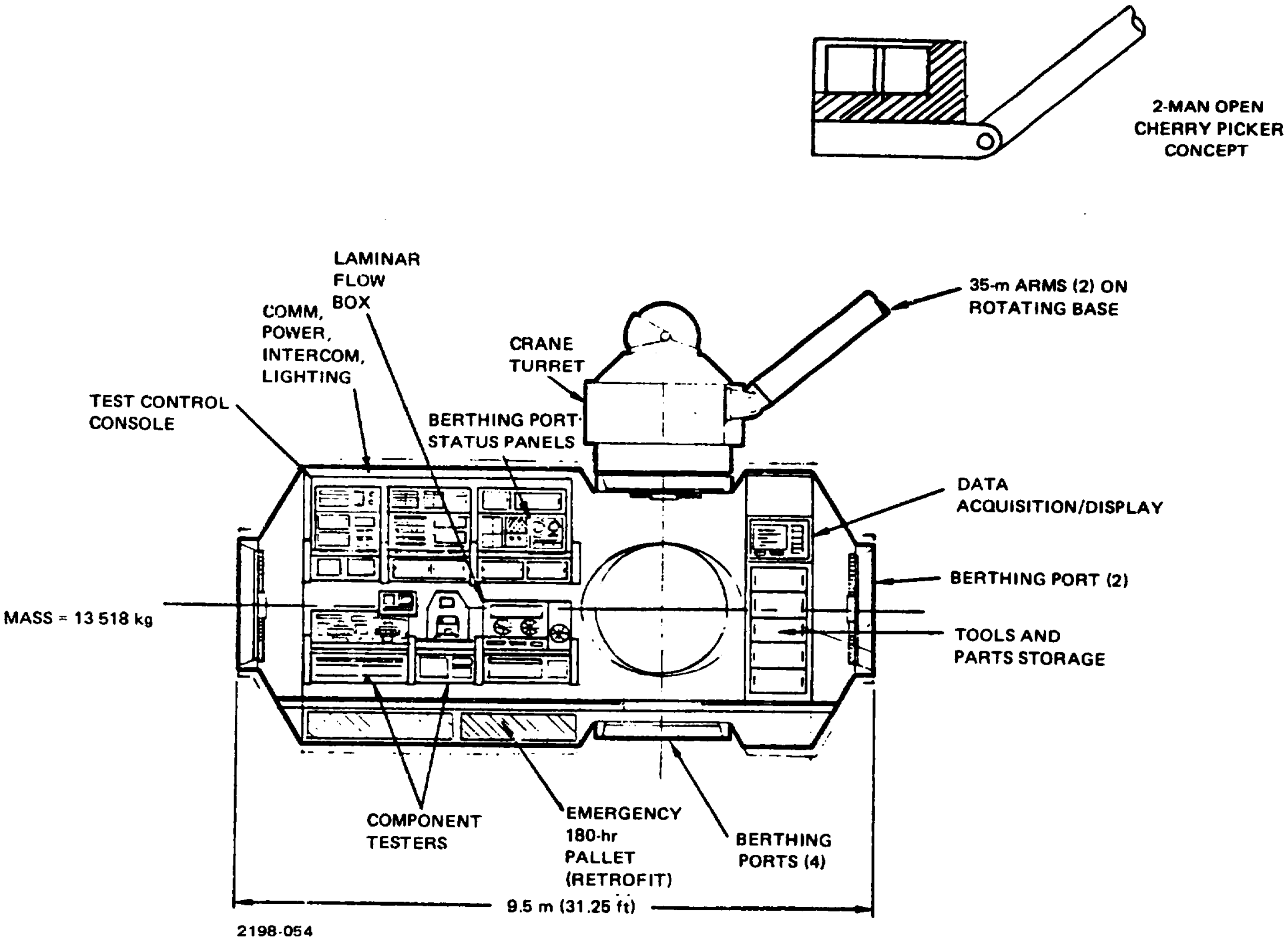
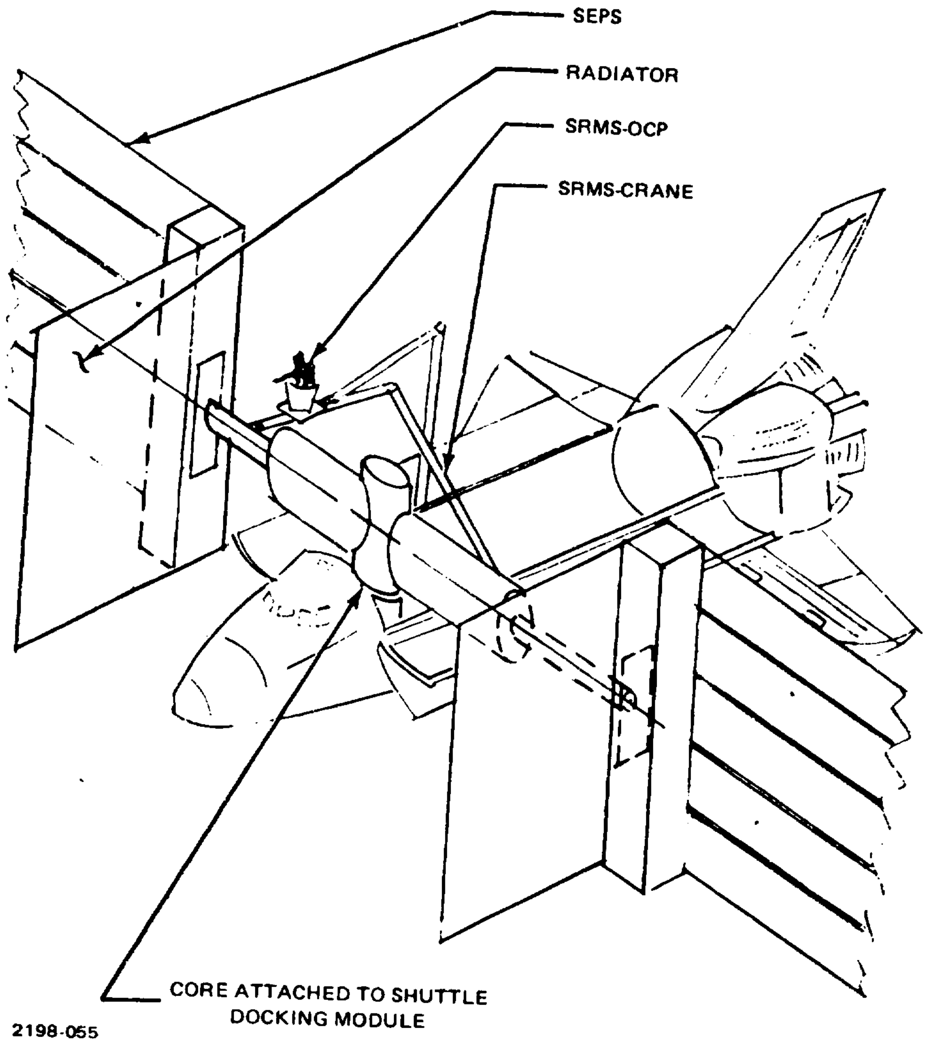


Figure 42. Construction Module Concept



OPEN CHERRY PICKER FUNCTIONS

- DIRECT MOVEMENT OF SRMS IN TRANSPORTING ELEMENTS
- PERFORM ALIGN & JOINING OPERATIONS
- MAKE MECHANICAL CONNECTIONS AT GIMBAL FITTINGS
- DEPLOY TELESCOPIC CYLINDERS
- OPEN MAST CANISTERS
- ASSIST IN DEPLOYMENT OF SEPS
- DEPLOY RADIATOR PANELS AND LOCK IN PLACE
- C/O ASSEMBLED STRUCTURE
- ASSIST SRMS IN DEPLOYMENT OF P/M TO SPACE

Figure 43. Assembly of Power Module — Flight No. 1

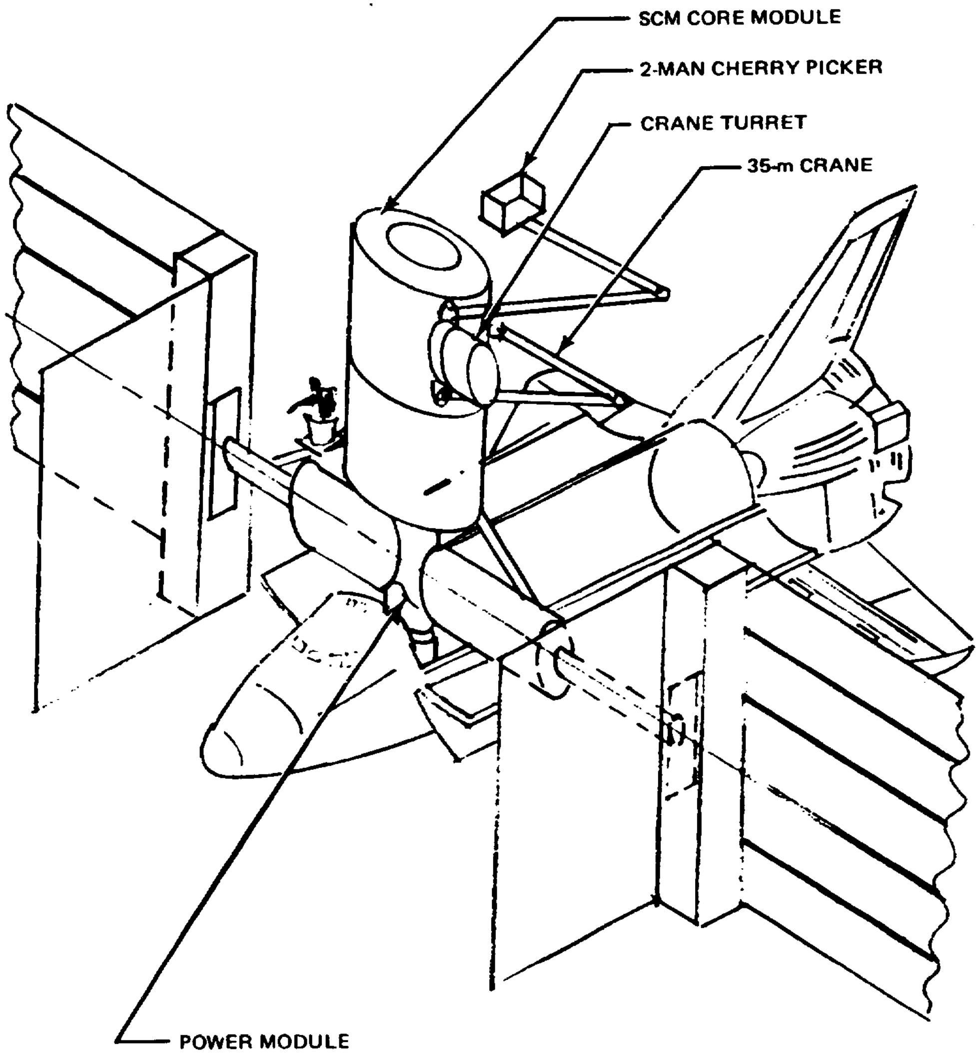
the structural fastening, deployment, and alignment of the PM components. The cherry picker works in parallel with the SRMS used for component handling and positioning. On flight No. 2, the SRMS captures the stationkeeping PM and berths it to the Orbiter. The OCP then assists in expanding the capabilities of this unit by adding the SCM to PM. Figure 44 shows the assembled SCM and lists the OCP functions in accomplishing this buildup.

The power module is packaged and stowed in the Orbiter payload bay (Figure 45) in flight No. 1. On orbit, the Power Module launch package is rotated out of the cargo bay and berthed at the Docking Module with the SRMS. The SRMS and OCP is then used to mate the mounting flange at the center of each of the two support beams with the gimbal fitting on the outboard end of each of the two telescoped cylinders. The telescoped sections are then extended and the flanges on the inboard ends secured. The radiator panels are then deployed by the OCP. The OCP checks out the entire assembled PM and then, with the SRMS deploys the functional assembly into orbit. The scenario for this sequence is depicted in Figure 46.

The SCM is stowed in the Shuttle payload bay in two sections. The cylindrical pressure vessel is placed in the forward part of the payload bay and the MRWS crane turret aft of the cylinder in Figure 41. The crane arms being folded compactly to fit within the payload envelope.

On orbit, the SCM is lifted out of the cargo bay and berthed to the Power Module with the SRMS. The SRMS is then used to lift the MRWS crane turret from the payload bay and with the aid of the OCP is berthed to one of the radial ports on the SCM core module. The SRMS grasps the crane turret and delivers it to the SCM core where the astronaut on the OCP make the attachments. The OCP assembles the 35-m cranes with the aid of the SRMS and attaches them to the crane turret. The last item assembled is the two-man open cherry picker to one of the SCM crane arms. This scenario is depicted in Figure 47.

The top level functional requirements for the open cherry picker are summarized in Figure 48 for the PM buildup and in Figure 49 for the addition of the SCM to the PM. Functions 1.0 through 6.0 are similar to those discussed previously. It should be configured to optimize astronaut reach to remote buildup areas, and it should also have a stabilizer at its base to secure the cab during performance of tasks. In this stowed position, it should be located close to the Shuttle egress hatch to minimize the EVA travel distance.



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OPEN CHERRY PICKER FUNCTIONS

- DIRECT MOVEMENT OF SRMS IN TRANSPORTING ELEMENTS
- PERFORM ALIGNMENT & BERTHING OPERATIONS
- REMOVE PROTECTIVE COVERS
- BERTH & FASTEN CRANE TURRET
- BUILD UP 35-m CRANE ARMS
- ATTACH CRANE ARMS TO CRANE TURRET
- BUILD UP SCM TWO-MAN OPEN CAB CHERRY PICKER
- ATTACH OCP TO CRANE
- C/O COMPLETE ASSEMBLY
- ASSIST SRMS IN LAUNCHING SCM IN ORBIT

Figure 44. Assembly of SCM to Power Module – Flight No. 2

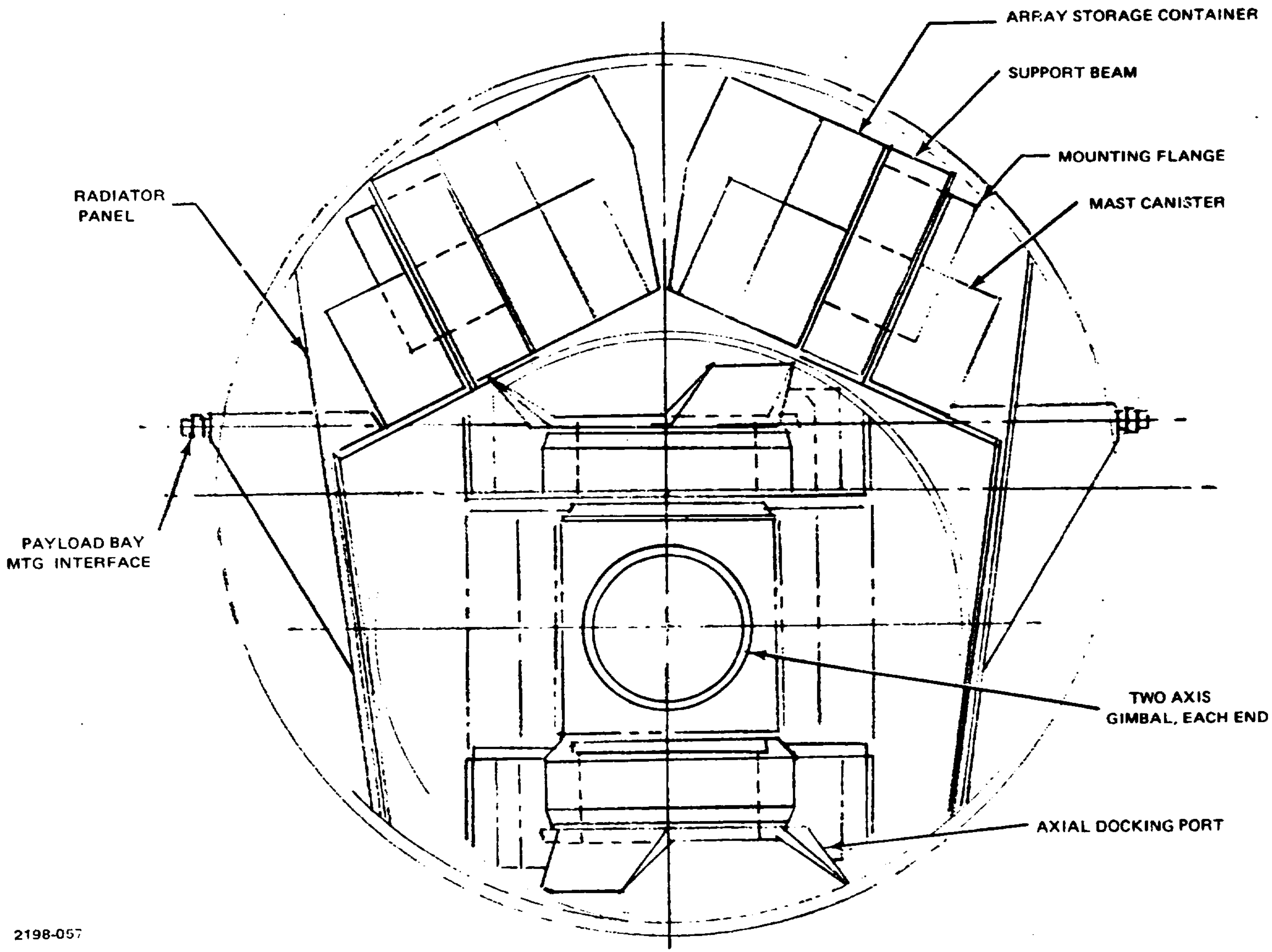


Figure 45. Power Module Launch Package

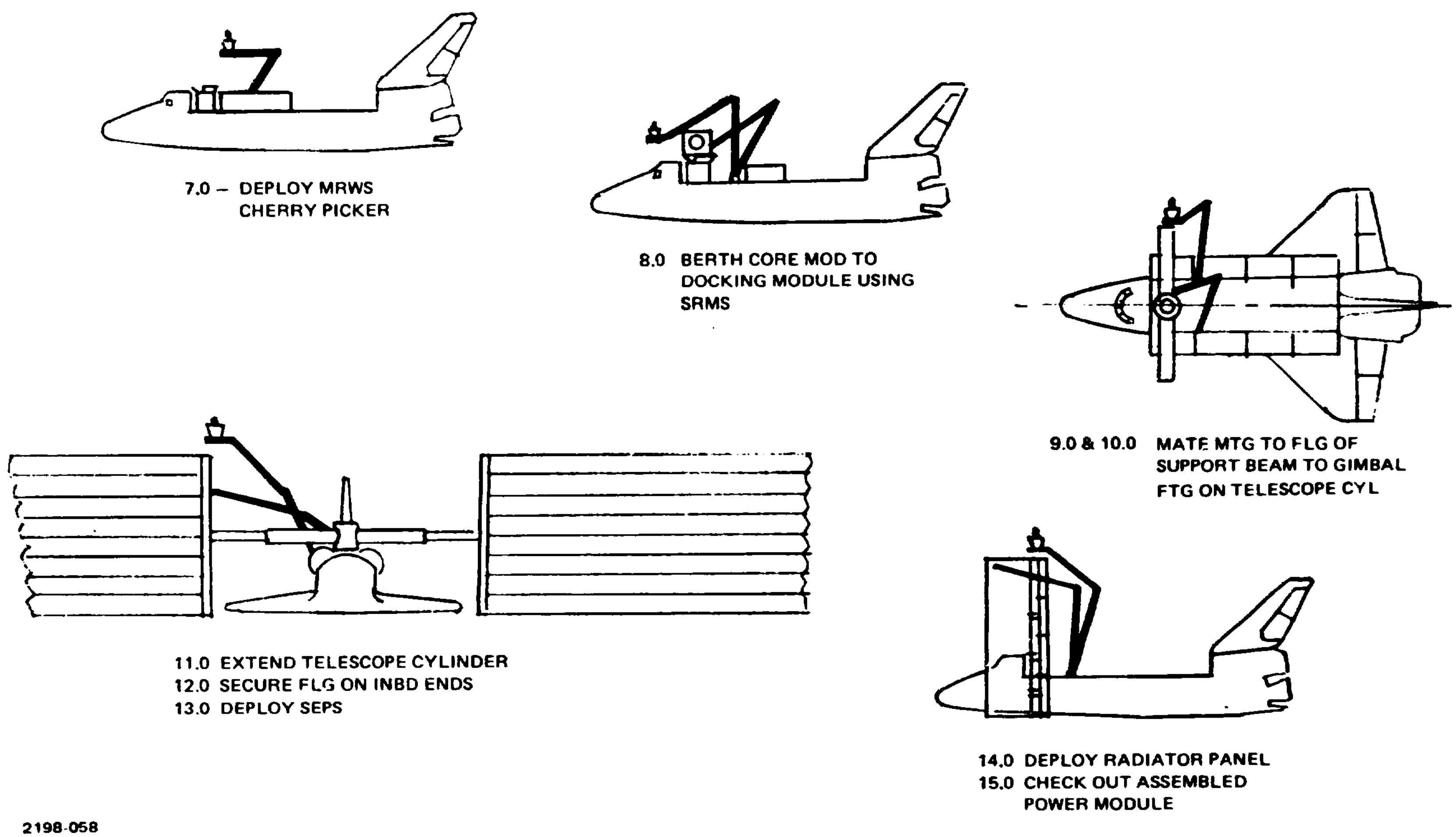


Figure 46. Power Module Deployment Scenario — Flight No. 1

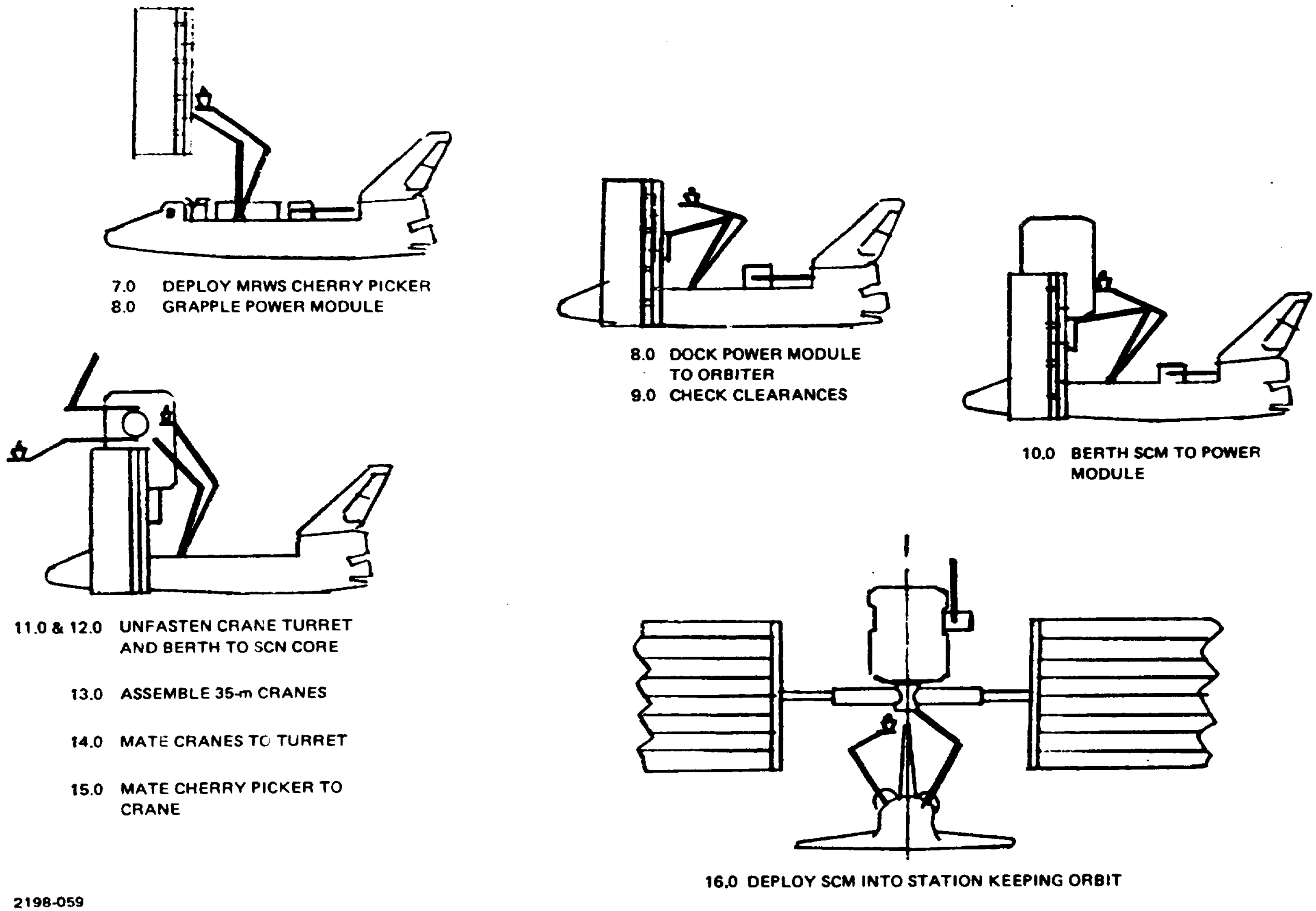


Figure 47. SCM Deployment Scenario – Flight No. 2

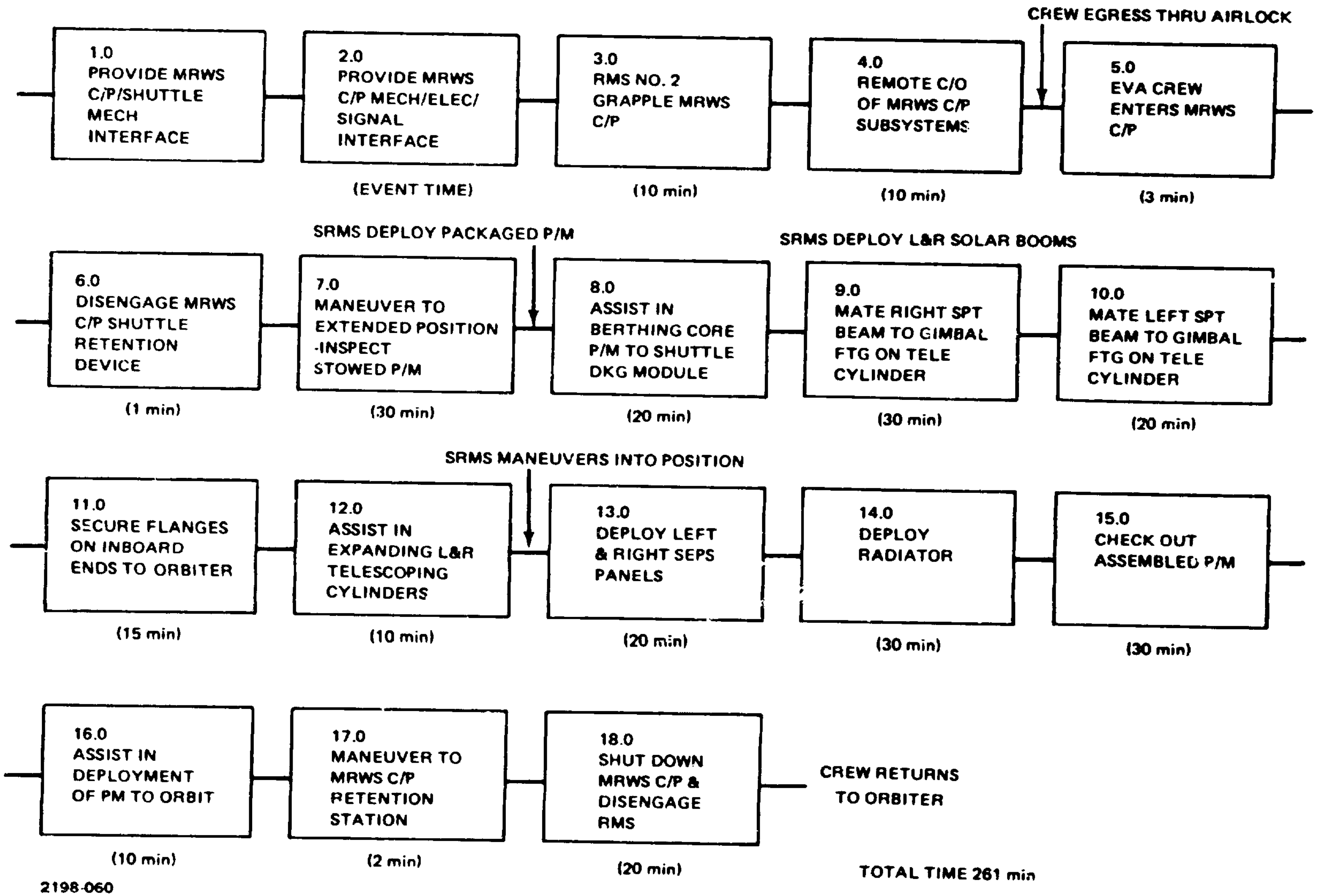


Figure 48. Open Cherry Picker Functions – Space Construction Base Deployment (Flight No. 1)

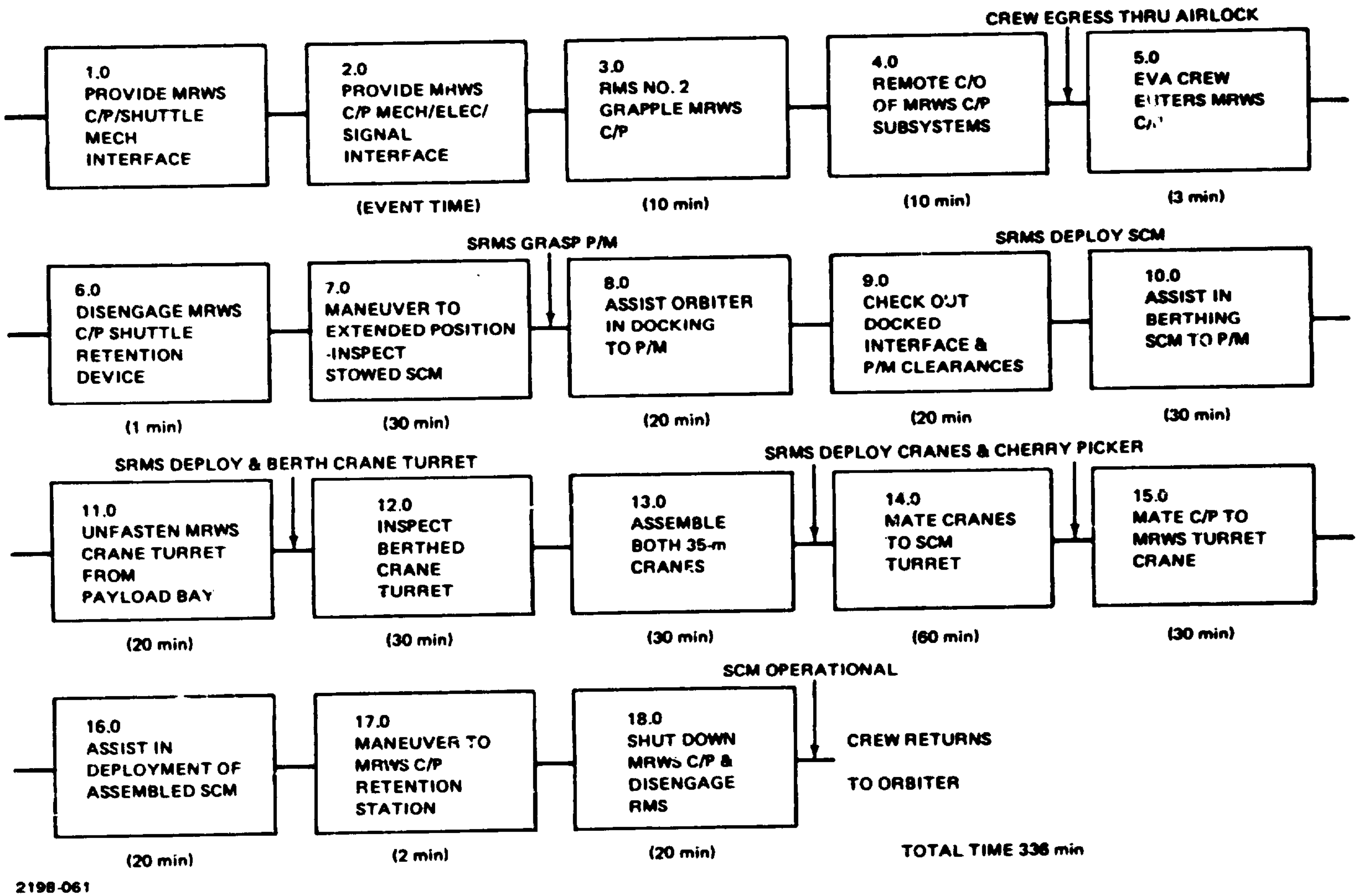


Figure 49. Open Cherry Picker Functions – Space Construction Base Deployment (Flight No. 2)

1.5.4 Task Analysis - Mating Right Support Beam to Gimbal Fitting on Telescope Cylinder

Figure 50 delineates the mission scenario for the OCP operations during the mating of the support beam to the gimbal fitting on the right telescoping cylinder (Function 9.0, Figure 49). During this sequence of operations, there is a significant interplay between the cherry picker and SRMS. Increased performance can be achieved by giving the OCP override control of the SRMS during close quarter operations.

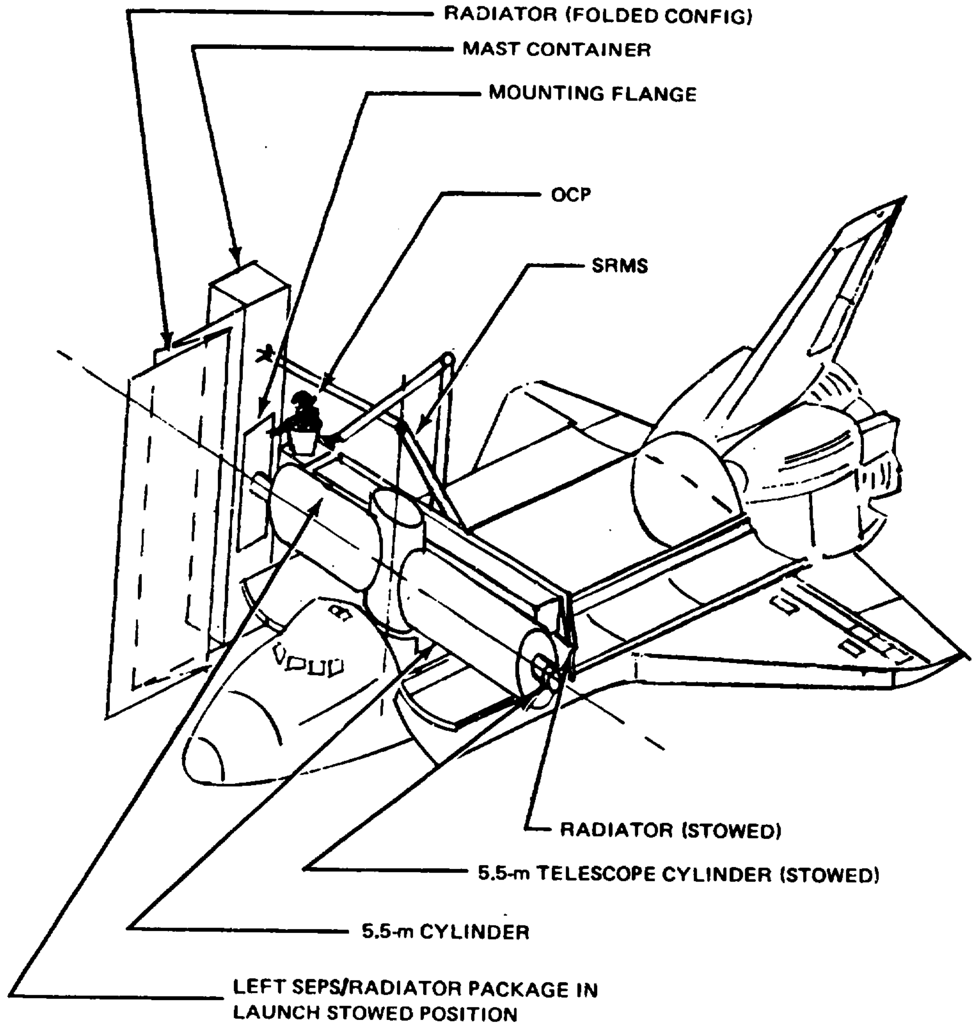
1.5.4.1 Accessibility - Attachment of the SEPS/RADIATOR container to the gimballed fitting on the telescopic cylinder of the P/M core is a coordinated effort between the SRMS crane and the SRMS open cab cherry picker. The SRMS crane delivers the large package to the vicinity of the stowed telescopic cylinder. The Astronaut in the C/P moves in close to the gimbal fitting, then informs the Orbiter crane operator that he has taken control of the SRMS crane. Initially he acquired a hard point on the large 15.5-m cylinder with the stabilizer, thereby stabilizing his platform. With controllers in the OCP, he moves the large container into position. Any small angular corrections can be made with his hands. The large container is moved further until the mounting bolt holes are aligned. Using appropriate tools, stored in the OCP, he fastens the two units together to proper torque values.

Be mounting the open cab on its keel and providing an open platform, the visual and reach accessibility is optimized. Properly designed foot and waist restraints will permit the Astronaut free use of both hands during this task. Figure 51 depicts a design that meets the requirements described herein.

1.5.4.2 Items to be Handled - The elements to be handled in this operation are:

- SEPS array storage package and folded radiator panel
  - 12 m x 1.7 m x 16.0 m, 1245 kg
- Torque wrench.

1.5.4.3 Operations - The removal of the right-hand SEPS array and folded radiator panel from its launch position on the 15.5 m cylinder and its installation to the gimbal fitting on the telescopic cylinder (Function 9.0, Figure 49) can be performed within the approximate time-line as shown in Table 13.



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FUNCTION REQUIREMENTS

9.1 – SRMS GRASP RIGHT SOLAR ARRAY PACKAGE

9.2 – OCP UNFASTEN PACKAGE FROM MTG FLANGE ON 15.5-m CYLINDER

9.3 – OCP GUIDE SRMS MOVEMENT TO TELESCOPE FITTING

9.4 – OCP PREPARE MOUNTING FLANGE FOR ATTACHMENT

9.5 – OCP GUIDE SRMS MOVEMENT TO EFFECT ATTACHMENT TO GIMBAL FITTING ON TELESCOPE CYLINDER

9.6 – OCP SECURE MATED PARTS

9.7 – OCP CHECK OUT SEPS CONTAINER & FOLDED RADIATOR FOR CLEARANCE

Figure 50. Open Cherry Picker Requirements – Function 9.0 – Mate Right Support Beam to Gimbal Fitting on Telescope Cylinder

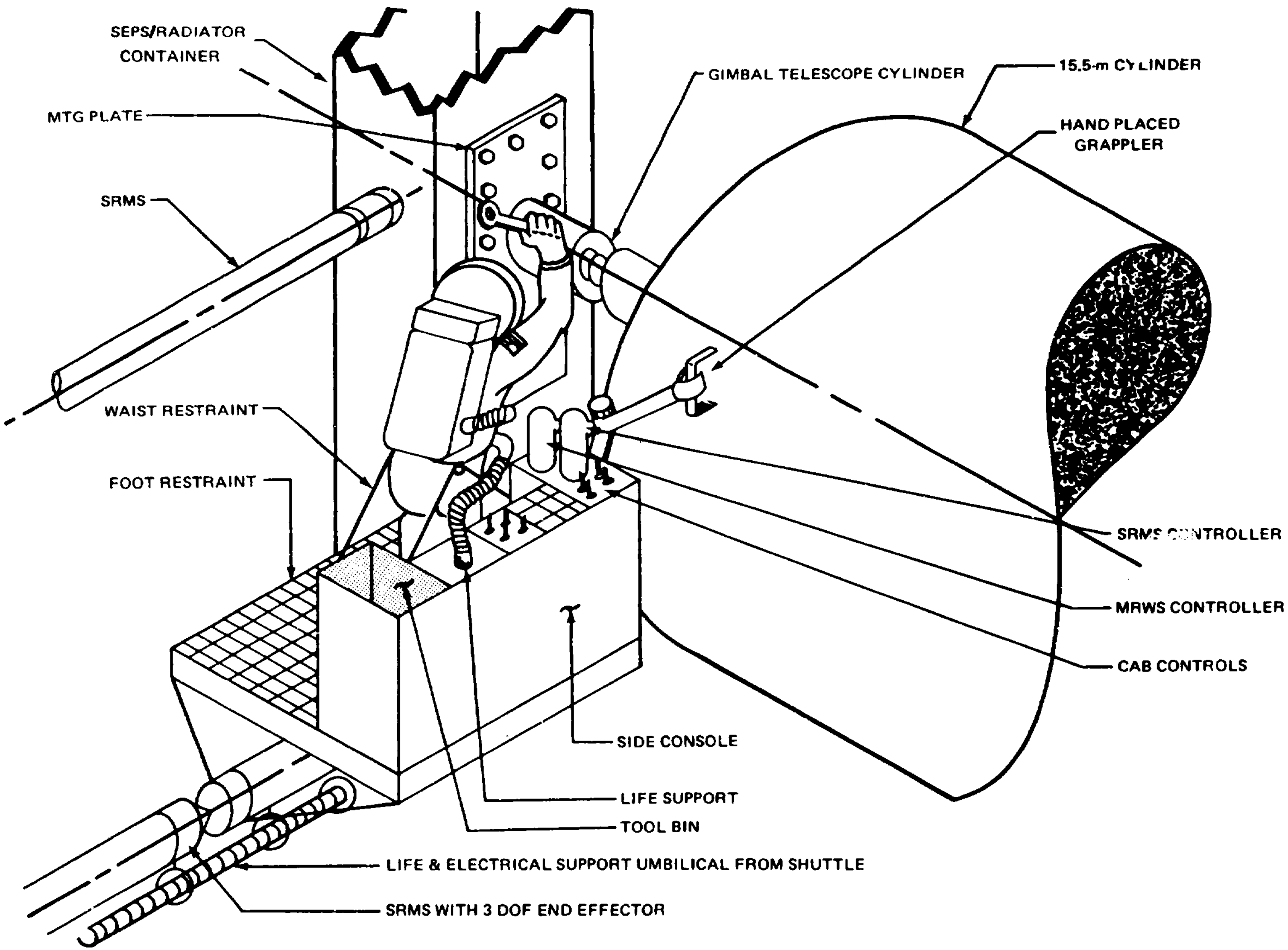

Figure 51. Open Cab Cherry Picker (Performing Function 9.0—Figure 49)

TABLE 13

MATING RIGHT SUPPORT BEAM TO GIMBAL FITTING TIME-LINE

FUNCTION	ΔT (min)	OPERATION
9.1	1	SRMS GRASP RIGHT SOLAR ARRAY PACKAGE
9.2	5	OCP UNFASTEN PACKAGE FROM 1.5m CYLINDER
9.3	5	SRMS MOVE PACKAGE TO GENERAL REA OF GIMBAL
9.4	2	OCP PREPARE MOUNTING FLANGE FOR ATTACHMENT
9.5	2	OCP GUIDE SRMS MOVEMENTS TO EFFECT ATTACHMENT
9.6	10	OCP SECURE MATED PARTS
9.7	5	OCP CHECKOUT SEPS CONTAINER & FOLDED RADIATOR FOR CLEARANCE
	30	TOTAL

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1.5.5 Additional Open Cherry Picker Design Requirements

None

1.5.6 Additional Issues to be Resolved

None

1.5.7 References

- McDonnell Douglas Corp. Space Station Systems Analysis Study Part 3: Documentation. Volume 3, July 1977.
- Zero-G, Workstation Design. ISC Internal Note No. 76-EW-1, June 1976.
- Crew Station Specification. MSC-07387, October 1972.

1.6 SPACE TELESCOPE

1.6.1 Mission Description

The space telescope is to orbit the earth at a nominal altitude of 500 km (311 mi). At that height, above the optically degrading effects of the earth's atmosphere, the orbiting observatory is expected to detect celestial objects 50 times fainter and seven times more distant than can be seen by earth-based telescopes. Its angular resolution will be about 10 times better than that of ground-based systems, and it will be able to observe across a continuous spectrum ranging from 1000 angstroms in the far ultraviolet to 1 micron in the near infrared.

The telescope's capability may let scientists see to the very edge of the universe, offering views of galaxies so distant they will be seen as they were when the universe was formed nearly 14 billion years ago, according to some theories. By contrast, the 200-in. telescope at Mt. Palomar, California, can penetrate to a distance estimated at 2 billion light years, which means that the images it provides originated 2 billion years ago.

Operations supporting the scientific observations function in three distinct segments: Optical Telescope Assembly (OTA), Scientific Instruments (SI), and Support Systems Module (SSM). The SSM provides the overall spacecraft support consisting of communication and data management, pointing and stabilization, power and thermal control. The OTA interacts in basic support through the fine guidance sensor. In addition, the OTA requires periodic alignment, focusing, and calibration. The instruments which make up the Space Telescope -SI- have their own sequence consisting of warmup, calibration, standby, observation, and readout. All instruments to be used for the observation are prepared so that they are ready at the preselected time. The Space Telescope (ST) line of sight is slewed to the target, based on the acquisition of two guide stars by the fine guidance sensors and the pointing control system. For certain instruments, a more accurate alignment must be made and the target must be aligned with certain tolerances with respect to the instrument. This is normally accomplished through ground control from the Mission Operations Center. The observation can then be initiated and data either stored in a tape recorder or transmitted directly to Spacecraft Tracking and Data Network Ground Stations or one of two Transmission Data and Relay Satellites. The targets may be viewed for duration ranging from a fraction of a second to several hours. For long observations, interruptions in the observation must be made, either because some targets can only be observed in the shadow portion of the orbit, or due to occultation of the target by the earth. In addition, passage through the South Atlantic Anomaly will require interruptions of observations due to background noise.

1.6.2 Spacecraft Description

Space telescope support systems module, Figure 52 in a partially disassembled state, will house the telescope optics in the forward shell and the scientific instruments in the aft shroud. The equipment section contains the attitude control, communications, data recording and handling and - except for external solar array - electrical power systems. Note the remote manipulator grappling fixture on the equipment section and tip docking probe points on the end of the aft shroud - used respectively in deploying and retrieving the telescope, and positioning it in the space shuttle

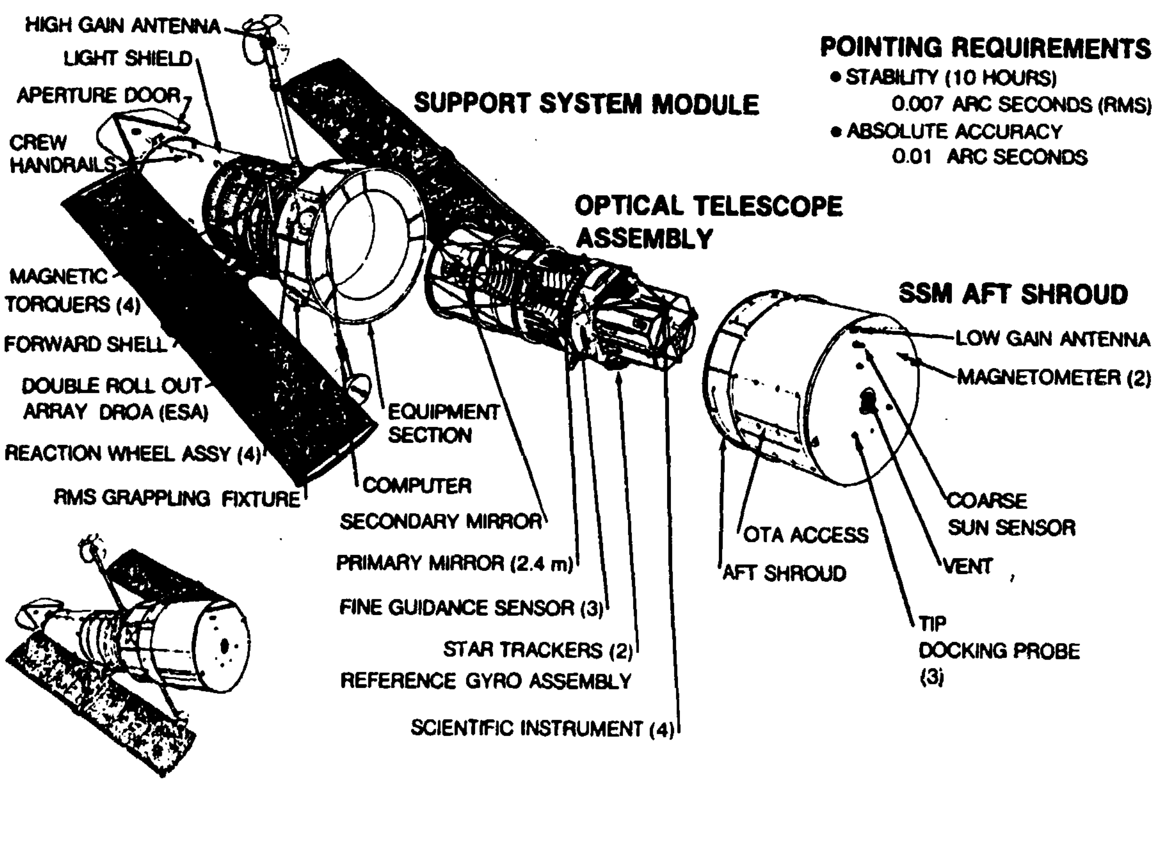

Figure 52. Space Telescope

cargo bay during periodic maintenance. Arrangement of the space telescope optics and sensors inside the support systems module is illustrated. The telescope is designed to accommodate up to five sensor packages - four mounted longitudinally in a cluster about the optical axis, and one mounted radially to receive information by means of a tilted mirror at the focal plane.

1.6.3 Support Functions and Mission Scenario

The space telescope is designed to be serviced in orbit by EVA astronauts. An open cherry picker MRWS would be an ideal support item because it transports the astronaut to the service site, provides a work platform, and is able to carry replacement units and tools.

Figure 53 is the space telescope Orbiter functions. Function 9.0 Service Space Telescope has been detailed to lower levels for service/replacement of components. Orbital functions are shown in Figures 54, 55, and 56; Deployment/Retrieval/Orbital Re-boost; Unscheduled and Scheduled Space Telescope Maintenance. Some of the servicing operations are illustrated in Figure 57, radial and axial scientific instrument changeout, and orbital replacement units (ORU's) changeout.

1.6.4 Task Analysis

The berthing platform is located in the aft section of the Orbiter payload bay within reach of the RMS. The platform rotates the ST to any orientation that is convenient for servicing operations. Items to be handled are listed in Figure 58, including size and mass. These items are removed from the Space Telescope, replaced by new units, and stowed in the payload bay.

The operations associated with replacing ORU's are shown in Figure 59 and the time for replacing four ORU's is approximately 1-½ hr (Table 14).

1.6.5 Additional Open Cherry Picker Design Requirements

- Replaceable unit handling equipment must be designed for the large items listed in Figure 58. Also guides may be required to remove/install these oversized items
- A carousel for smaller electronic boxes similar to that shown in Figure 59
- Accommodations in the tool box for the tools necessary to remove/fasten components

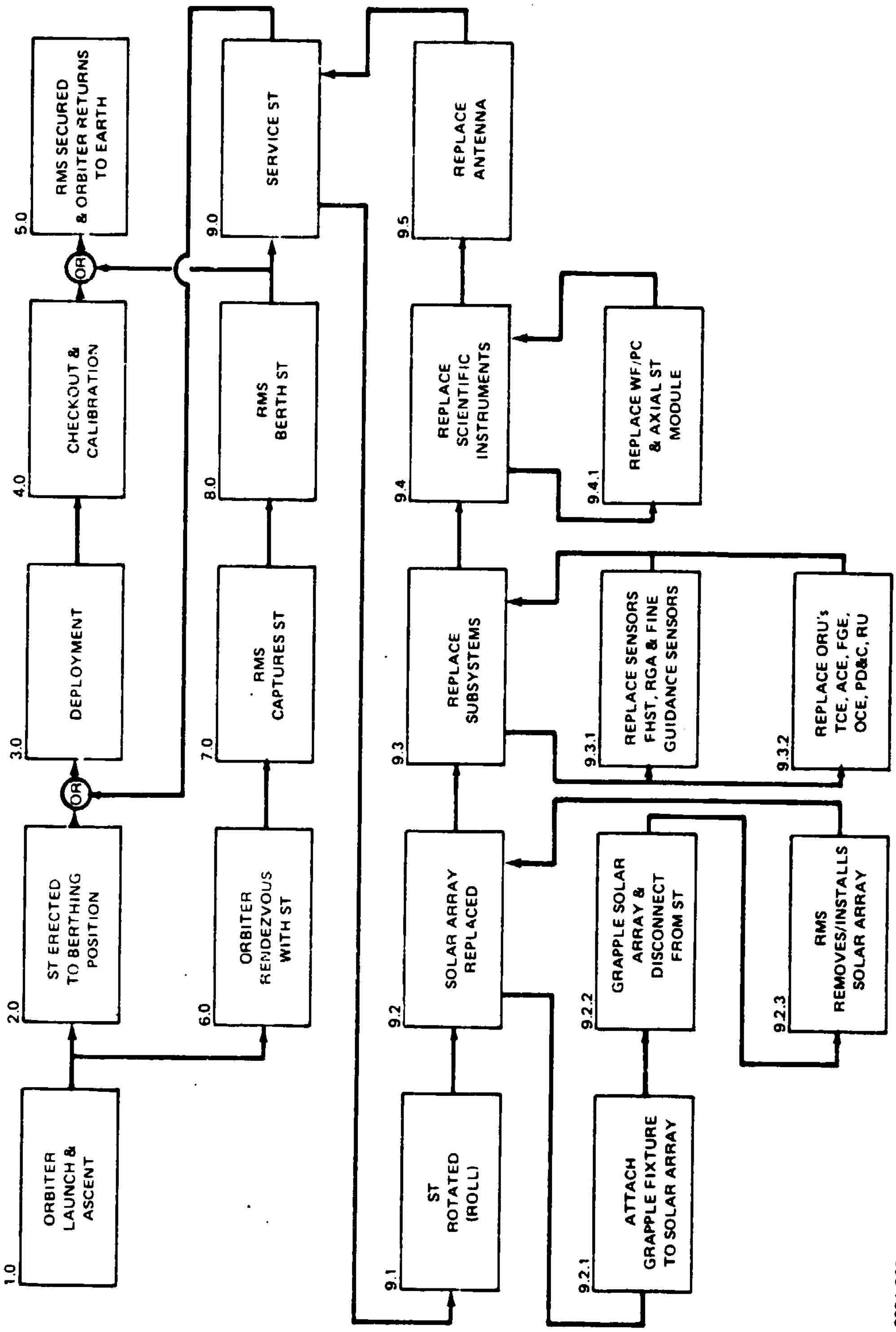

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Figure 53. Space Telescope (ST) Orbiter Functions

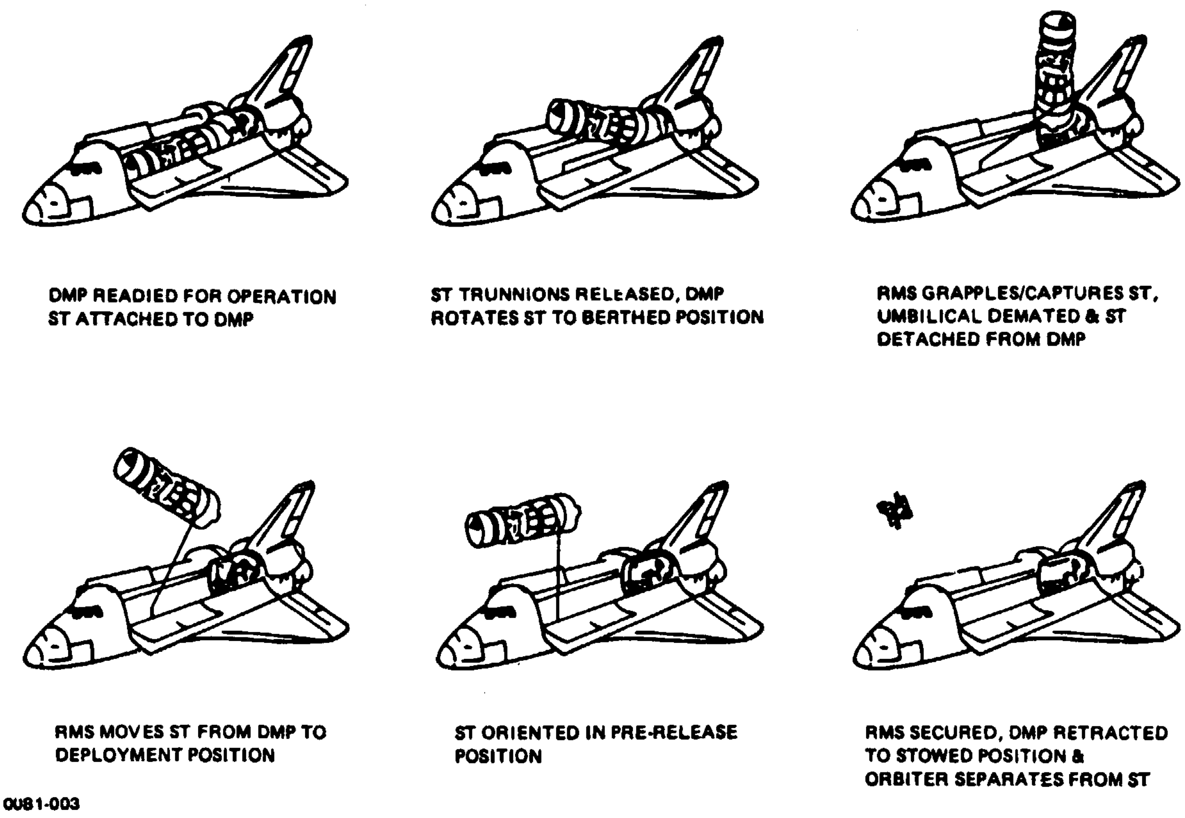

Figure 54. Deployment Retrieval/Orbital Re-Boost

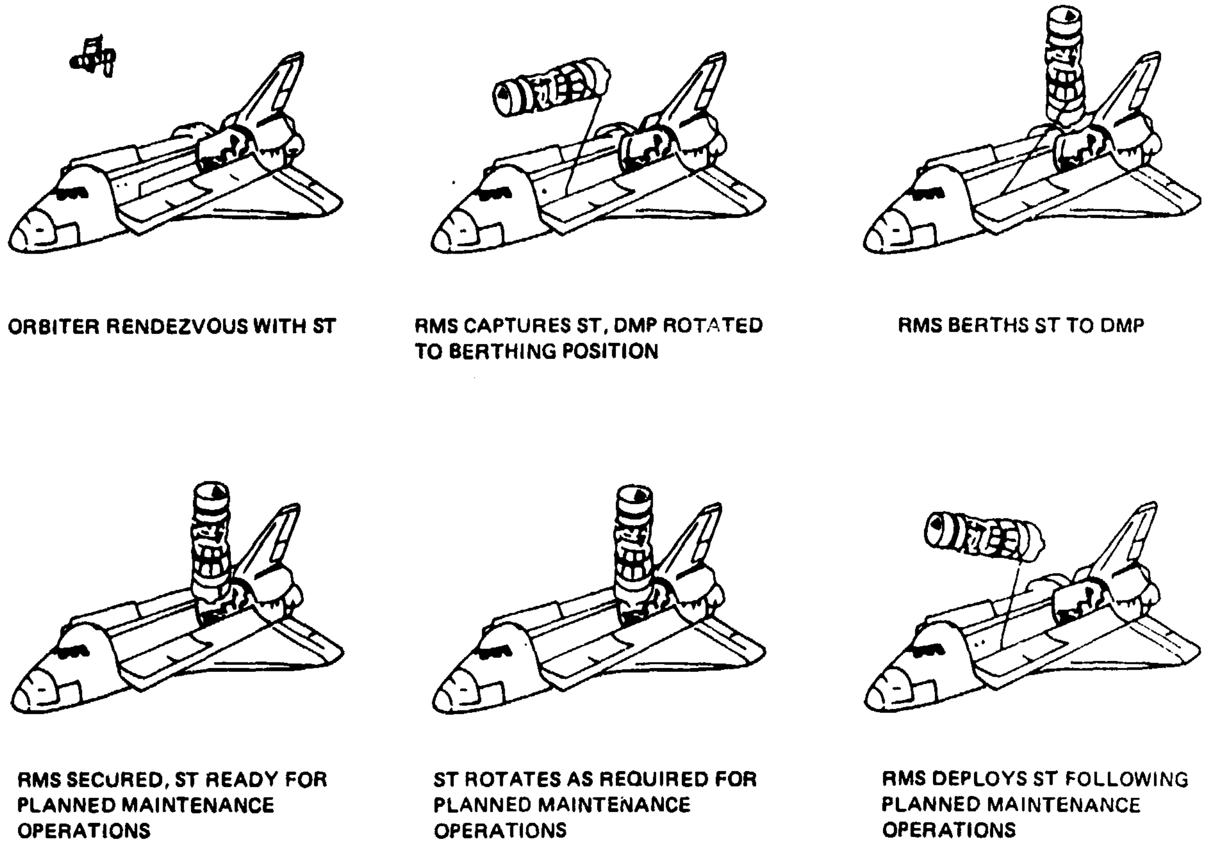

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Figure 55. Space Telescope On-Orbit Planned Maintenance

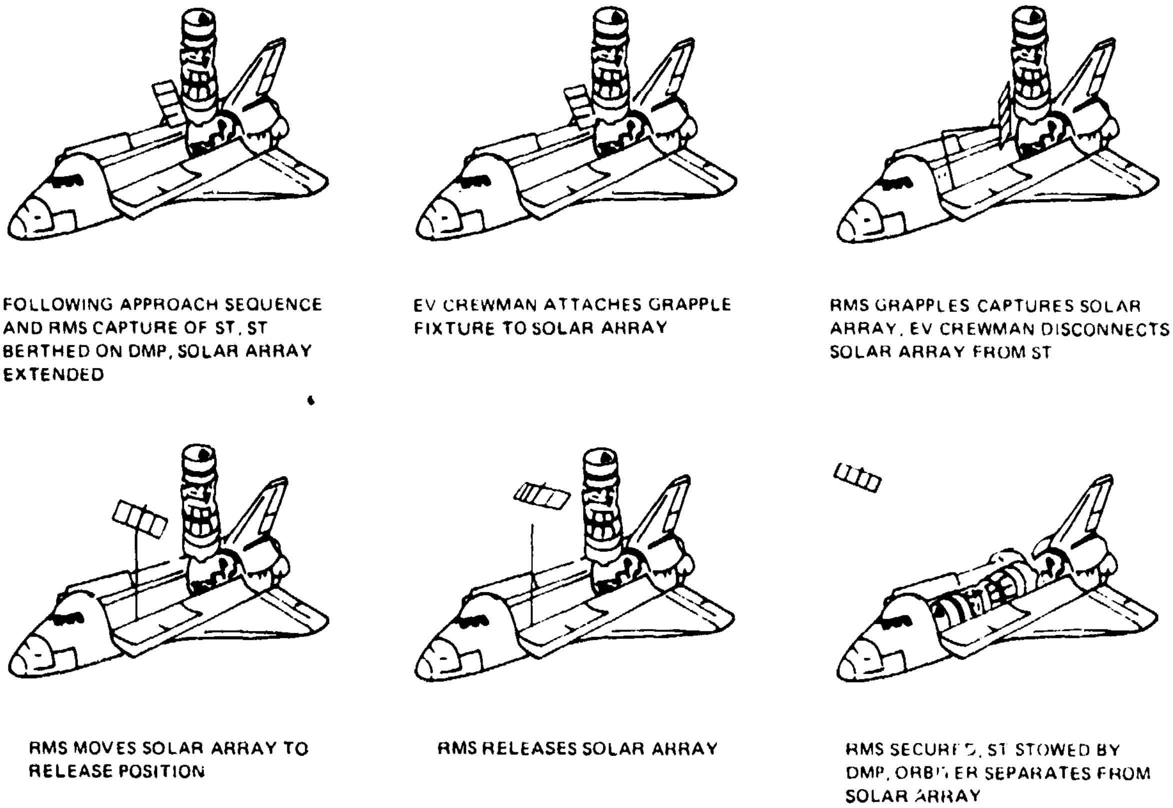

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Figure 56. Space Telescope On-Orbit Unscheduled Maintenance

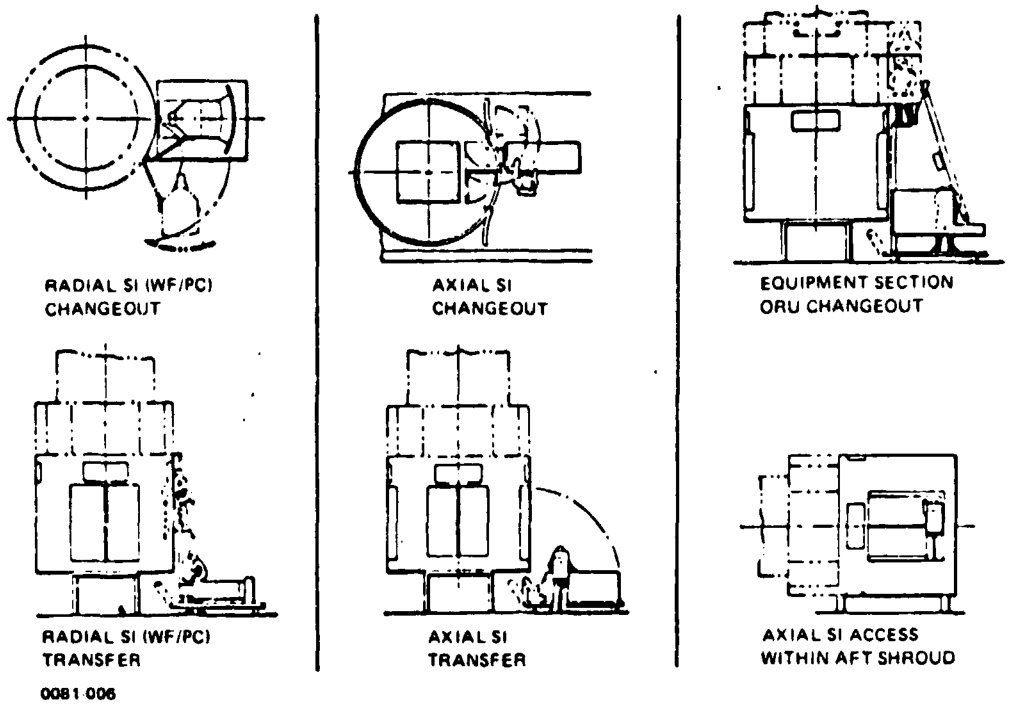
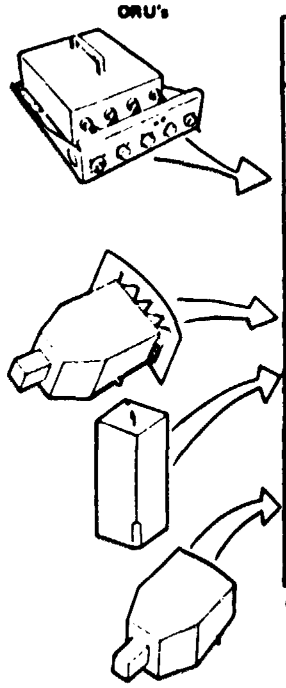


Figure 57. Equipment Changeout



	ORBITAL REPLACEABLE UNITS	QTY	SIZE (in.)	WEIGHT (lb)
ELECTRONICS	TCE	2	26x20x7	69
	ACE	1	37x10x7	54
	FGE	3	7½x10x7	32
	OCE	1	21x10x7	25
	PD&C	1	25x10x7	40
	RU	4	32x7x7	8
SCIENTIFIC INSTR.	WF/PC SCIENTIFIC INSTR.	1	31x84x88	500
	AXIAL SI MODULE	4	36x36x87	700
SENSORS	FINE GUIDANCE SENSOR (FGS)	3	21x44x74	TBD
	REFERENCE GYRO ASSEMBLY	3		TBD
	FIXED HEAD STAR TRACKER	3		TBD

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Figure 58. Items to be Handled

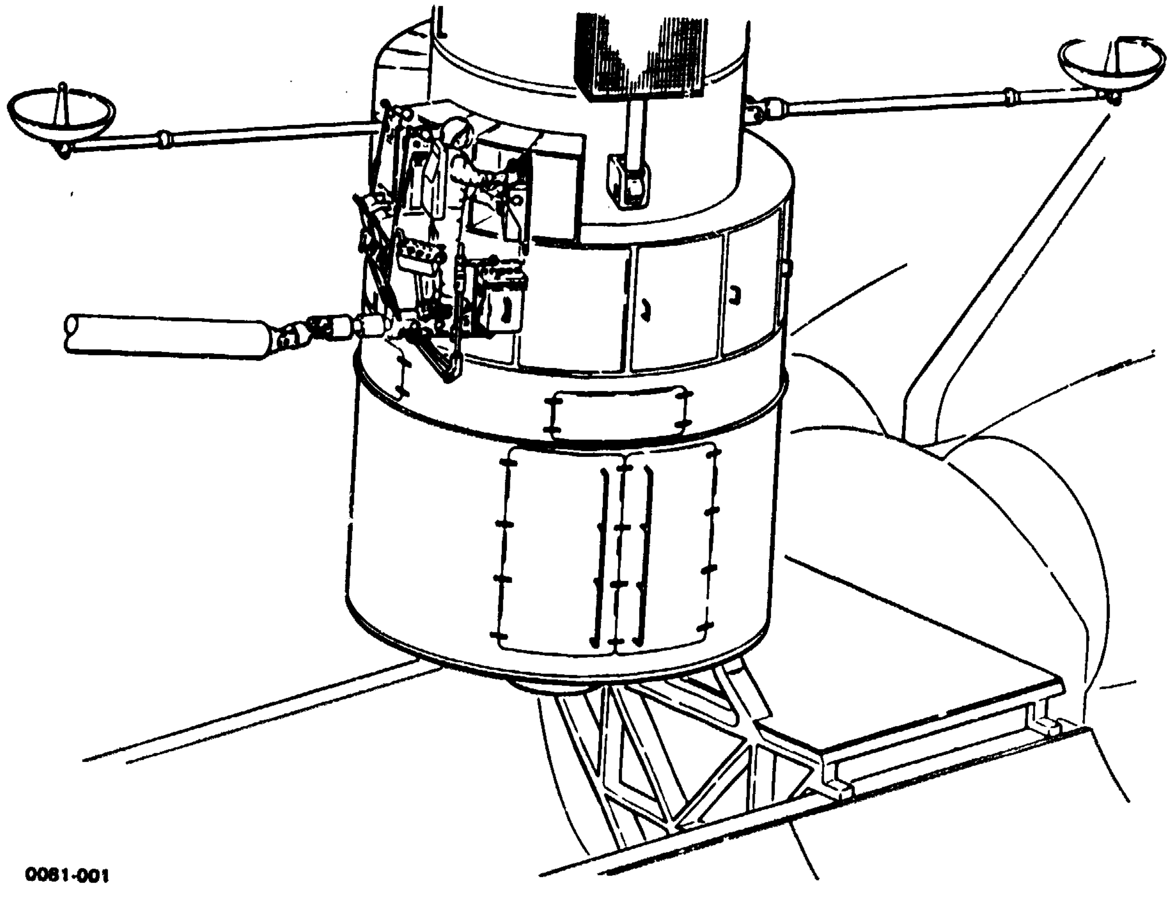

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Figure 59. ORU Changeout

TABLE 14

TIME FOR REPLACING FOUR ORU's

TIME (min)	OPERATION
1.0	TRANSLATE TO ORU STORAGE
20.0	REMOVE 4 ORU's & MOUNT ON OCP HANDLING FIXTURE
1.0	TRANSLATE TO ST EQUIPMENT SECTION
2.0	RELEASE ORU DOOR
20.0	REMOVE 4 ORU's FROM DOOR & MOUNT ON OCP HANDLING FIXTURE
20.0	INSTALL REPLACEMENT ORU (4) ON DOOR
2.0	SECURE DOOR
1.0	TRANSLATE TO ORU STOWAGE
20.0	STOW 4 ORU's
87.0 = 1 hr: 27 min TOTAL	

0081-009

- An extension may be required to the RMS with another wrist joint to permit reaching in the aft section of the Orbiter payload bay.

1.6.6 Additional Issues to be Resolved

- Definition of large equipment handling device
- Stowage location of replaceable components.

1.6.7 References

- LMSC-D495154, Space Telescope Support Systems Module Phase B Definition Study. Lockheed Missiles & Space Co. Inc., 15 March 1976.
- Space Telescope Briefing to Astronaut Bruce McCandlass. Marshall Space Flight Center, 7 November 1978.
- Aviation Week & Space Technology, 8 August 1977.

Section 2

MID-TERM MISSIONS

During 1977, three studies were performed to define concepts for a space construction base with a planning IOC of 1985. All three studies identified the need for an MRWS in the role of a crane turret, open cherry picker, or closed cabin (pressurized) cherry picker.

The three space construction base (SCB) concepts that evolved from these studies are shown on Figure 60. The Strongback concept, that evolved from the MDAC, Space Station Systems Analysis study (SSSA) (NAS 9-14958) utilizes a combined crane and open cherry picker mounted to a fixed crane turret. In this construction concept, the work is moved to the construction equipment requiring, in some instances, a mission-peculiar jig with three degrees-of-freedom to place all parts of the work within reach of the construction equipment. The second concept, labelled ET, utilizes an expended Shuttle external tank as a work platform, and utilizes a railed closed cabin cherry picker. In this concept, from Grumman's SSA study (NAS 8-31993), the construction equipment is given one degree-of-freedom to reach the work. In the third approach, evolved in the Orbit Construction Demonstration Article (OCDA) study (NAS 9-14916), a closed cabin cherry picker is mounted to a rotating long boom providing two degrees-of-freedom to position the construction equipment relative to the work. In this case, mission-peculiar jigs require one degree-of-freedom for equipment access to all parts of the work.

In all three approaches, a crane arm length of approximately 35 m was defined. This selection is supported by the results of a study presented at the combined AIAA/ASME 19th Structures, Structural Dynamics Material Conference and entitled Space Platforms (C.J. Goodwin). The seven representative structures with 12 distinct construction tasks (Table 15), were analyzed to determine the work platform length and crane length needed to reach all parts of the work. In all cases, the appropriate degree-of-freedom in the work fixture was used. The results of the equipment access study is

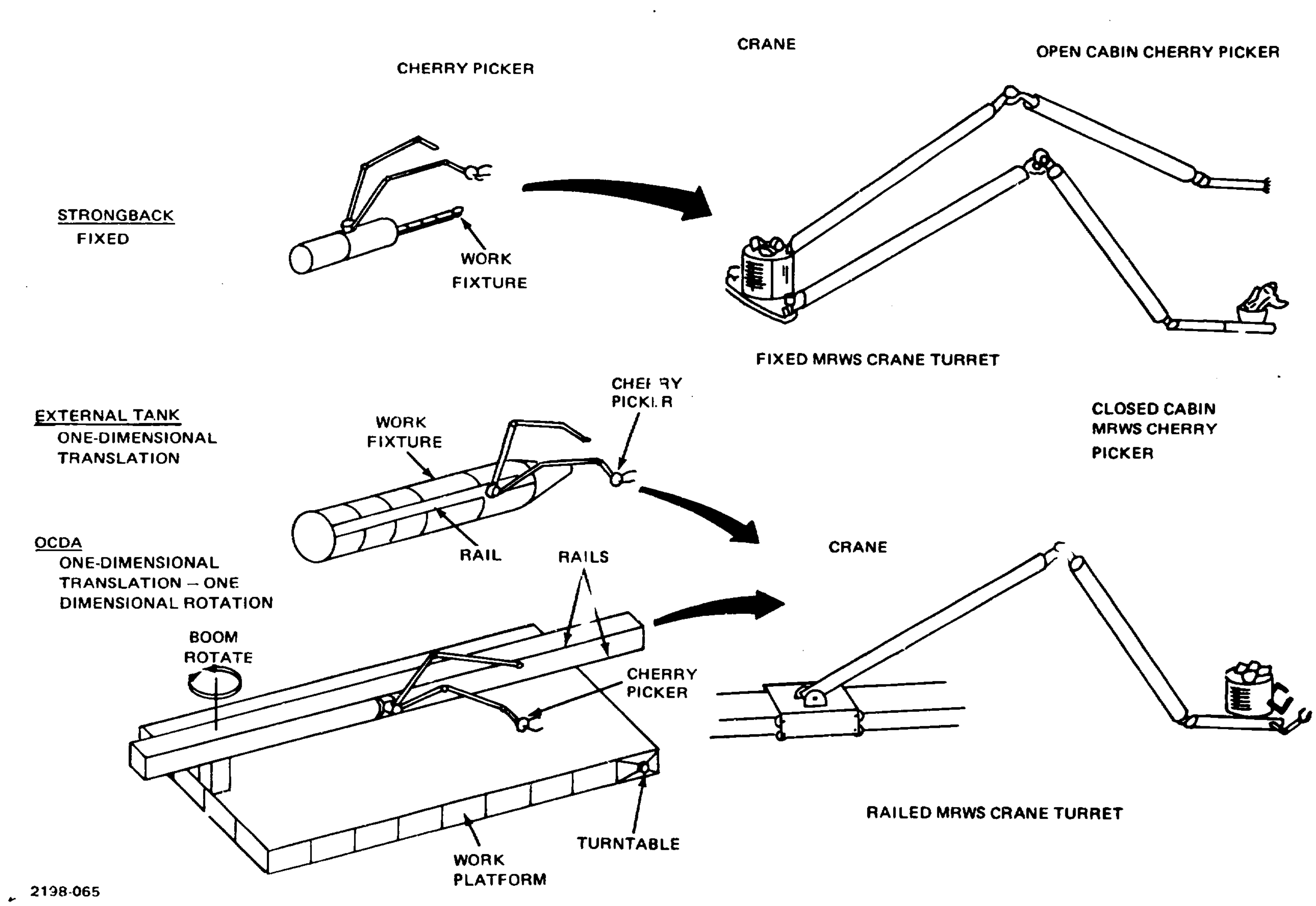
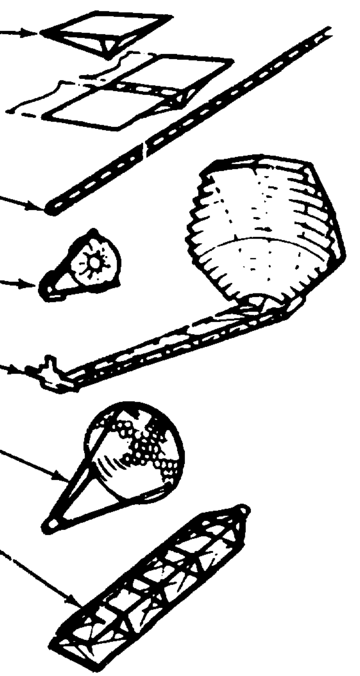


Figure 60. Identified Uses of MRWS in Support of Construction in the 1985 to 1990 Time Frame

TABLE 15

REPRESENTATIVE LSS USED FOR CONSTRUCTION SYSTEM SIZING

DESCRIPTION		EVENTUAL ORBIT	MASS (kg x 10^3)	SIZE (m)
250 kW SOLAR ARRAY	PWR FOR SP STA	29° 400 km	2	50 x 50
2 MW SPDA MODULE	4 REQ	GEOS	4	111 x 50
1 km MAPPING ANTENNA		GEOS	5	1000 x 3
83 kW BRAYTON SOLAR COLLECTOR	PWR FOR SP STA	28° 400 km	10	30 DIA 40 L
RADIOMETER		55° 400 km	75	100 DIA 200 L
PSP 1		GEOS	28	60 DIA 70 L
600 kW SPDA		GEOS	15	32 W 140 L



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summarized in Figure 61 for a railed platform arrangement similar to the ET arrangement shown in Figure 60. To achieve access to all parts of the work, a crane reach of at least 30 m, a work platform length of at least 65 m, and a single DOF jig is required. A similar assessment of the fixed base equipment concept indicates that a crane reach of at least 30 m is required as well as a jib that provides 2 DOF.

The above results are highly dependent upon the dimensions of the mission articles assumed. Final selection of a construction equipment approach must wait until these mission articles are clearly defined. Therefore, both the fixed base and railed concepts should be evaluated for MRWS requirements for the mid-term (1985-1990) time phases.

The large structures mission articles that are candidates for construction in the mid to late 1980's fall into the general catagories of:

- Solar Power Development Articles
- Large Antennas.

To achieve a balanced mix of mission articles and construction approach in the MRWS task analysis, the missions shown in Figure 62 were used. The Strongback concept, with an MRWS crane turret and the construction of two Solar Power development articles, and the OCDA concept, with a railed cherry picker, were analyzed for construction of a 100-m radiometer and a 61-m multibeam communications antenna.

2.1 MICROWAVE POWER TRANSMISSION DEVELOPMENT ARTICLE (TA-1)

2.1.1 Mission Description

For a commitment to be made to SPS, demonstration of technical capability and economic feasibility is required. Answers are required to fundamental questions on the cost of fabricating large structures in space, the practicality of large-scale energy collection and microwave transmission, the control of radio frequency interference effects, and other critical issues. Then, if a commitment decision is made, a development program must be initiated.

Accordingly, a minimum system capable of resolving many critical technology issues at the lowest possible cost was derived during the SSSA

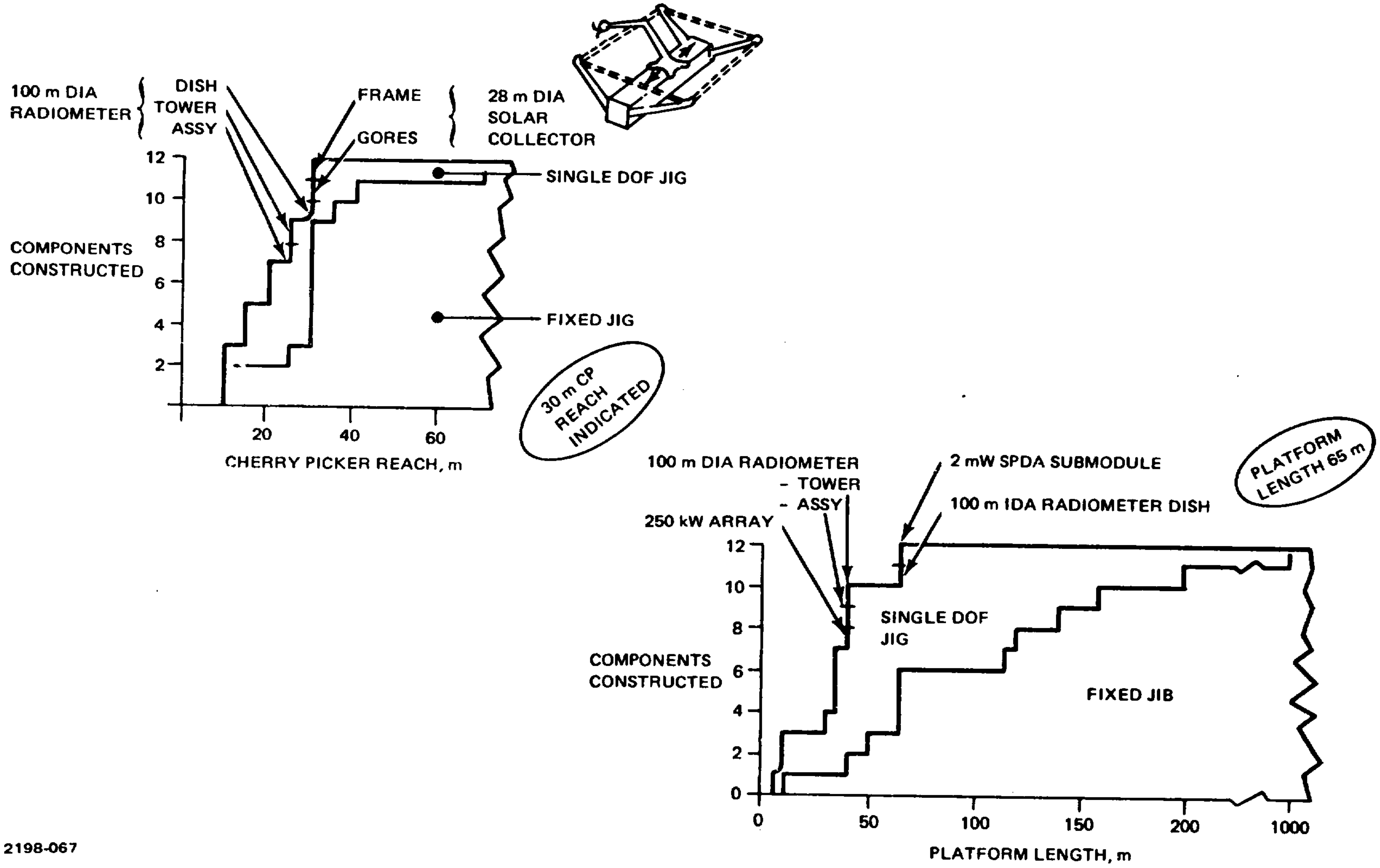

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Figure 61. Representative Large Space Structure Used for Construction System Sizing

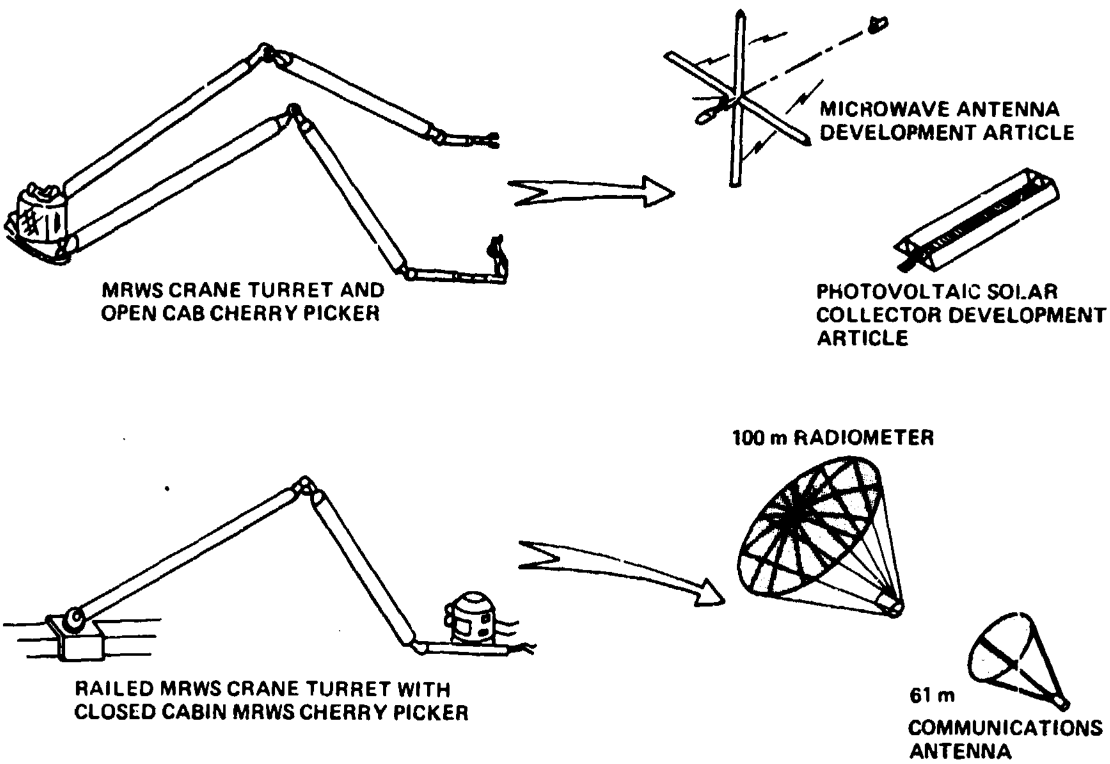


Figure 62. Representative Missions Used for MRWS Task Analysis

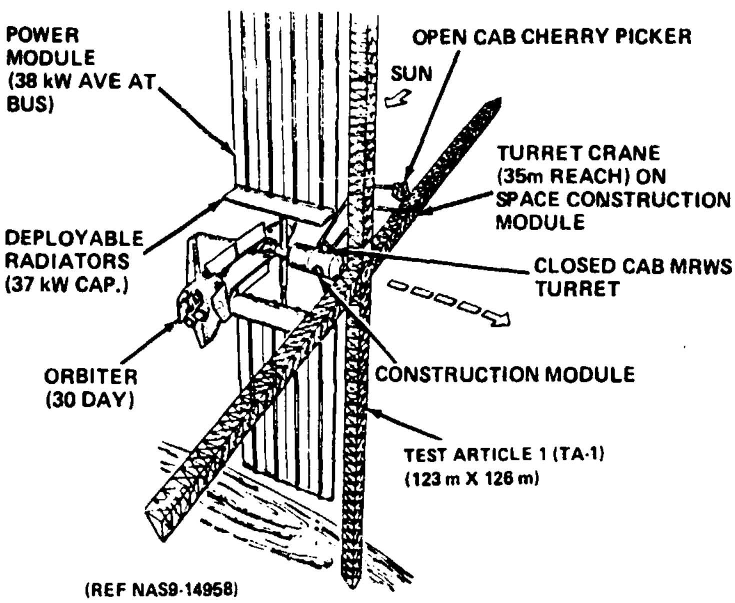
studies (NAS9-14958) and was designated Test Article-1 (TA-1). This would be followed by a second test article (TA-2), which would provide cost data and information pertinent to the determination of how an SPS might be fabricated and assembled on orbit, as well as key end-to-end functional verification of such issues as two-dimensional phase control and the thermostructural effects.

2.1.2 Spacecraft Description

The TA-1 antenna consists of two long, crossed arms mounting pairs wave guides, amplitrons, and phase control electronic units. The horizontal arm is 123 m long and the length of the vertical arm is 126 m. To minimize the cost of TA-1, the arms are fabricated and assembled on the ground in lengths compatible with the Orbiter cargo bay.

After the orbital berthing of the power module and the space construction module, the construction may proceed to the assembly of the TA-1 antenna system. The assembly is accomplished in a Shuttle tended mode using both 35-m cranes on the space construction module. One crane is used to transport structure while the other supports the open cherry picker. The completed TA-1 antenna, in the Shuttle tended mode, is shown in Figure 63.

2.1.2.1 TA-1 Shuttle Launch Configuration - The 123-m horizontal arm is divided into seven segments, each 17.57 m (57.65 ft) in length. The 126-m vertical arm is divided into eight segments that are 15.75 m (51.67 ft) long. Each panel segment with its structure, waveguides, amplitrons, and power distribution system, is completely assembled on the ground and folded as shown in Figure 64 for launch. The shear strut spacing for each segment is selected so that the amplitrons fit between the shear struts with the segment folded. The seven panel segments of the horizontal arm and the eight panel segments of the vertical arm are mounted on a launch pallet which serves also as the jig for orbital deployment and joining of adjacent panel segments. A cross section of the launch package is shown in Figure 64. The launch pallet is divided into two sections which are hinged together at one end. Each section extends nearly the full length of the cargo bay so that when the sections are hinged open, their combined length is more than twice the length of a 17.57 m horizontal-arm panel segment.



TA-1 OBJECTIVES

- EVALUATE FAB OF MICROWAVE ANTENNA
- EVALUATE MISSION & CONTROL
- EVALUATE RFI EFFECTS
- EVALUATE PLASMA EFFECTS
- END-TO-END FUNCTIONAL VERIFICATION

MRWS FUNCTIONS

- CONTROL CRANE OPERATION
- INTERFACE WITH C.P. OPERATOR
- CO-ORDINATE CRANE/CHERRY PICKER OPERATIONS
- EMERGENCY EVA

OPEN CAB C.P. FUNCTIONS

- PRESSURE SUIT OPERATIONS CLOSE TO WORK
- TRANSPORT HARDWARE TO WORK SITE

2198-069

Figure 63. MRWS Requirements in Support of Microwave Antenna Development (TA-1) Construction

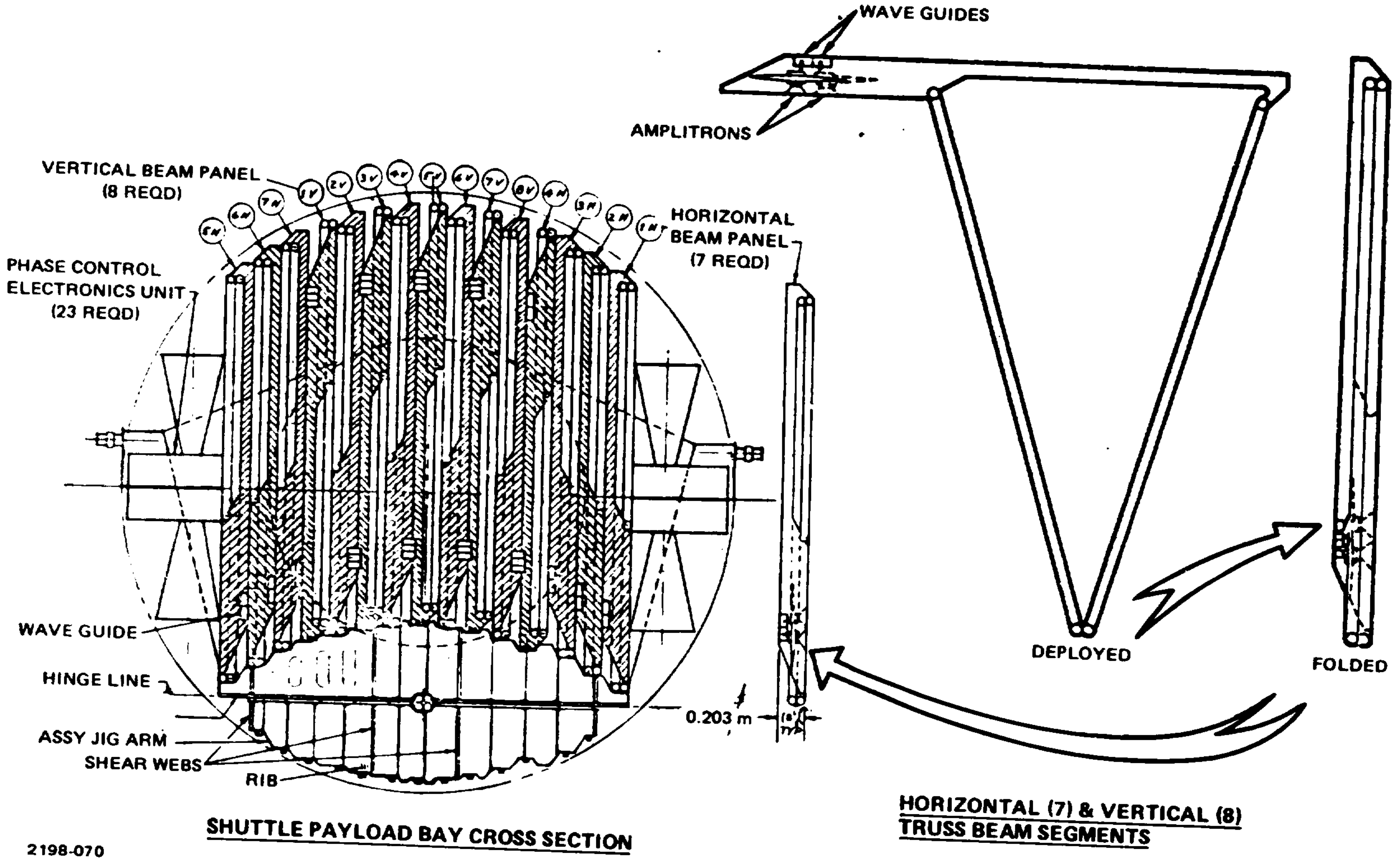


Figure 64. TA-1 Stowed Launch Configuration in Shuttle Payload Bay

The 23 phase-control-electronics units are stowed along both sides of the launch package. The individual units are bolted together to form a beam for launch, and the ends of the beam are attached to the bulkhead frames on the pallet which mounts the orbital interface trunnions.

2.1.2.2 TA-1 Deployment and Assembly - The TA-1 consists of two long crossed arms, one 123-m long and one 126-m long, and is assembled in orbit using components fabricated on the ground. The arms are made up of 15 truss beams approximately 15-m long which are stored on a folded pallet in the payload bay. The pallet support structure has a double section which unfolds on-orbit, resulting in the pallet being over twice as long as the individual 15-m beam segments stored on the pallet. The first folded truss beam segment is removed from the pallet and transferred to the other side where it is deployed and electronics installed. This erected 15-m section is then moved to the outer portion of the unfolded pallet. The second beam section is then removed from the pallet and transferred to the other side where the preceding segment was originally deployed. This second segment is deployed, its electronics are installed, and it is joined to the first segment; then the combined segments are maneuvered outward until the second segment rests on the unfolded section of the pallet. The third segment is then removed, and the process keeps repeating until the arms of the antenna have been completed. As each arm is completed, it is installed on a separate standoff.

Isometric views of the TA-1 deployment sequence are shown in Figure 65.

2.1.3 Support Functions and Mission Scenario

For deployment and assembly of the TA-1, two cranes operating on the SCM are required. One to move the payloads to their required interfaces, and one to support an open MRWS cherry picker. Figure 66 contains the top level functional requirements for the MRWS crane turret and the MRWS open cherry picker in the deployment and assembly of the TA-1 antenna. It is obvious that the operator in the crane turret controls movement of large elements from one point to another while the Astronaut in the cherry picker performs the physical alignment and attachment functions. Because of his close proximity to the work area, he should have overriding control capability of the crane for close in movements.

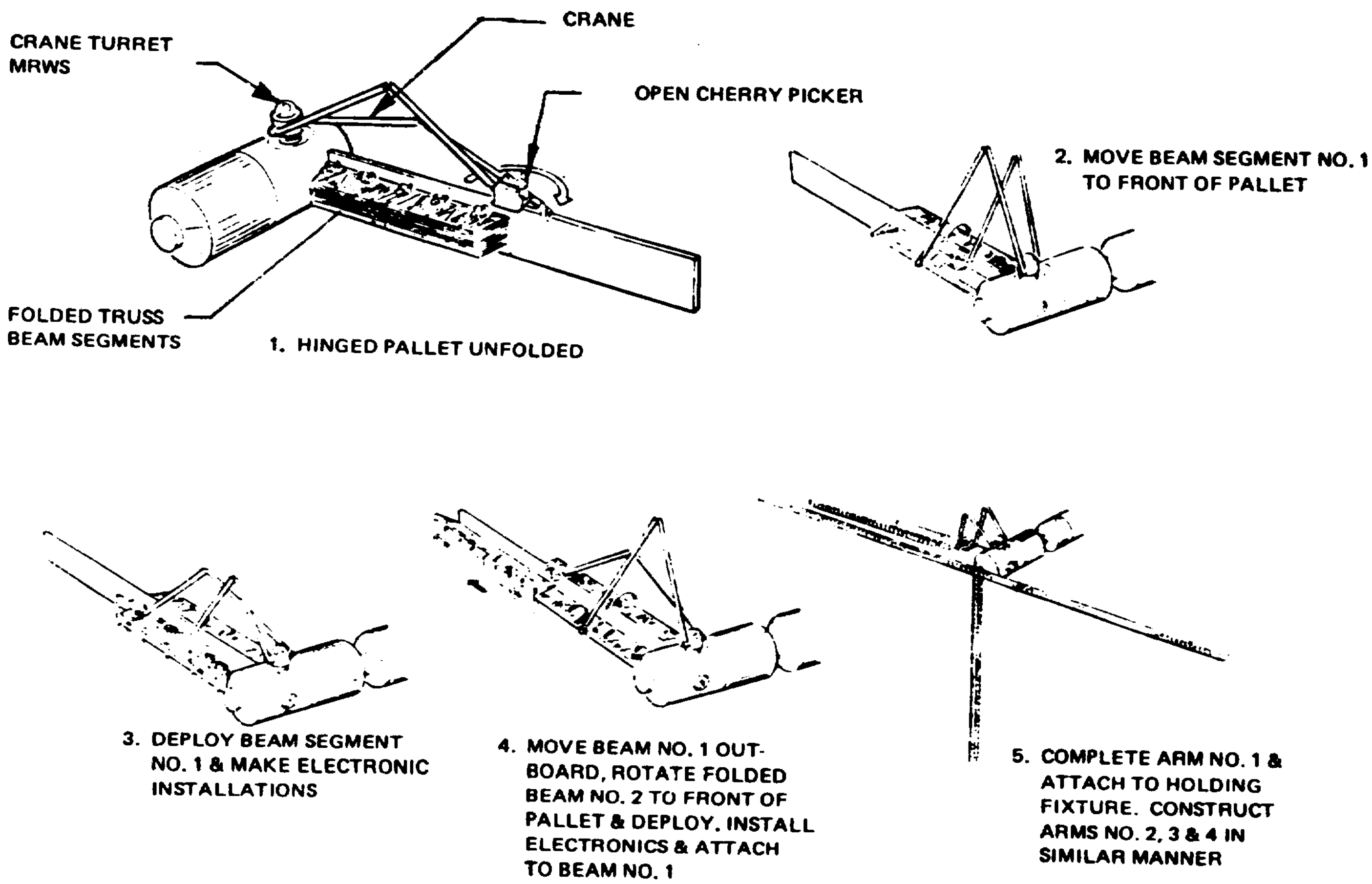


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Figure 65. TA-1 Deployment and Construction Sequence

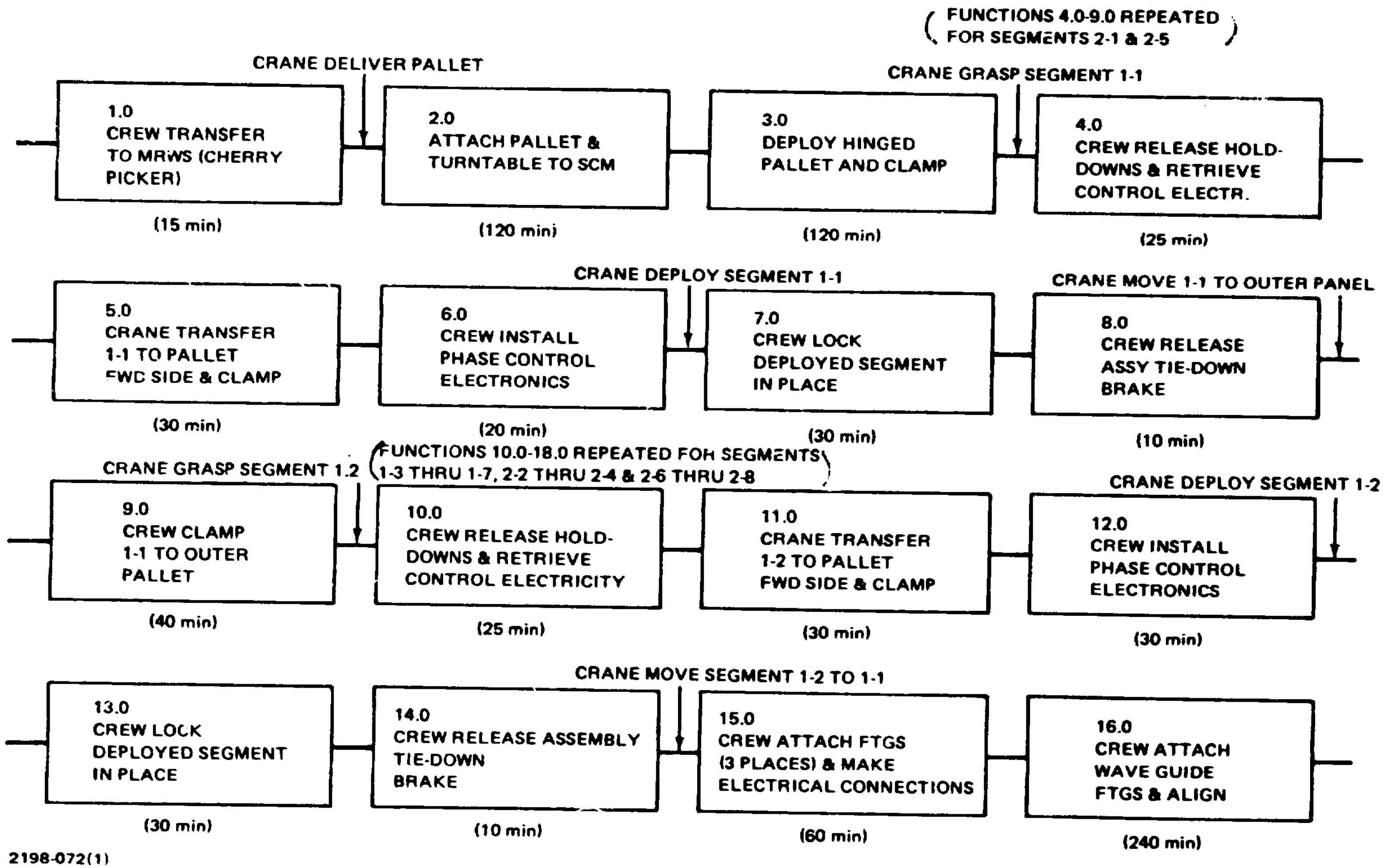

Figure 66. MRWS Functional Requirements Support of TA-1 Construction (Sheet 1 of 2)

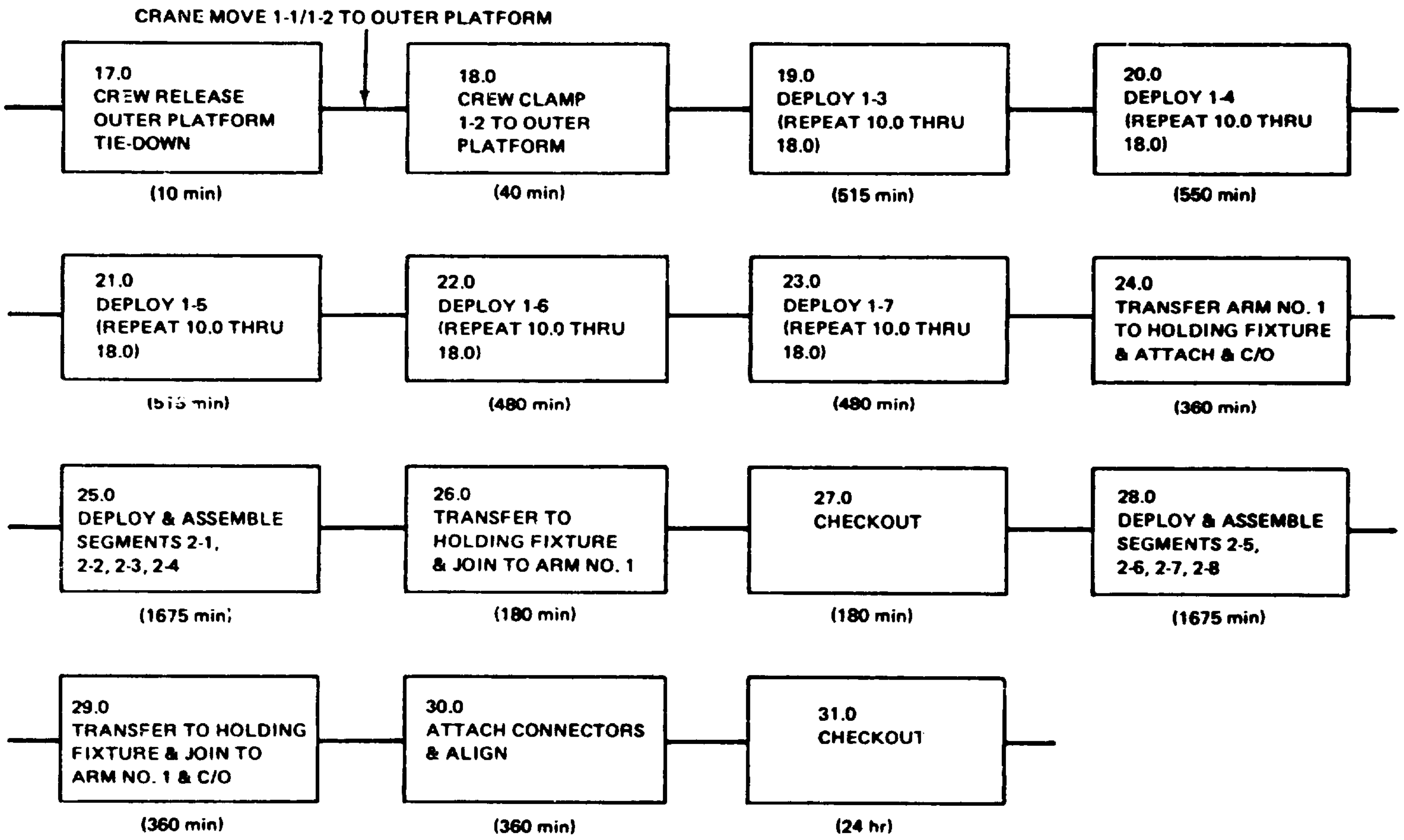

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Figure 66. MRWS Functional Requirements in Support of TA-1 Construction (Sheet 2 of 2)

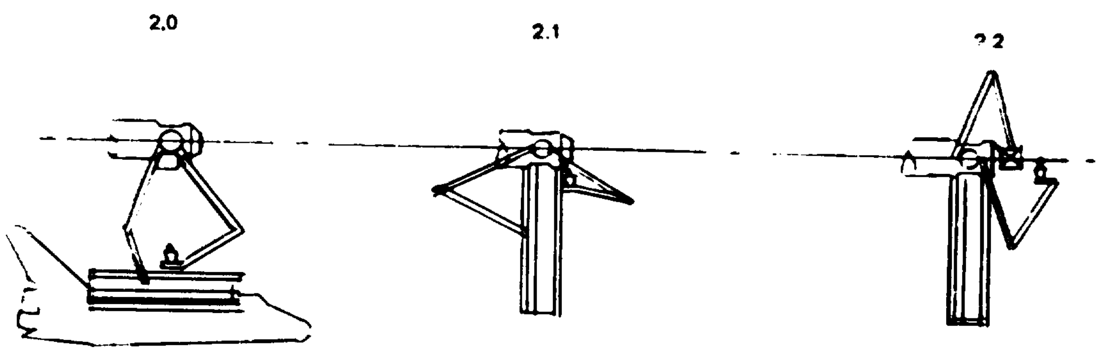
2.1.4 Task Analysis - Deployment and Assembly of Antenna Arm

2.1.4.1 Accessibility - The deployment and assembly of the seven segments which make up the horizontal arm of the antenna was used in analyzing the functional requirements of each MRWS. The crane turret operator is afforded a good view of the crane arm when moving the seven folded antenna segments from the back to the forward side of the pallet. The reach of the crane arm is not taxed during this sequence. The operator in the cherry picker has a better vantage point during the latter part of each task. He can place the open platform in close to the work zone and thereby direct the final movement of the crane. When properly located he can position the open cab platform with the stabilizer, both his hands are now free to perform alignment and assembly functions. Figure 51 depicts a design that satisfies the needs of an open cherry picker. Figure 67 shows the sequence of operation with functional requirements for both MRWS's listed.

2.1.4.2 Items to be Handled - The elements of the TA-1 antenna to be handled in this operation are:

- TA-1 antenna folded package in Shuttle payload bay, 4.5 m dia x 17.6 m long
- Horizontal beam panels (7), 0.2 m x 3.5 m x 17 m
- Vertical beam panels (8), 0.2 m x 3.5 m x 15.8 m
- Amplitrons
- Waveguides
- Phase control electronics units (23)
- Turntable adapter
- Hand tools
- Torque wrench.

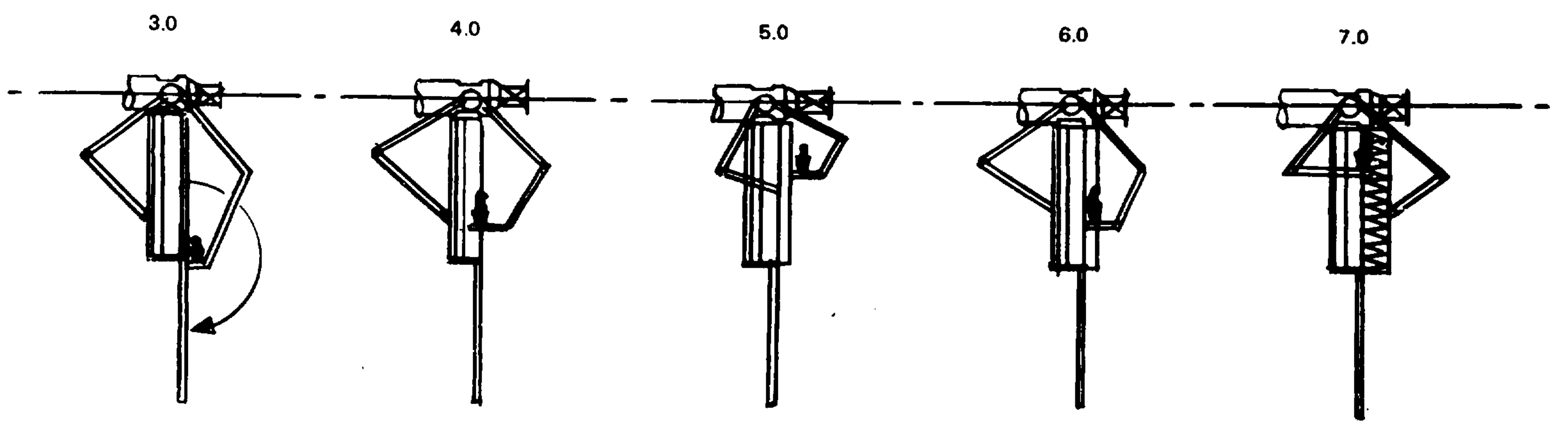
2.1.4.3 Operation - The deployment and assembly of a given beam segment is illustrated in Figure 68. The time to accomplish this task has been analyzed and is listed in Table 16.



TASK	CRANE TURRET FUNCTIONS	MRWS OCP FUNCTIONS
2.0 ROTATE TA-1 PACKAGE OUT ON PIDAS & RETRIEVE WITH CRANE	o SNARE, TRACK, EXTRACT & ROTATE PACKAGE	o MONITOR CLOSE OPERATIONS o PROVIDE CCTV VIEW o PROVIDE ADDITIONAL LIGHTING o DIRECT CRANE OPERATOR o REMOVE SNAGS HANGUPS
2.1 ATTACH PACKAGE TO SIDE PORT OF SCM	o MOVE PACKAGE TO SIDE PORT o HOLD PACKAGE STEADY DURING FASTENING SEQUENCE	o ASSIST IN BERTHING OPS o PERFORM TIE DOWN FUNCTION o PROVIDE TV & LIGHTING
2.2 REMOVE TURNTABLE ADAPTER & INSTALL AT END PORT ON SCM	o EXTRACT TURNTABLE o MOVE TO END PORT o HOLD FAST DURING TIE DOWN	o UNFASTEN FROM PACKAGE o PERFORM ALIGNMENT & TIE DOWN o CHECK OPS OF TURNTABLE

2198-073(1)

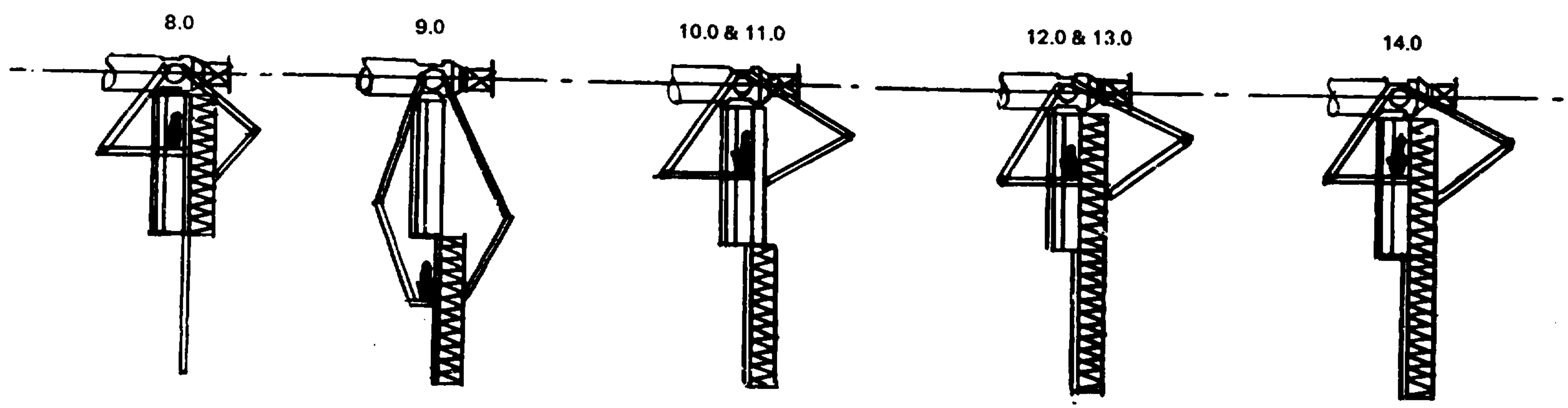
Figure 67. MRWS Functions 2.0 through 24.0 – Assemble Horizontal Arm and Install on Turntable (Sheet 1 of 4)



TASK	CRANE TURRET FUNCTIONS	MRWS OCP FUNCTIONS
3.0 DEPLOY HINGED PALLET & CLAMP	o GRAPPLE PACKAGE TO STIFFEN	o RELEASE LOCKING MECHANISMS o ROTATE PALLET 180^{o} o INSTALL LOCKING BOLTS
4.0 CREW RELEASE SEGMENT 1-1 HOLD DOWN & RETRIEVE ELECTRONICS	o GRAPPLE SEGMENT 1-1 & STABILIZE	o UNFASTEN 1-1 HOLD DOWNS o REMOVE ELECTRONICS & STOW ON OCP CAB
5.0 TRANSFER SEGMENT 1-1 TO FWD SIDE & CLAMP	o MOVE SEGMENT 1-1 TO FWD SIDE o HOLD IN ALIGNED PLACE FOR TIEDOWN OPERATIONS	o GUIDE 1-1 TO FWD SIDE o ALIGN 1-1 TO PALLET o SECURE 1-1 TO PALLET
6.0 INSTALL PHASE ELECTRONICS	o GRAPPLE PACKAGE TO STIFFEN & MINIMIZE MOTION	o INSTALL ELECTRONICS o MAKE ELECTRICAL CONNECTIONS o CHECK OUT INSTALLATION
7.0 DEPLOY SEGMENT 1-1 & LOCK	o DEPLOY SEGMENT 1-1 & HOLD IN EXTENDED POSITION	o LOCK IN EXTENDED POSITION

2198-073(2)

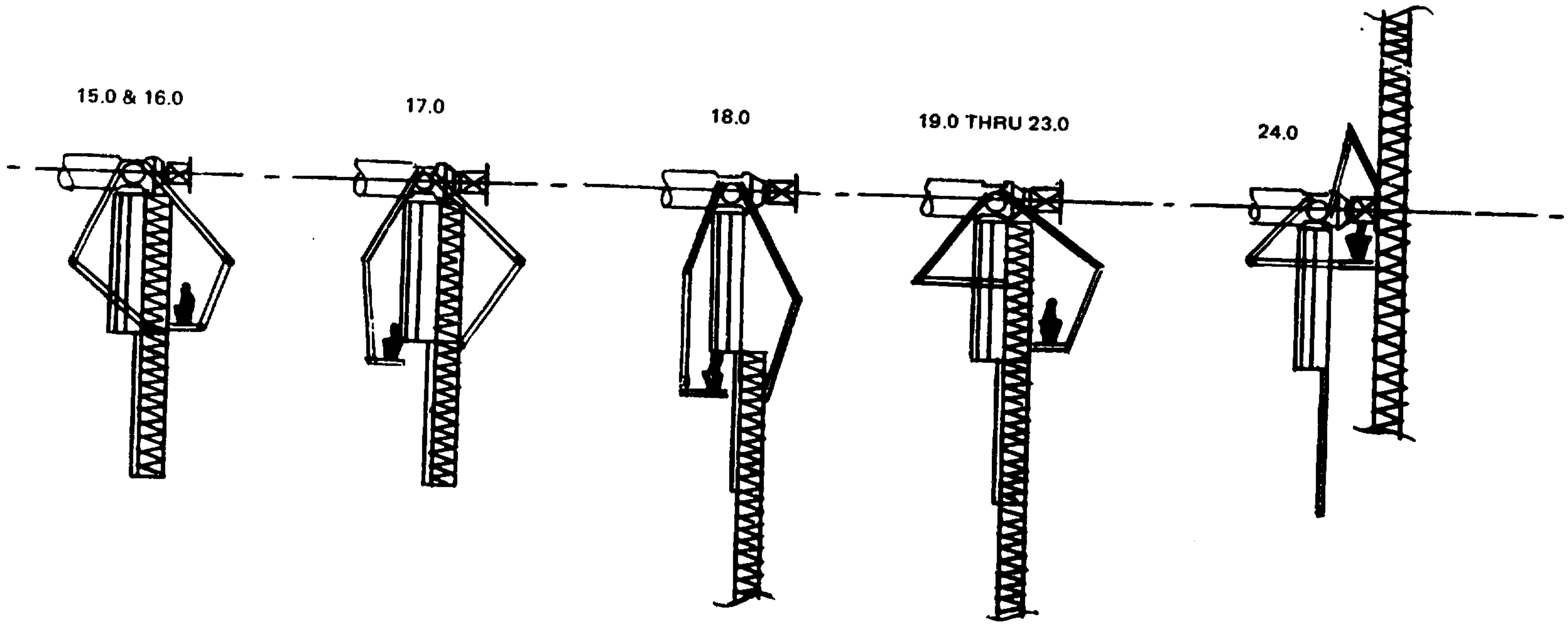
Figure 67. MRWS Functions 2.0 through 24.0 – Assemble Horizontal Arm and Install on Turntable (Sheet 2 of 4)



TASK	CRANE TURRET FUNCTIONS	MRWS OCP FUNCTIONS
8.0 PREPARE SEGMENT 1-1 FOR MOVEMENT	o STABILIZE SEGMENT 1-1	o UNFASTEN 1-1 FROM PALLET o CHECK FOR CLEARANCES
9.0 MOVE SEGMENT 1-1 TO OUTBD PALLET LOCATION & SECURE	o TRANSPORT SEGMENT 1-1 TO NEW LOCATION o HOLD IN PLACE FOR ALIGNMENT & FASTENING	o OVERRIDE CONTROL OF CRANE o FINITE ADJUSTMENT FOR ALIGNMENT o FASTEN 1-1 TO OUTBD PALLET
10.0 & 11.0 RETRIEVE CONTROL ELECTRONICS AND TRANSFER SEGMENT 2-1 TO FWD SIDE	o TRANSPORT SEGMENT 2-1 TO FWD SIDE o STABILIZE SEGMENT 2-1	o ACQUIRE CONTROL ELECTRONICS o CONTROL CRANE DURING 2-1 TRANSFER o SECURE 2-1 IN PLACE
12.0 13.0 INSTALL PHASE CONTROL ELECTRONICS, DEPLOY SEGMENT 2-1 & LOCK	o DEPLOY SEGMENT 2-1 o STABILIZE UNIT AFTER DEPLOY	o INSTALL ELECTRONICS o ASSIST IN 2-1 ERECTION & SECURE
14.0 RELEASE SEGMENT 2-1	o STABILIZE SEGMENT 2-1	o UNFASTEN SEGMENT 2-1

2198-073(3)

Figure 67. MRWS Functions 2.0 through 24.0 – Assemble Horizontal Arm and Install on Turntable (Sheet 3 of 4)



TASK	CRANE TURRET FUNCTIONS	MRWS OCP FUNCTIONS
15.0 ATTACH SEGMENT 1-2 TO 1-1 16.0	o MOVE SEGMENT 1-2 TO 1-1	o ATTACH FTGS & ELECT CONNECTIONS o ATTACH WAVEGUIDE & C/O
17.0 RELEASE SEGMENT 1-2 & 1-1 ASSY	o STABILIZE ASSEMBLED 1-2 & 1-1	o UNFASTEN ASSEMBLED UNIT
18.0 RELOCATE ASSY OUTBOARD	o MOVE ASSY OUT ON JIG FIXTURE	o DIRECT CRANE OPERATION o CHECK CLEARANCES
19.0 THRU 23.0 REPEAT FUNCTIONS 2.0 THRU 18.0	o REPEAT PREVIOUS FUNCTIONS	o REPEAT PREVIOUS FUNCTIONS
24.0 INSTALL ASSY ON TURNTABLE	o MOVE ASSY TO TURNTABLE o STABILIZE ASSY ON TURNTABLE FOR OCP OPERATION	o DIRECT CRANE OPERATION o ATTACH ASSY TO TURNTABLE o CHECK OUT INSTALLATION

2198-073(4)

Figure 67. MRWS Functions 2.0 through 24.0 – Assemble Horizontal Arm and Install on Turntable (Sheet 4 of 4)

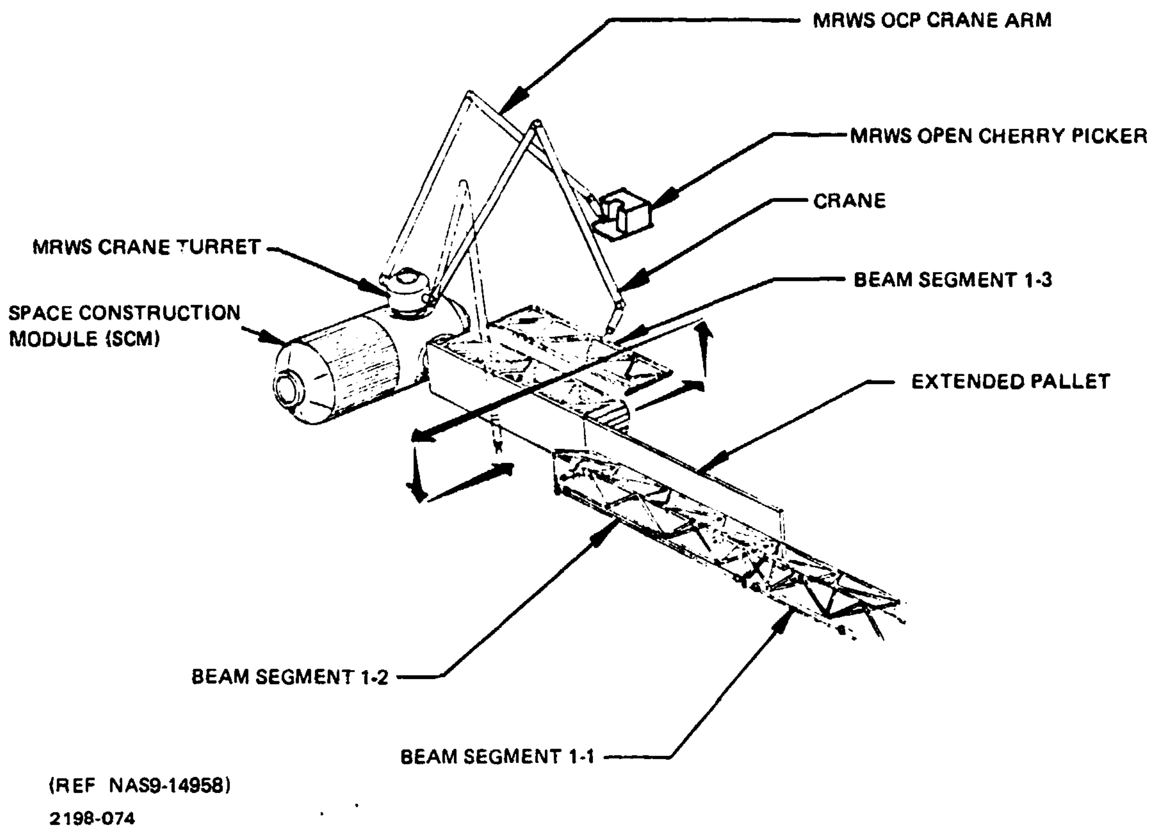


Figure 68. TA-1 Antenna Beam Transfer and Buildup Sequence

TABLE 16

BEAM SEGMENT DEPLOYMENT AND ASSEMBLY TIME-LINE

FUNCTION	ΔT (min)	OPERATION
.0	2.6	CRANE MOVES TO PALLET
.1	1.0	CRANE GRASPS SEGMENT 1-3
.2	1.3	CREW MOVES UP TO PALLET
.3	6.0	CREW RETRIEVES CONTROL ELECTRONICS
.4	5.9	CREW RELEASES HOLD DOWNS ON SEGMENT 1-1
.5	0.3	CREW CLEARS PALLET TO A DISTANCE OF 5 m
.6	5.4	CRANE MOVES (1-1) TO ASSEMBLY PLATFORM
.7	0.8	CREW MOVES UP TO (1-1)
.8	7.7	CREW LATCHES (1-1) TO ASSEMBLY PLATFORM
.9	0.3	CRANE CLEARS ASSEMBLY PLATFORM TO A DISTANCE OF 5 m
.10	38.5	CREW INSTALLS PHASE CONTROL ELECTRONICS
.11	0.3	CREW CLEARS PANEL TO A DISTANCE OF 5 m
.12	2.3	CRANE ARM MOVES IN TO (1-1)
.13	5.0	CRANE DEPLOYS BEAM PANEL
.14	0.3	CRANE CLEARS (1-1) TO A DISTANCE OF 5 m
.15	0.8	CREW MOVES IN TO (1-1)
.16	29.8	CREW LOCKS BEAM PANEL IN PLACE
.17	3.3	CREW RELEASE ASSY TIE DOWN BRAKE
	111.6	TOTAL

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2.1.5 Open Cherry Picker Design Requirements

2.1.5.1 Stabilizer - A grappler/stabilizer device which locks the open cherry picker work platform to the work zone is required. For the open cherry picker, a simple hand-operated extension with angular adjustment and locking would satisfy the requirements. The astronaut would extend the semi-rigid structure by hand, make the required adjustments, and then lock the grappler in place. The nominal reach of this unit should be approximately 2 m. Simulation tests are required to verify the adequacy of a single grappler versus two or three grapplers.

2.1.5.2 Controls and Displays - The MRWS open cherry picker should provide a small console, located to one side, with the following controls and displays as a minimum:

- OCP Crane Controller - A hand controller which controls the six degrees of motion of the crane arm on which the OCP is mounted
- OCP Controller - A two-axis switch controlling pitch and yaw and a thumb wheel switch controlling the roll position of the platform.
- Crane Turret Arm Override Control - A hand controller controlling the six degrees of motion of the crane turret arm. This controller has to be interfaced with the MRWS crane turret to provide an override feature when desired
- Electric Power Control Panel - Switches to turn power on and off and circuit breakers to protect all circuits
- ICS Communication Panel - Controls to permit communication with crane turret operator and other EVA crew men
- Elapsed Time Clock - Clock to indicate time elapsed on any sequence of operations and total time spend EVA by crew
- Lighting Control Panel - Switches to control external flood lights to illuminate the work area.

2.1.5.3 Life Support - For nominal operation, the open cherry picker operator will be wearing an extravehicular mobility unit (EMU). He will leave the MRWS crane turret via the space construction module hatch and proceed to the open cherry picker. The back pack will provide sufficient oxygen for an 8-hour shift with a 30-min contingency for emergency operations. The open cherry picker will not have any life support equipment onboard.

2.1.5.4 Support and Restraint - The primary aim of this system is to restrain the crew man securely so that he can use both hands for his work. A set of foot (boot) restraints, which can be moved to desired locations and locked, is required. In addition, a constant force waist restraint, similar to that used in the Lunar Module is also required.

2.1.5.5 Tool Bin - A cabinet for stowage of required hand tools is required. This cabinet should be able to take a varied array of tools that may be required for the numerous missions contemplated.

2.1.6 Crane Turret Design Requirements

2.1.6.1 Cabin Configuration -

- Size - large enough to house one operator with controllers, instrument panels, windows, and restraint system
- Shape - cylindrical in shape, 1.5 to 2.0 m in dia and 2.0 to 3.0 m high, for optimum structural integraity
- Windows - should be provided in the forward and overhead quadrants of the cylinder. Because the cabin rotates on its vertical axis, the lateral window size can be minimized with out degredation of external vision. The forward windows should provide 60° downward vision and, with the overhead windows, provide 75° upward vision
- Cabin Motion - The TA-1 construction area is in the forward quadrant of the SCM. Cabin rotation ± 135° from a straight ahead position will provide complete coverage of planned work zone.

2.1.6.2 Turret Configuration - The turret part of this vehicle should be part of the cabin. The cabin and turret should rotate on the SCM interface as a unit (separate rotation of the cabin and turret produces a complicated sealing interface with lower reliability). The cabin/turret rotation of ± 135° will cover all required work zones.

2.1.6.3 Cranes - The lifting crane and the OCP crane should be 35 m long and configured as shown in Figure 69. This length will provide good coverage in the primary work zone where the antenna segments are built up and installed. It will provide marginal reach when deploying the finished segment to the outboard position on the jig. The angular limits of each joint is a subject for further study.

2.1.6.4 Cabin Interfaces - The cabin and crane turret should interface with the SCM berthing part as one unit. The interface connection must be via a large bearing which permits cabin rotation, as noted, and passage of crewman from SCM up to control station inside of cabin. A pressure hatch should be provided in the SCM to seal off the open cherry picker in the event of pressure shell failure.

2.1.6.5 EVA Provisions - Early MRWS cabins depicted an overhead hatch with a docking ring. Analysis of TA-1 antenna construction indicates that the docking ring and overhead hatch are not required. Docking and EVA requirements can be best satisfied thru the fourth unused berthing interface on the SCM. By eliminating the docking and EVA requirement from the MRWS crane turret, the cabin design can be greatly simplified.

2.1.6.6 Cabin Controls and Displays - The following controls and displays are required as a minimum:

- Crane Arm Controllers - Each crane arm is to be controlled by a 7 DOF proportional rate controller similar to that shown in Figure 62. The integration of the switches into a single, hand-size control permits an operator to concentrate on his work instead of switches. Motions of the controller are made to simulate the crane arm being controlled, thus improving the man-machine interface. The crane arm defined in NAS-14958 (Figure 70) differs from that shown in Figure 68. Further studies are required in achieving compatible controller/crane units

- Cabin/Turret Rotation - A rotary switch to provide control of cabin/turret rotation

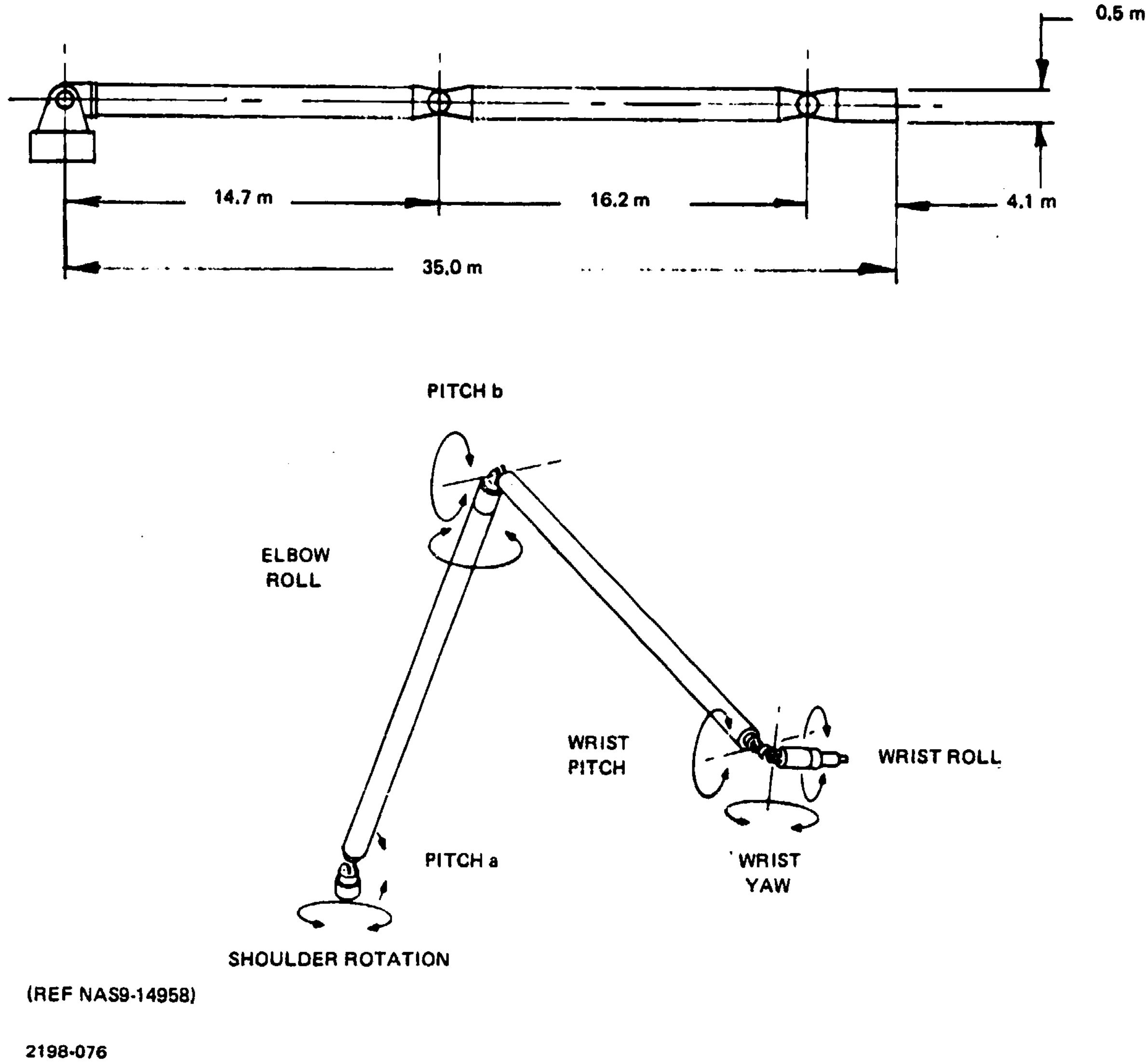
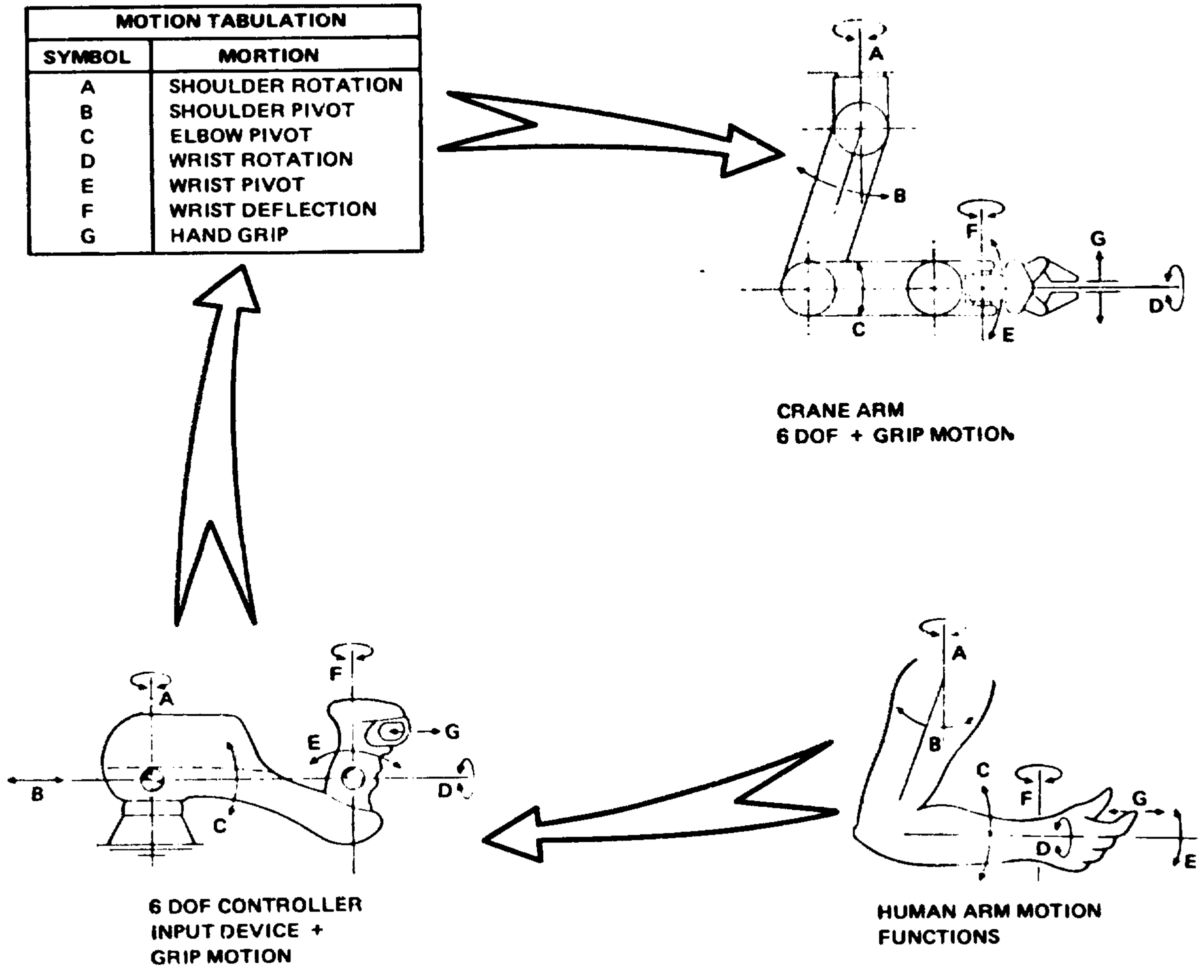


Figure 69. Seven DOF System for Best Reach-Around Capability

MOTION TABULATION	
SYMBOL	MORTION
A	SHOULDER ROTATION
B	SHOULDER PIVOT
C	ELBOW PIVOT
D	WRIST ROTATION
E	WRIST PIVOT
F	WRIST DEFLECTION
G	HAND GRIP



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2198-077

Figure 70. Proportional Rate Controller

- TV Monitors - Two TV monitors required to show work zone from different angles
- Electric Power - An electric power control panel to control power to all required units
- Communication - A communication panel to provide a link with the SCM, OCP, EVA astronaut and other spacecraft
- Support and Restraint - Foot and waist restraints required to allow the operator free use of both hands
- Life Support - Life support should be directly from the SCM
- Elapsed Time and Clock
- Lighting Control Panel - Control internal and external lights
- Caution and Warning Annunciator Panel.

2.1.7 Issues to be Resolved

- One-man versus two-man OCP
- Feasibility of controlling crane from OCP
- Feasibility of controlling both crane arms in parallel
- Hand controller configuration
- Quantity and location of TV cameras and floodlights
- Access path from SCM to OCP
- Best location of OCP console
- Type of unbilical services to OCP
- Feasibility of eliminating docking hatch and EVA hatch from crane turret cabin
- Feasibility of rotating crane turret and cab as one unit on SCM berthing interface
- Optimum crane arm length and joint configuration
- Definition of loads on crane turret during assembly operation

- Stabilizer quantity and configuration
- OCP cabin platform configuration to optimize crewmans reach to work zone
- Type of controllers in crane turret cabin.

2.1.8 References

- McDonnell Douglas Space Station Systems Analysis Study Part 3: Documentation. Vol. 3, July 1977.
- Zero-G, Workstation Design, JSC Internal Note No. 7-EW-1, June 1976.
- Crew Station Specifications, MSC-07387, October 1972.

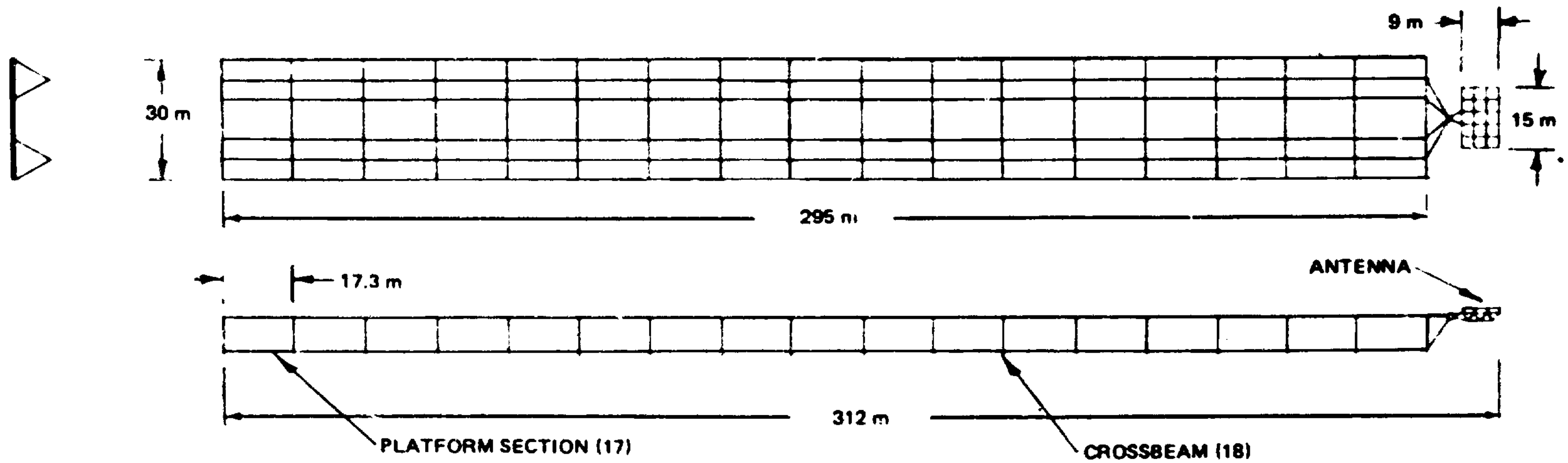
2.2 PHOTOVOLTAIC SOLAR COLLECTOR DEVELOPMENT

2.2.1 Mission Description

The spacecraft (TA-2) will be fabricated from the Space Construction Base and orbited in LEO. The spacecraft will be used to investigate solar collector issues, full power density microwave transmission, and system end-to-end functional verification. TA-2 in conjunction with TA-1 would provide cost data and information pertinent to the determination of how an SPS might be fabricated and assembled on orbit, as well as key end-to-end functional verification of such issues as two-dimensional phase control and thermostructural effects. TA-2 will operate at a nominal altitude of approximately 400 km and an inclination of 28.5 degrees.

2.2.2 Spacecraft Description

The spacecraft consists of 17 sections, 17.3-m long, which are attached to one another and to 18 crossbeams. Mounted at one end of the platform is a gimballed microwave antenna. The 10-m center portion of the platform contains solar blankets and the two outer 10-m triangular frames contain refective material. The configuration is shown in Figure 71. Each section consists of a series of 15 panel frame packages. Panels are hinged to unfold and, when attached to crossbeams, form the cross-sectional shape. The individual frames are 3.3-m wide and 17.3-m long (Figure 72). Some frames



- o 358 kW_{RF}
- o 24,700 kg
- o 5900 m^2 ACTIVE AREA
- o 456 kW
- o 295 m x 30-m COLLECTOR
- o 15 m x 9 m ANTENNA

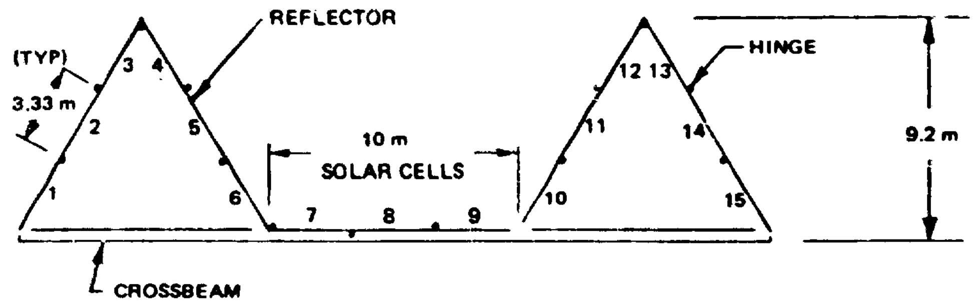


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Figure 71. Photovoltaic Solar Collector Development Article (TA-2) Configuration

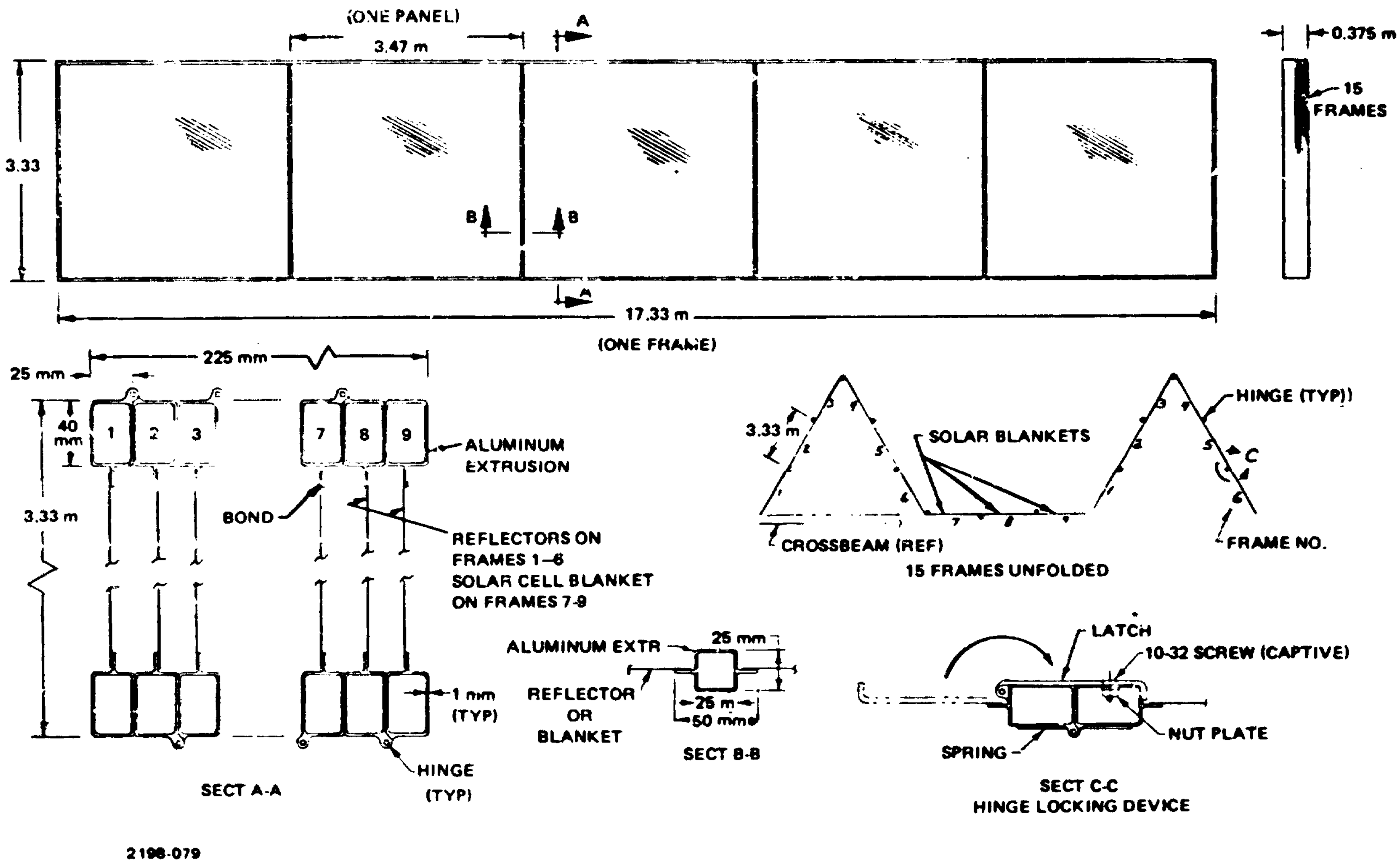

Figure 72. Power Platform Section Details

have solar cell blankets suspended from them and the rest have reflective material. Each section is fabricated on earth and folded into a package 0.3-m x 3.33-m x 17.33-m long. The crossbeams are hinged in the middle for stowage in the construction pallet. Table 17 summarizes the TA-2 mass properties.

2.2.3 Support Functions and Mission Scenario

The TA-2 deployment and assembly concept using the SCB is shown in Figure 73. The platform deployment and assembly sequence is shown in Figure 74. The construction pallet is delivered to the SCB by the orbiter. The crane and cherry picker remove the pallet from the orbiter and transfer and attache it to the SCB. The assembly beam tracks are deployed and locked. The crossbeams are then unfolded and attached to the assembly tracks, 17.3 m apart. One section consisting of 15 folded frames is then removed and positioned over the crossbeams. The central three frames are unfolded and locked to 10-m width (Frame No. 7, 8, and 9) and attached to the crossbeams. The operation is repeated until all 15 frames are deployed and locked and attached to the crossbeams.

The deployed section is then attached to the previously deployed section and the whole assembly is unclamped from the assembly tracks. The section is then moved outboard one section length and reclamped to the assembly tracks. The deployment sequence is repeated until all 17 sections are deployed and assembled together and to the crossbeams.

The microwave antenna is assembled in a similar fashion. The components are fabricated on the earth and folded up into packages delivered to the SCB by the orbiter. They are deployed and assembled together using the SCB crane and cherry picker MRWS. The antenna is then attached to the end of the solar collector platform.

MRWS support functions were established for an open cabin cherry picker and crane turret attached to the construction module of the Space Construction Base as shown in Figure 73. The mission scenario is shown in Figure 74 and Figure 75 contains the support functions for the MRWS and crane turret in the deployment and assembly of the solar collector portion of the spacecraft.

C-3

TABLE 17

TA-2 MASS SUMMARY

	MASS (kg)	
SOLAR COLLECTOR	14,316	
• STRUCTURE		12,027
• SOLAR CELL BLANKET		1,790
• REFLECTORS		499
MICROWAVE ANTENNA	2,098	
• AMPLITRONS		174
• WAVEGUIDE PANELS		643
• PHASE CONTROL ELECTRONICS		680
• PANEL LEVELING DEVICE		101
• THERMAL PROTECTION (ELECTRONICS)		150
• STRUCTURES		350
ROTARY JOINT & SUPPORTS	1,150	
SUPPORTING SUBSYSTEMS	300	
SUBTOTAL	17,864	
CONTINGENCY (25%)	4,466	
TOTAL	22,330 kg (49,240 lb)	

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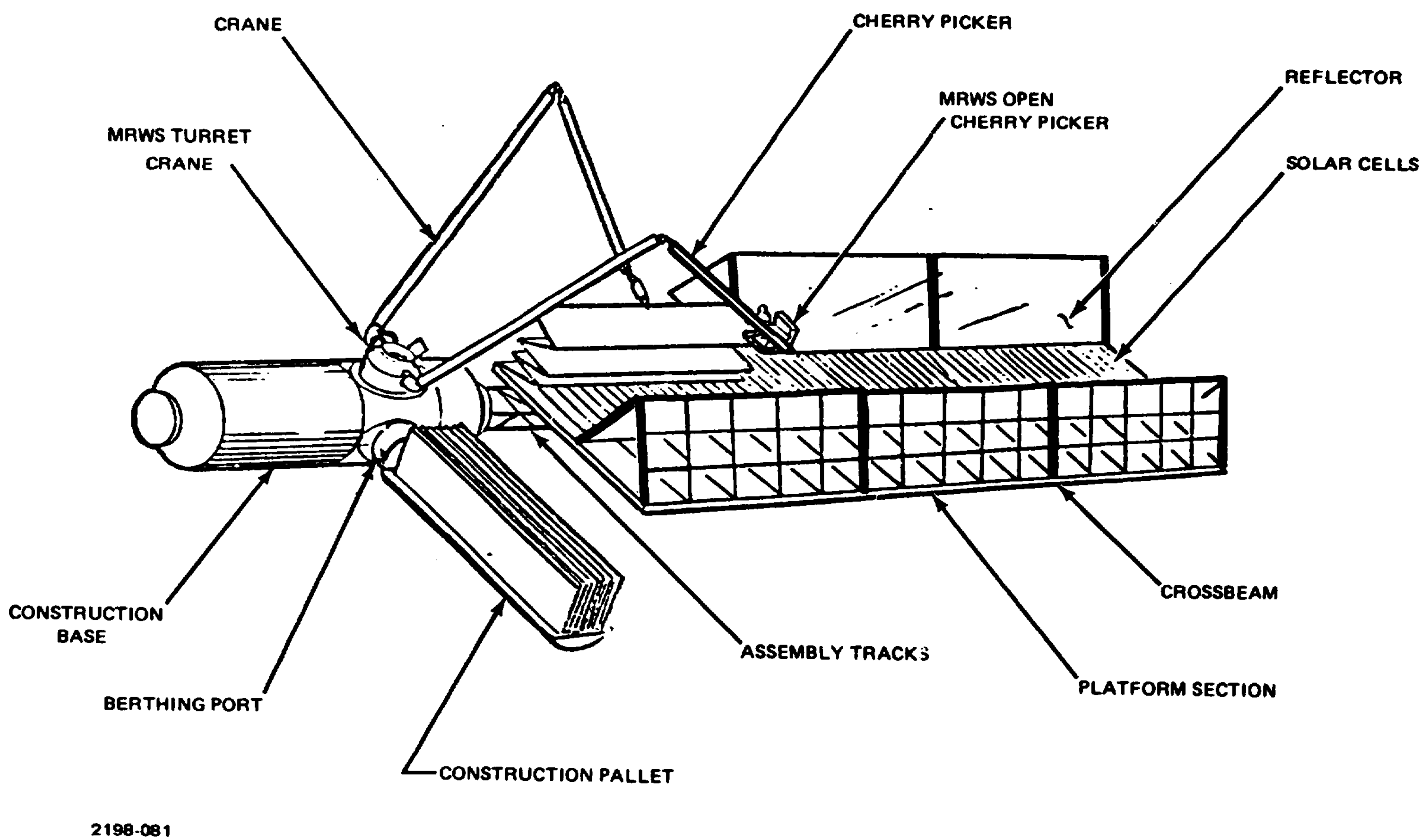


Figure 73. Platform Construction Concept

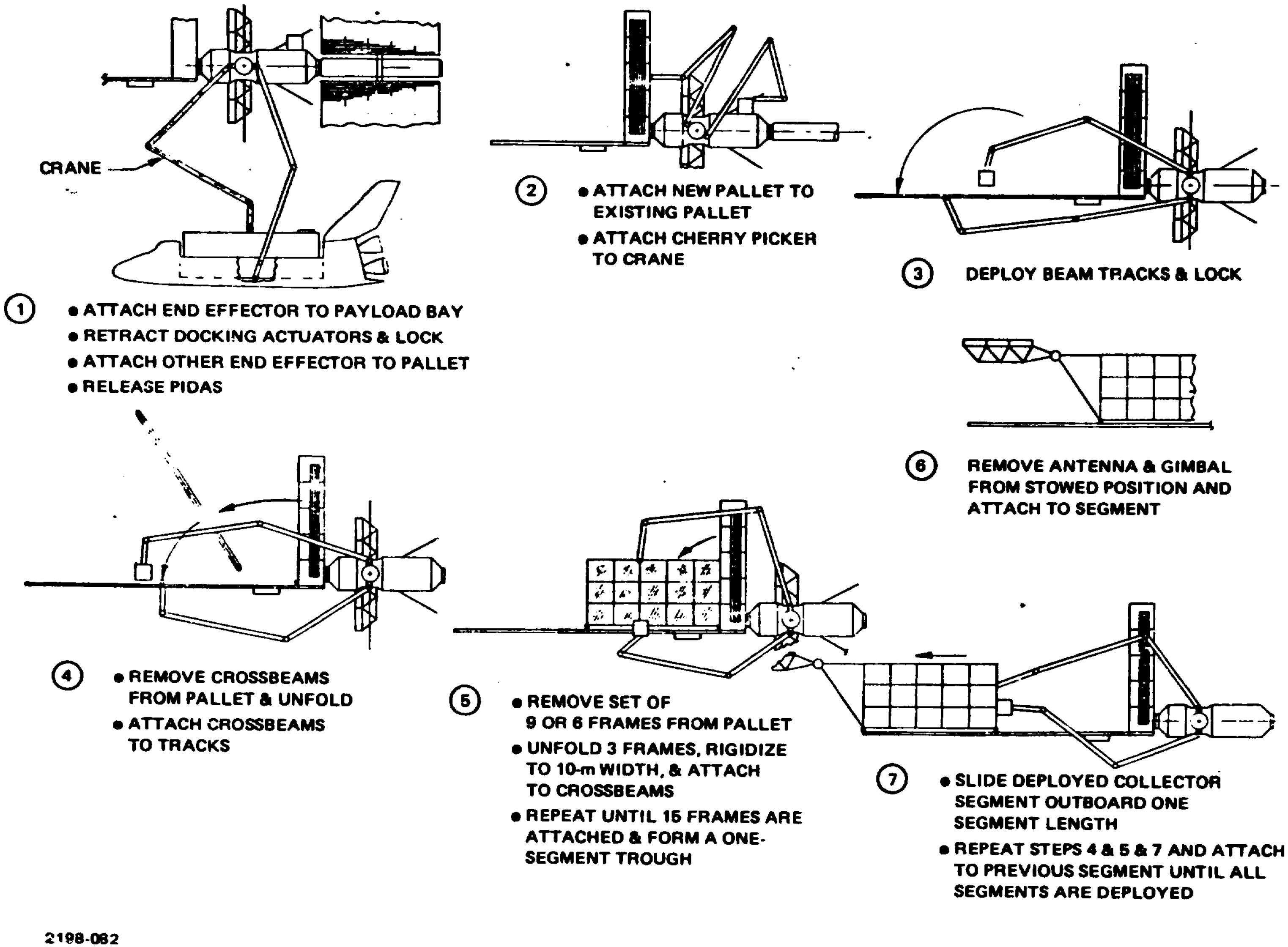
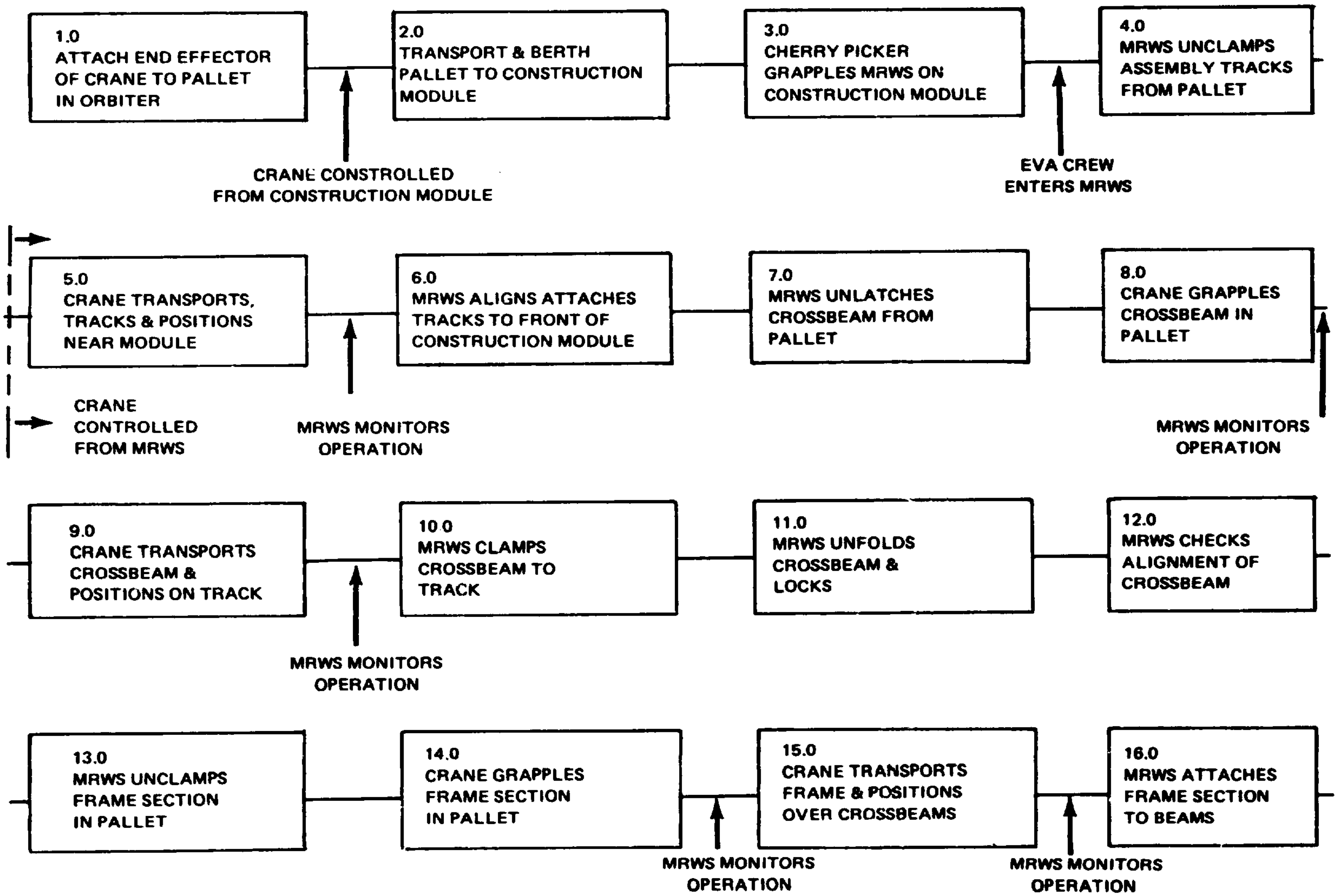
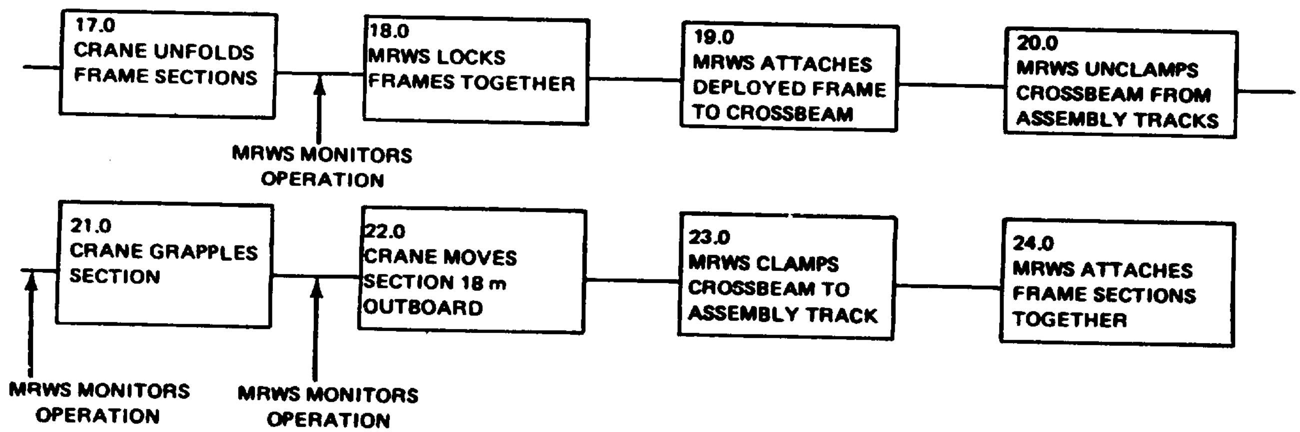


Figure 74. Platform Deployment Sequence



2198-083(1)

Figure 75. Open Cherry Picker Turrent Crane Functions — Deploy and Assemble Solar Collection Platform (Sheet 1 of 2)



2198-083(2)

Figure 75. Open Cherry Picker Turret Crane Functions — Deploy and Assemble Solar Collector Platform (Sheet 2 of 2)

2.2.4 Task Analysis - Deploy and Assembly Solar Collector

2.2.4.1 Accessibility - Figure 76 shows the crane and MRWS cherry picker reach/berthing envelope in relationship to the worksite area. The shaded area in the figure includes the construction area in front of the construction module and the pallet, berth to the side of the module. Figure 77 shows the accessibility and clearance required for the MRWS to lock one of the joints of the solar array frames. The crane is utilized to hold and unfold the frames to the proper angles.

2.2.4.2 Items to be Handled - The crane must grapple, transport, and position the following items:

• Construction Pallet (Figure 73)	4.4 dia x 18 m	10,000 kg
• Assembly Tracks	2 x 2 x 17 m	100 kg
• Crossbeams	0.14 x 0.50 x 30 m	20 kg
• Stowed Frame Section (Figure 74)	0.3 x 3.33 x 17.3 m	450 kg
• Assembled Frame Section	9.2 x 30 x 17.3 m	490 kg

The MRWS must also handle assembly tools, bolts, and clamps of negligible weight.

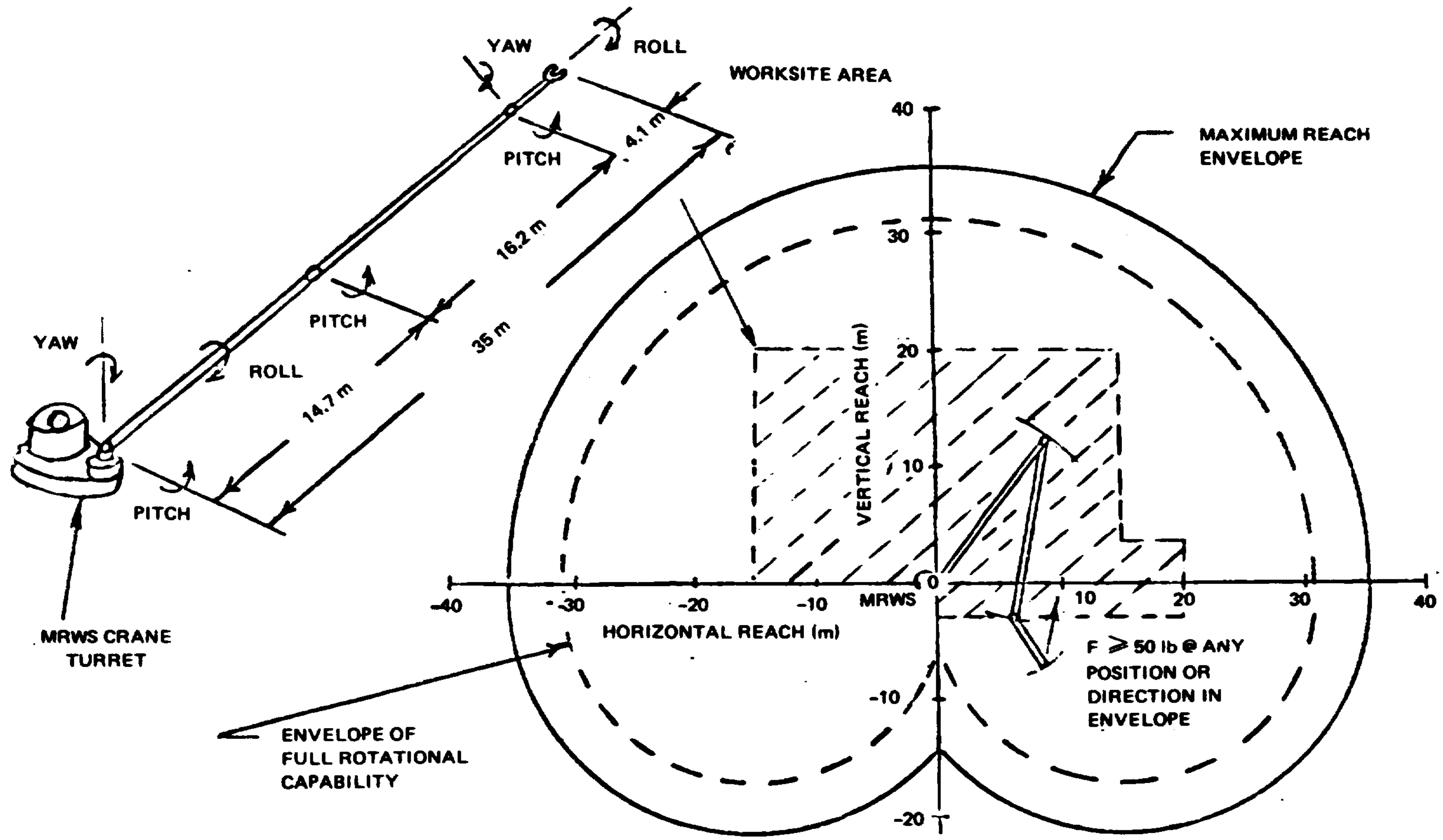
2.2.4.3 Operations - Deploy and assemble crossbeams and solar collector frame sections. The operation given in Table 18 is repeated 16 more times to assemble solar collector platform.

2.2.5 Crane/Cherry Picker Requirements

Requirements for the crane/cherry picker are given in Table 19.

Support Equipment

Several items of equipment are needed to support orbital operations. Mounting equipment is required for MRWS in the Space Construction Module. Cherry picker and effector grapple fixture between open cabin and cherry picker. Hand controllers are required for cherry picker operations. Means must be



2198-084

Figure 76. Crane/MRWS Arm Reach/Berthing Envelope

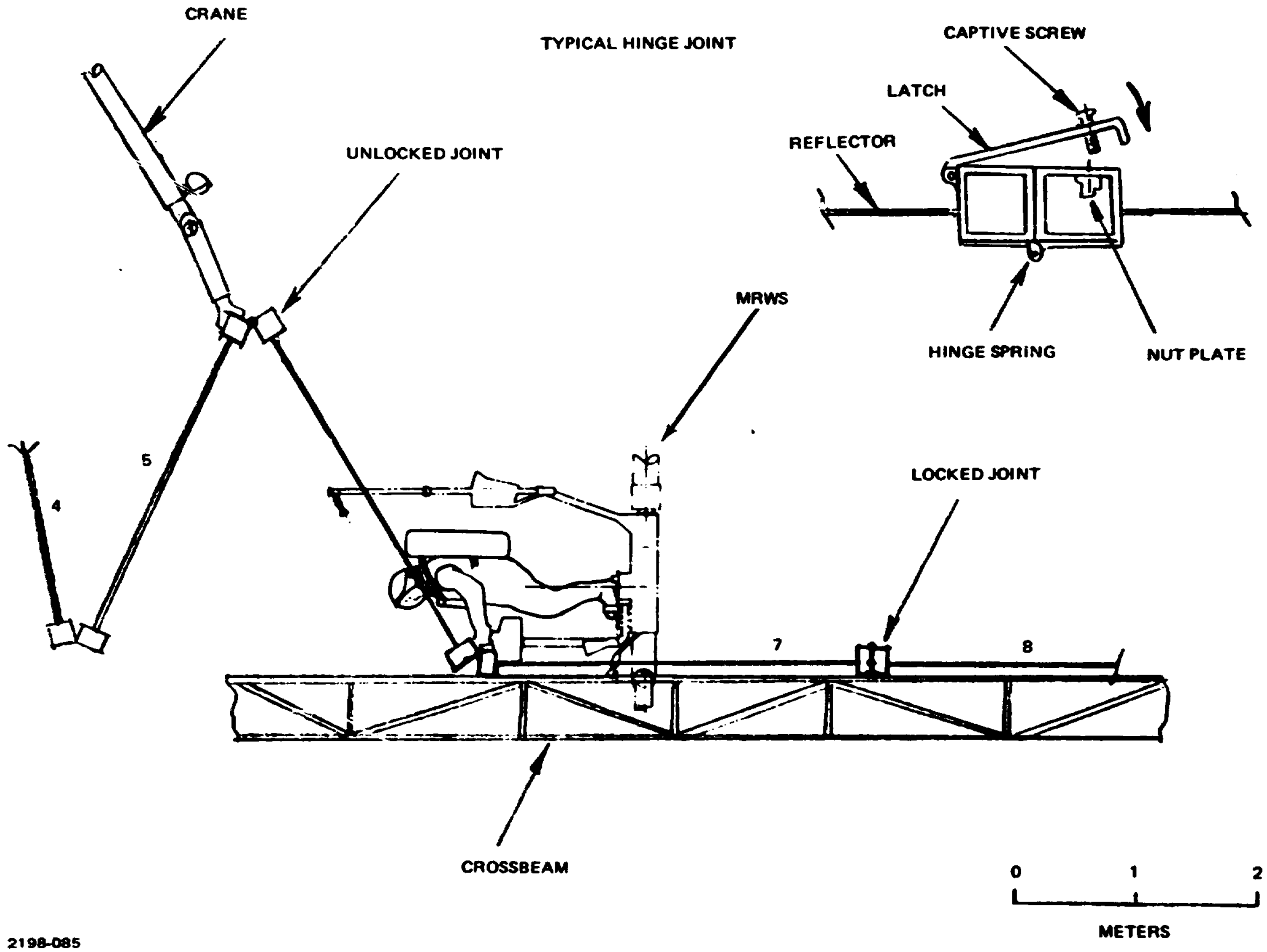


Figure 77. Accessibility and Clearance

TABLE 18

CROSSBEAMS AND SOLAR COLLECTOR FRAME ASSEMBLY TIME-LINE

ΔT (hr : min)	OPERATIONS
:10	UNCLAMP CROSSBEAM FROM PALLET BY OCP
:20	CRANE TURRET GRAPPLE, TRANSPORT & POSITION CROSSBEAM
:10	OCP CLAMP CROSSBEAM TO ASSY TRACK
:10	OCP UNFOLD & LOCK CROSSBEAM
:30	OCP CHECK ALIGNMENT OF BEAM
:10	OCP UNCLAMP FRAME SECTION FROM PALLET
:20	CRANE TURRET GRAPPLE, TRANSPORT & POSITION FRAME ON CROSSBEAMS
1:00	OCP ATTACH FRAMES 1-9 TO CROSSBEAM
2:00	OCP UNFOLD, LOCK & ATTACH FRAMES 1-9 TO CROSSBEAM
1:30	OCP UNFOLD, LOCK & ATTACH FRAMES 10-15 TO CROSSBEAM
:10	OCP UNCLAMP ASSY FROM TRACK
:30	CRANE TURRET MOVES ASSY 18 m OUTBOARD
:10	OCP CLAMP ASSY TO TRACK
7:10	TOTAL

2198-086

TABLE 19

CRANE/CHERRY PICKER REQUIREMENTS

PARAMETERS	CRANE	CHERRY PICKER
REACH	35 m	35 m
MORPHOLOGY	WRIST JOINT PYR SHOULDER JOINT PYR ELBOW JOINT P	WRIST JOINT PYR SHOULDER JOINT PYR ELBOW JOINT P
MANEUVER SPEED-NO LOAD	0.6 m/sec	0.5 m/sec
LOADED	0.2 m/sec	N/A
TIP FORCE	220 N	N/A
TORQUE CAPACITY	–	N/A
POSITION RESOLUTION	±0.1 M, ± 5° TIP	ASTRONAUT

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provided on pallets and parts for grasping by end effectors at the end of crane arm. Special hand-held assembly tools are needed for use by the EVA astronauts. Storage space for tools and assembly parts must be provided on the MRWS. Worksite illumination must be provided located on crane arm and MRWS cabin. CCTV system is necessary for construction functions and surveillance of EVA crew in cherry picker. TV cameras should be located on crane arms and MRWS and TV monitors provided in the Space construction module and the MRWS.

2.2.6 Issues to be Resolved

	Crane Turret	Cherry Picker
• One or more astronauts required to perform construction task		x
• Auxiliary control of turret crane arm from open cherry picker	x	x
• Stiffness, velocity, tip force, and position accuracy of arm	x	x
• Method of control of arm to limit oscillations of arm tip	x	x
• Type of controller and displays necessary to operate arm	x	x
• Visibility requirements for construction task and collision avoidance	x	
• Safety considerations such as arm joint lock in case of failures, rate limiting of arm to reduce impact energy	x	x
• Number and location of TV cameras and illumination	x	x
• Types of end effectors required for handling modules, parts, and tools	x	x

	Crane Turret	Cherry Picker
• Special mounting provisions on modules and parts for grasping and handling	x	x
• Types of hand held tools to assemble joints		x
• Cabin configuration for astronauts maneuverability and accesibility to work area, storage of tools and parts, location of cherry picker controls and displays, location of TV cameras and lights		x
• EVA system requirements such as work duration, suits, translation, mobility and restraint, safety, airlocks, and pre/post EVA		x
• Turret configurations such as fixed versus rotatable control station, visibility requirements of windows, number of operators, and type of structure.	x	x

2.2.7 References

- Space Station Systems Analysis Study.
- Part III McDonnell Douglas MDC G6922 Final Report.
- Part II McDonnell Douglas MDC G6715 Final Report.

2.3 100-m RADIOMETER

2.3.1 Mission Description

Analysis of future radiometer requirements indicate the need for a 400-m dia antenna that operates at 30 GHz. A 100-m dia antenna is a first step towards this goal. A 100-m antenna is potentially beyond the practical limitations of deployable antennas and at the lower end of the spectrum of space erectable antennas. The lessons learned and technology developed for the 100-m antenna would be directly applicable to the larger antennas. The goal of this mission is to assemble a radiometer antenna within the practical constraints of a construction base, which would measure much of the microwave radiation involved in the natural emmissions of terrestrial bodies with a reasonable degree of resolution. The specific microwave spectrum of interest is based on NASCR-2621 report (Hedgepath, S.M.: Survey of Future Requirements of Large Space Structures. NASA Report CR-2621 (Contract NAS1-1378), Astro Research Corp., January 1976).

2.3.2 Spacecraft Description

The 100-m radiometer design provides a good compromise between the practical limit of a mid 1980's construction base, the orbiter transport and the frequency regime of interest. It uses 94 ribs, each with a flange of 0.125 m to achieve the 0.25-cm, RMS surface accuracy, and a practical limit with respect to the 13.5-m hub circumference available. Together with the 16 circumferentials, this design will optimize the radiometer gain within the practical OCDA/orbiter constraints. The contour error will be within $\lambda/50$ for frequencies up to 2.5 GHz and $\lambda/10$ for frequencies up to 12 GHz.

The parabolic surface is formed by a series of concentric conical frustra. The support structure is comprised of a series of radial ribs and circumferentials.

To augment this design approach, an active contour control device (thermal expander) has been added to maintain the parabolic contour of the flexible reflector (mesh) surface. This active contour control system is controlled by a laser sensing contour mapping automatic compensation system. The radiometer configuration consists of a core module (Figure 78) which houses and supports the subsystem module, a central mast, stow canister and deploy mechanism, the tip module, and the antenna hub.

Attached to the core module is the reflector surface support structure consisting of 16 circumferentials and 94 radial ribs. Figure 79 contains the mass estimate for the 100-m radiometer configuration.

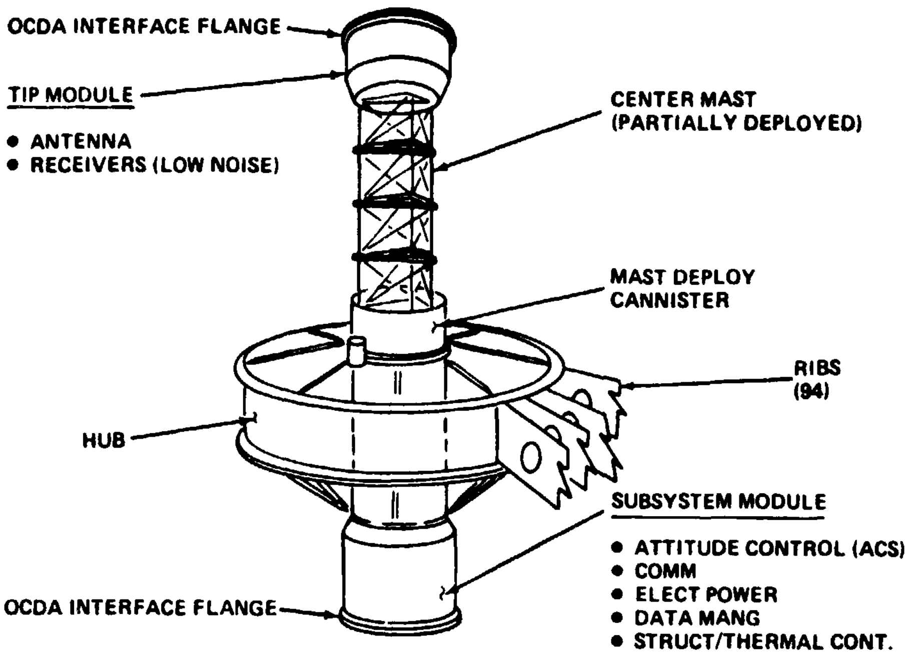
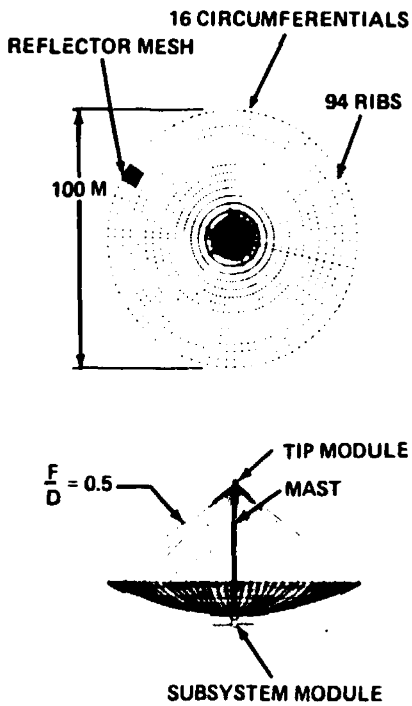


Figure 78. Core Module Hub and Center Mast Configuration



ELEMENT	MASS ESTIMATE Kg		MASS ESTIMATE LBM	
• ANTENNA	(6238)		(13755)	
– SURFACE MESH		200		441
– STRUCTURE				
○ CIRCUMFERENTIALS		460		1,014
○ RIBS		3,778		8,330
– HUB		600		1,323
– MAST		200		441
– MECHANICAL SYST		1,000		2,205
• SUBSYSTEMS	(965)		(2128)	
– STRUCTURE/THERMAL CONTROL		200		441
– ATTITUDE CONT (ACS)		40		88
– COMM		200		441
– ELECT POWER		180		397
– DATA MANG (DM)		315		695
– SENSORS		30		66
TOTAL	(7203)		(15883)	

2198-089

Figure 79. 100-m Radiometer Configuration

2.3.3 Support Functions and Mission Scenario

MRWS support functions were established for a railed closed cabin cherry picker operating on the 108-m railed boom (Figure 80). The functional requirements for the MRWS rate are summarized in Figure 81. The following delineate the generic requirement:

- Function 1.0 - The closed cabin cherry picker must be sized to fit within the Shuttle cargo bay along with a 35-m long supporting crane arm and railed carriage
- Function 2.0 - The interface with the 35-m long crane arm must be configured similar to the Shuttle RMS and provide power and signal line routing to the MRWS. The estimated power requirements are between 1.5 and 2.5 kW.
- Function 3.0 - The MRWS supporting crane arm and railed carriage must be configured to be handled by the SRMS for mounting to the construction base railed system
- Function 4.0 - After installation, the MRWS must be configured for remote control from the Shuttle payload handling station for the purpose of berthing or docking the MRWS to the Shuttle docking module or EVA egress hatch if the docking module is not carried by the Shuttle. This feature permits a shirt sleeve transfer of crew from the Shuttle to the MRWS cabin
- Function 5.0 - The MRWS should be configured with built in test for both remote checkout and manual checkout
- Function 6.0 - The MRWS crane arm and carriage should feature a hold-down fixture while the system is unmanned. This system should be capable of being disengaged both manually and remotely
- Function 7.0 through 12.0 - These are peculiar to the construction of the radiometer and will be discussed under Paragraph 2.3.4, Task Analysis
- Function 13.0 - This is a generic mission requirement in that the closed cabin cherry picker should be configured for retrieval by the Shuttle RMS and returned to earth.

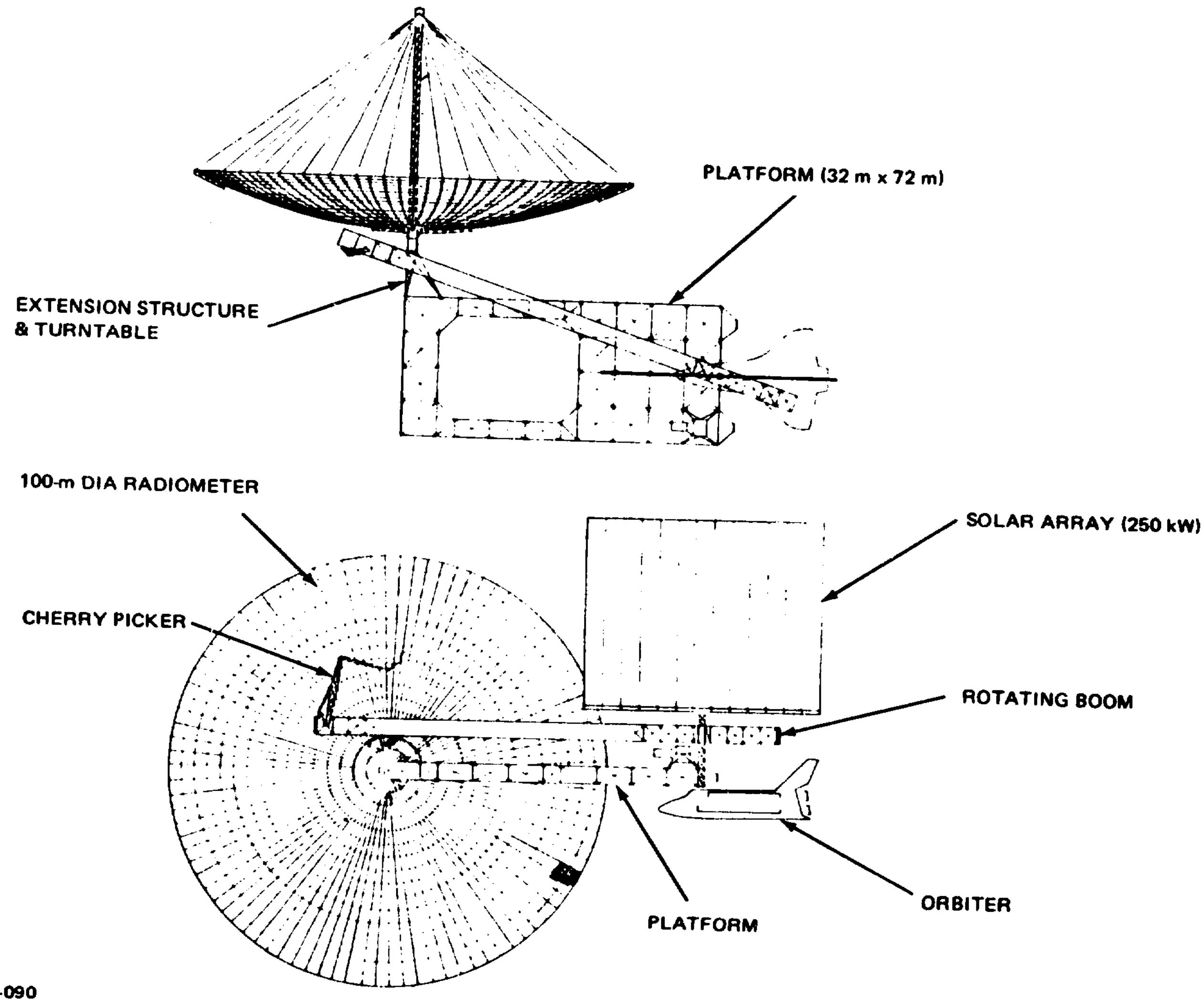


Figure 80. OCDA/100-m Radiometer Construction Using Railed Cherry Picker

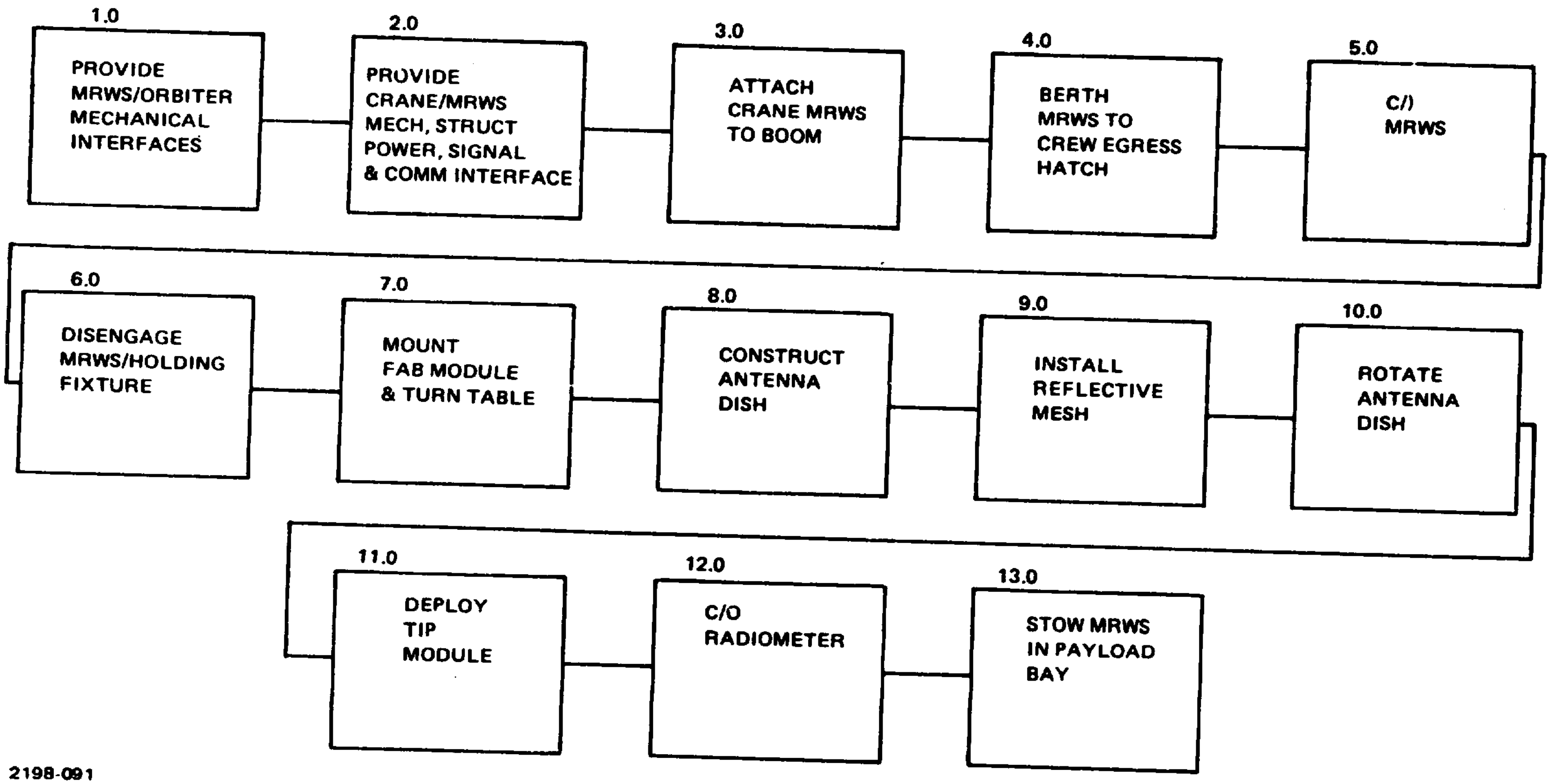


Figure 81. 100-m Radiometer Construction MRWS Support Functions – Railed Closed Cabin Cherry Picker

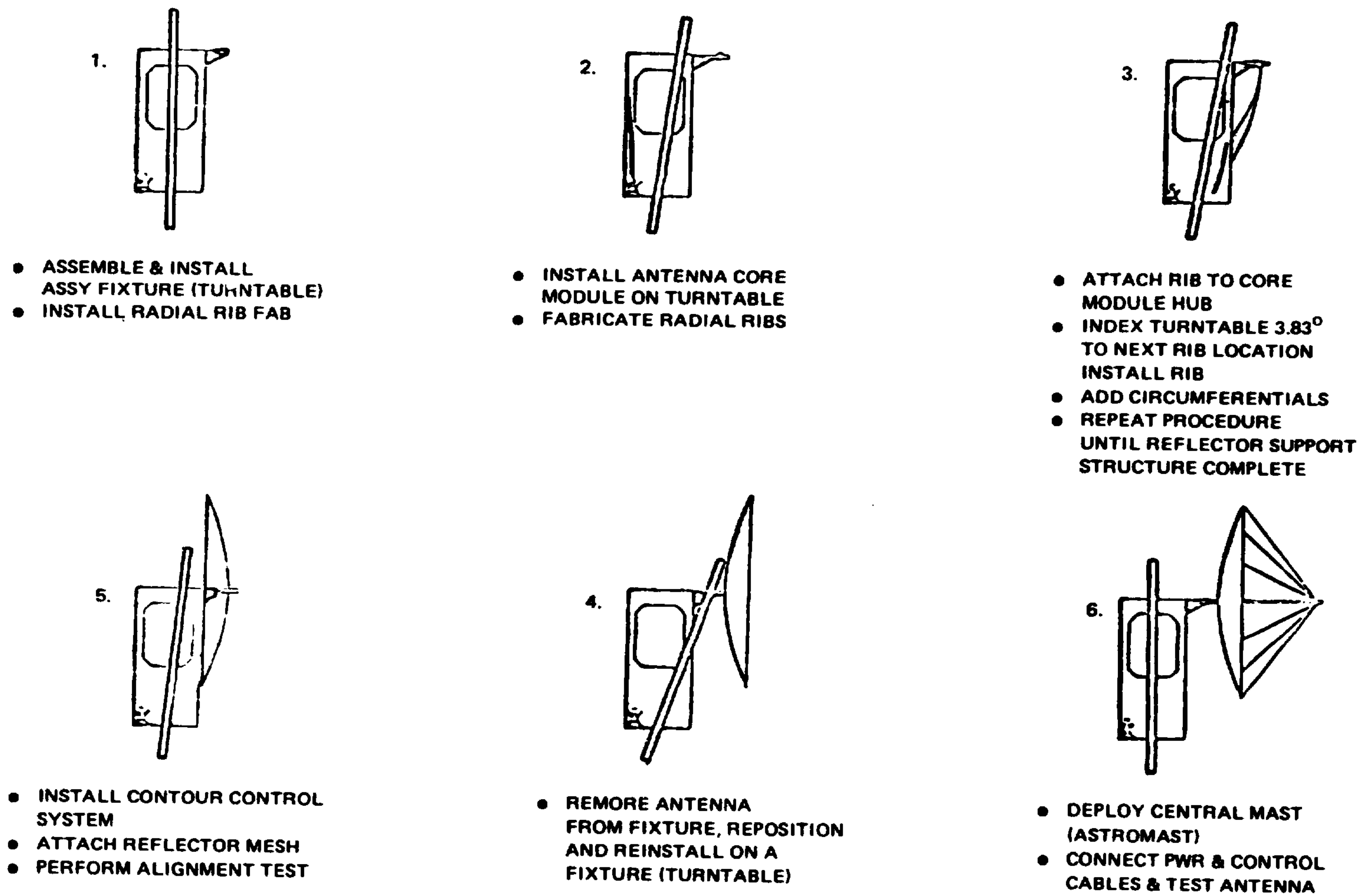
The MRWS functions during the 100-m radiometer assembly is summarized in Figure 82. The assembly function has been estimated to require 45 days using two 8-hr shifts per day. The first step requires that the MRWS retrieve a fixture (turntable) from logistic module that transported the device 100-m along the boom. The MRWS then installs the fixture on the work platform requiring a crane reach of at least 10 m. The MRWS then retrieves an automated fabrication machine from the Shuttle cargo bay and installs it on the work platform. In the second step, the MRWS retrieves the antenna core module from a logistics module that transported it to the turntable. The MRWS then berths the device. During the third step, the MRWS is required to retrieve rib sections from the fab module, transport them to the turntable, and mate them to the core module hub. Circumferentials are then added to stiffen the antenna structure. In the fifth step, the antenna mesh is mated to the contour control devices that are located at each rib circumferential intersection. In the fourth step, the MRWS is required to maneuver the entire antenna (100-m dia and 16,000 Kg) for final deployment of the antenna central mast and feed system.

2.3.4 Task Analysis

The two major operational systems for the closed cabin cherry picker are the stabilizer and dexterous manipulator. The stabilizer is used to hold payloads during railed carriage motion or crane movement. It is also used for vernier adjustments of payloads and to stabilize the crane arm/MRWS during detailed dexterous manipulator work. The dexterous manipulators are used to grasp small payloads or tools, move these devices around the immediate work site, push-pull connecting levers, insert or withdraw bolts and fittings, and twist fasteners and other connection locks.

Table 20 summarizes the characteristics of the elements being handled and the type fitting used in the antenna or supporting equipment assembly. These characteristics should be used to determine grappler requirements for the transport and handling functions, and the fitting approach utilized to determine dexterous manipulator performance requirements.

Table 21 summarizes the tasks performed with the dexterous manipulator along with an estimate of the task time and manipulator functions. The



2198-092

Figure 82. 100-m Radiometer Assembly Sequence

TABLE 20

WORKSITE ELEMENTS 100-m RADIOMETER CONSTRUCTION (Sheet 1 of 3)

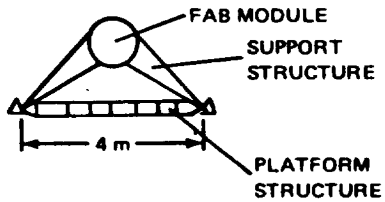
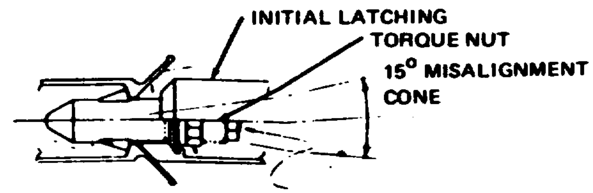
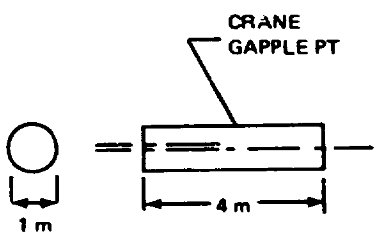
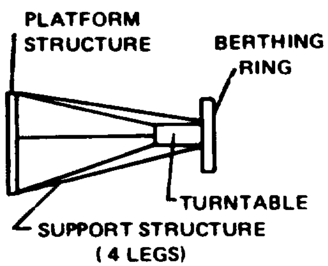
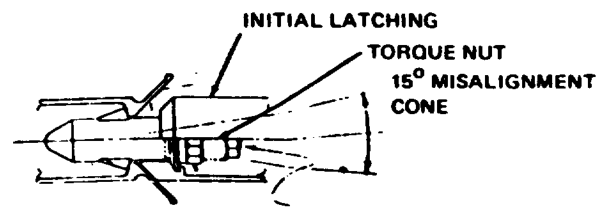
ELEMENT	CHARACTERISTICS	FITTINGS
1 – FAB MODULE SUPPORT STRUCTURE 	• 2.5-m LONG TAPERED BEAM • 0.1 m AT APEX • 0.7 m AT TRUNK • 20 kg MASS	5 ON EACH SUPPORT BEAM 
2 – FAB MODULE 	• 2000 kg MASS	N/A
3 – ANTENNA TURN TABLE 	• 6-m LONG TAPERED SUPPORT STRUCTURE • TURNTABLE 2-m HIGH WITH 2-m DIA BERTHING RING • MASS = 2000 kg (APPROX)	5 ON EACH SUPPORT BEAM 

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TABLE 20

WORKSITE ELEMENTS 100-m RADIOMETER CONSTRUCTION (Sheet 2 of 3)

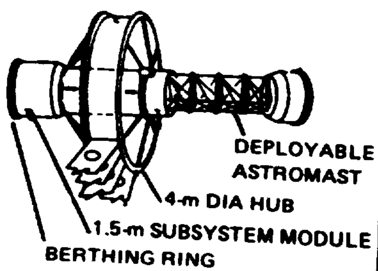
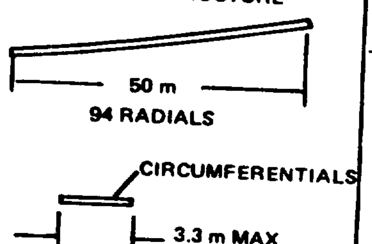
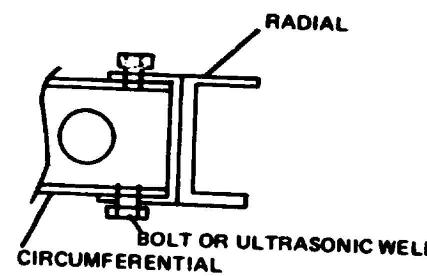
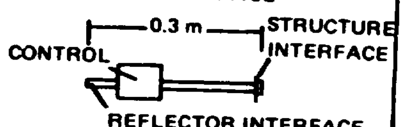
ELEMENT	CHARACTERISTICS	FITTINGS
4 – ANTENNA HUB 	1800 kg MASS	BERTHING RING
5.0 ANTENNA STRUCTURE 	• 50 m COMPOSITE CONTOURED RADIALS ~ 20 kg • COMPOSITE CIRCUMFERENTIALS 3.3-m LONG (MAX.) ~1 kg (MAX.)	
6.0 CONTOUR CONTROL DEVICE 	• 0.3-m LONG ACTIVE CONTOUR CONTROL DEVICE • 0.5 kg PER UNIT • 1504 UNITS	• AUTOMATED OPERATION • INSERT & LOCK TYPE DEVICE • RUNNING CABLE CLIPPED TO RADIALS

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TABLE 20

WORKSITE ELEMENTS 100-m RADIOMETER CONSTRUCTION (Sheet 3 of 3)

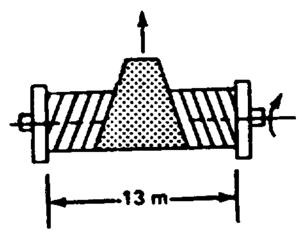
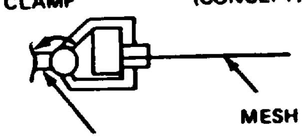
ELEMENT	CHARACTERISTICS	FITTINGS
7.0 RF MESH SPOOL DISPENSOR 	• 25 kg PER SPOOL • MRWS CARRIER PROVISIONS TO CARRY DISPENSER	

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TABLE 21

MISSION OPERATION/DEXTEROUS MANIPULATOR FUNCTIONS (Sheet 1 of 2)

MISSION	CHERRY PICKER OPERATIONS USING MANIPULATOR	FUNCTION: GRASP/ VISE	MOVE	PUSH-PULL	INSERT	WITHDRAW	TWIST	HOLD -2 ARM OPERATION	TASK TIME (hr:min)
100-m RADIOMETER CONSTRUCTION *	1.0 MOUNT ANTENNA TURNTABLE								
	1.1 DEPLOY ANTENNA SUPPORT STRUCTURE	●		●					:30
	1.2 ATTACH ANTENNA MAST STRUCTURE TO TURNTABLE	●	●*		●		●		:30
	1.3 INSTALL B ANTENNA STAYS	●	●		●			●	:40
	1.4 REMOVE TURNTABLE FROM TRANSPORTER	●				●			:20
	1.5 ATTACH TURNTABLE TO PLATFORM FASTEN TENSION STAYS	●		●	●		●	●	2:00
	1.6 CONNECT POWER CABLES	●	●		●		●	●	1:00
	2.0 MOUNT RIB FABRICATION MODULE								
	2.1 REMOVE & DEPLOY FAB MOD SUPPORT STRUCTURE	●	●	●		●		●	:30
	2.2 ATTACH STRUCTURE TO PLATFORM	●	●		●		●	●	1:00
	2.3 INSTALL FAB MODULE ON PLATFORM	●		●	●		●		2:00
	2.4 CONNECT POWER CABLES	●	●		●		●	●	:30
	2.5 INSTALL MATERIAL DISPENSERS	●		●	●		●	●	:30

* MAY BE GRAPPLER FUNCTION

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TABLE 21

MISSION OPERATION/DEXTEROUS MANIPULATOR FUNCTIONS (Sheet 2 of 3)

MISSION	CHERRY PICKER OPERATIONS USING MANIPULATOR	FUNCTION: GRASP/ VISE	MOVE	PUSH-PULL	INSERT	WITHDRAW	TWIST	HOLD 2 ARM OPERATION	TASK TIME (hr:min)	
100-m RADIOMETER (CONTINUED)	3.0 INSTALL ANTENNA HUB	●		●	●		●		1:00	
	4.0 CONSTRUCT ANTENNA DISH STRUCTURE									
	4.1 INSTALL MATERIAL DISPENSERS	●	●*	●	●		●		:30	
	4.2 MANUFACTURE RIBS (94)								47:00	
	4.3 REMOVE RIBS & STOW	●		●	●				:15	
	4.4 POSITION RIBS TO HUB	●	●*	●	●		●	●	23:30	†
	4.5 FASTEN RIBS TO HUB	●		●	●		●	●	23:30	†
	4.6 INDEX HUB								8:00	†
	4.7 INSTALL CIRCUMFERENTIONALS	●	●*	●	●		●	●	128:00	†
	4.8 INSTALL STITCH CIRCUMFERENTIONALS	●	●*	●	●		●	●	1:20	††
	4.9 ADJUST CIRCUMFERENTIONALS TENSION TIES	●		●				●	4:00	
	5.0 INSTALL ANTENNA REFLECTOR MESH									
	5.1 LOAD DISPENSOR	●	●*		●		●		31:00	
	5.2 MOUNT THERMAL TENSIONERS	●**							284:00	
	5.3 CONNECT POWER & CONTROL CABLES	●	●	●	●		●	●	24:00	

* MAY BE GRAPPLER FUNCTION

** SHOULD BE AUTOMATED OPERATION (PROCESS CYCLE = 1504 ; 6 DEVICES/hr)

† 94 REPETITIVE OPS   †† 1472 REPETITIVE OPS

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TABLE 21

MISSION OPERATION/DEXTEROUS MANIPULATOR FUNCTIONS (Sheet 3 of 3)

MISSION	CHERRY PICKER OPERATIONS USING MANIPULATOR	FUNCTION: GRASP/ VISE	MOVE	PUSH-PULL	INSERT	WITHDRAW	TWIST	HOLD -2 ARM OPERATION	TASK TIME (hr:min)
100-m RADIOMETER (CONTINUED)	5.4 REMOVE REFLECTIVE MESH SPOOL DISPENSORS	●	●			●		●	8:00
	5.5 MOUNT SPOOL TO HUB	●	●		●		●		4:00
	5.6 DEPLOY MESH GORES	●	●	●					12:00**
	5.7 ATTACH TO RIB END	●			●		●	●	12:00**
	5.8 ATTACH CONTOUR CONTROL TENSION TIES	●		●	●			●	251:00 †
	5.9 REMOVE & STOW MESH SPOOLS	●	●*			●		●	8:00
	6.0 REPOSITION DISH	●		●	●		●		1:00

* MAY BE GRAPPLER FUNCTION † 1504 REPETITIVE OPERATIONS

** 24 OPERATIONS

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relationship between manipulator functions and manipulator design factors are:

Manipulator Function	Design Impact
1 Grasp/Vise	• End effector spread • End effector grip force • Sensor paramteres
2 Move	• Length • Degrees of Freedom • Dexterity • Tip speed • Tip force
3 Push-Pull	• Tip force • Force feel
4 Insert	• Accuracy (Resolution) • Force feel • Dexterity
5 Withdraw	• Tip force • Force feel • Dexterity
6 Twist	• Wrist dexterity • Wrist torque
7 Hold	• Arm stiffness • Need for 2 arms

Figure 83 illustrates the geometrics for installation of the antenna wire mesh. The MRWS cabin geometric illustrated is typical of a one-man crew station that is mounted to a base, with stabilizer, and crane arm interface fixture. A 5-ft manipulator arm was found to be adequate for this task. Note that the stabilizer is disengaged because there is no convenient place for a grapple fixture. This situation is typical, suggesting that the crane arm stiffness must be sufficient to perform cherry picker functions without the aid of a stabilizer.

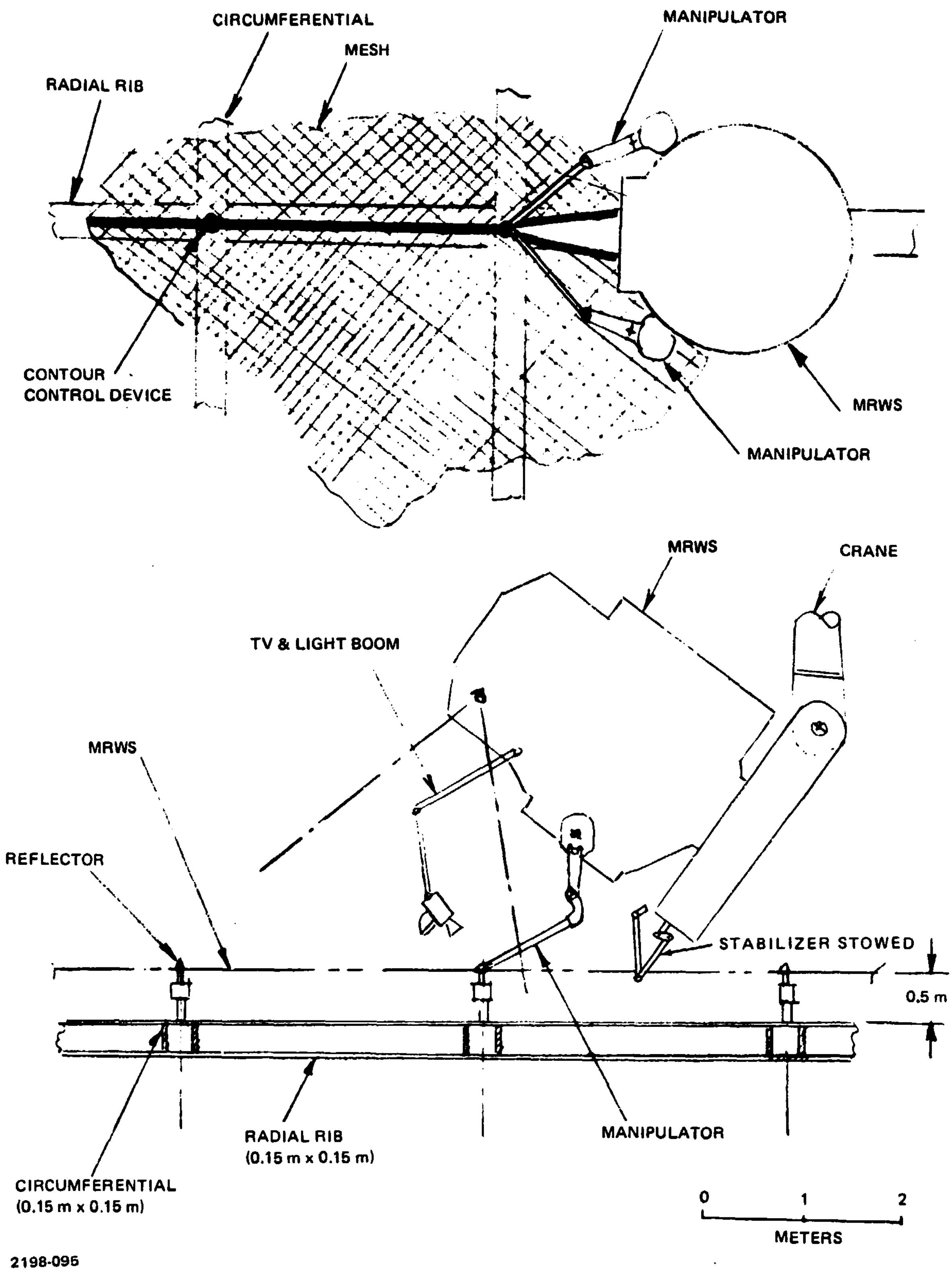


Figure 83. Antenna Mesh Reflector Installation

2.3.5 Closed Cabin Cherry Picker Requirements

2.3.5.1 Cabin Design - A one-man crew station appears adequate for performing the antenna assembly operations. The task times (Table 21) are relatively long allowing serial operations of the crane movement, stabilizer functions, and dexterous manipulator functions. The cabin should be designed to be compatible with the Shuttle EC&S for shirt sleeve transfer of crew (14.7 psi, 2 gas system) and for two 8-hr shifts per day for 6 days without resupply.

2.3.5.2 Manipulator/Stabilizer Design - The stabilizer should be designed to handle payloads as large as 100 m in diameter with a mass as great as 16,000 kg, and the dexterous manipulator should be at least 5-ft long.

2.3.5.3 Controls and Displays - Hand controllers for simultaneous control of two dexterous manipulators and hand controllers for operation of the grappler should be provided.

2.3.5.4 Power - The MRWS should utilize construction base power routed along the rail system and up the crane arm.

2.3.6 Issues to be Resolved

- One versus two-man crew cabin
- Definition of grappler design requirements
- Definition of dexterous manipulator design requirements
- Definition of cabin controls and displays
- Power and lighting requirements definition.

2.3.7 References

Orbital Construction Demonstration Study, Final Report Col II.
GAC NSS-OC-RP-012, June 1977.

2.4 61-m COMMUNICATIONS ANTENNA (MULTIBEAM ANTENNA)

2.4.1 Mission Description

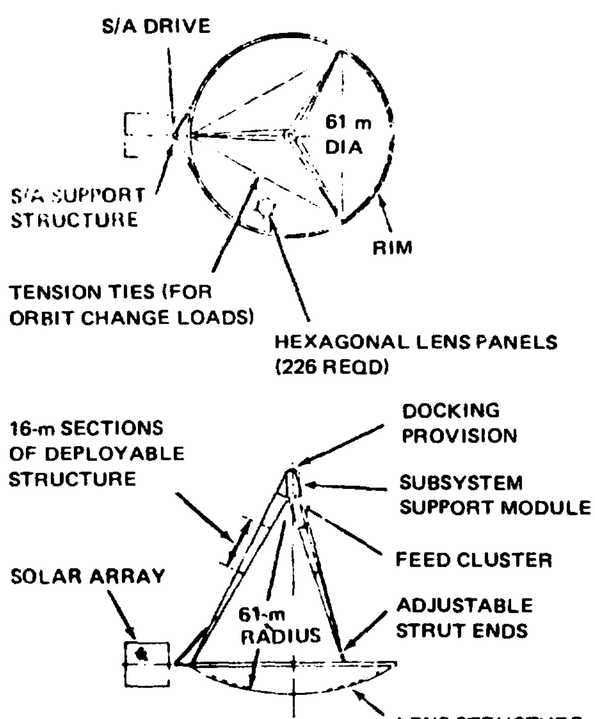
This mission demonstrates the orbital assembly and test of a bootlace lens, multibeam communications satellite. It ultimately will be positioned in geostationary orbit to provide highly directional beams that receive and transmit signals to and from 256 locations in the United States. The primary objective is the construction and testing of a large bootlace lens antenna from a space construction base.

2.4.2 Spacecraft Description

The antenna configuration (Figure 84) features a large lens aperture, a subsystem module, three long struts, and a solar array. The lens structure consists of panels, generally of hexagonal shape, connected together to form a spherical shell (Figure 85). The panels are sized to allow efficient packing in the Shuttle cargo bay (4.5-m dia). The lens structure is made up of the equivalent of 226 panels, partial panels being required to complete the circular shape of the aperture. Adjacent panels are held together with an interface connection plate and three fasteners. Each connection plate is fitted with a retroflector on the feed side of the lens structure to assist in the subsequent alignment and conformation analysis. The completed lens is then fitted with a rim around the outside to stiffen the shell and provide an attachment for the support struts. The rim is a preformed member made of thin material that can be elastically flattened and rolled up to enhance Shuttle stowage. The aperature is completed with the addition of the support strut fittings (3) and the tension ties. The tension ties relieve the rim and lens panels of the spreading load induced by the geometry of the support struts during acceleration from low earth to geostationary orbit.

The arrangement of the various components of the lens panels is illustrated in Figure 86. The hexagon lens panels are designed to allow folding the earth side honeycomb panel to enhance Shuttle packing. Upon removal from the cargo bay, the panel will be deployed. The panel spacing (0.3 m) was chosen to given sufficient delay line length to permit the required delay effect for a 30.5-m radius antenna system.

The support structure struts consist of end-to-end sections of deployable structure. Assembly of the strut structure is accomplished in an end-to-end assembly of secuons. The struts are fitted with a terminal connection at the lens end of the strut to allow adjustment.



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ELECTRICAL POWER REQUIREMENTS	POWER (WATTS)
COMMUNICATIONS ELECTRONICS	43,785
TT & C	65
FLIGHT CONTROL	50
PROPULSION	21
THERMAL CONTROL	40
ELECTRICAL POWER & INTEGRATION	20
TOTAL	43,980

MASS PROPERTIES	LBM	Kg
• ANTENNA APERTURE		
– LENS PANELS	19,460	8,825
– APERTURE RIM	2,063	936
• FEED SUPPORT STRUCTURE	1,875	850
• SUBSYSTEM MODULE		
– STRUCTURE	125	57
– FEED/DUPLEXER ASSEMBLY	156	71
– COMMUNICATIONS ELECTRONICS	563	255
– TT/C	37	17
– FLIGHT CONTROL	147	67
– PROPULSION	87	39
– THERMAL CONTROL	63	29
– ELECTRICAL POWER & INTEGRATION	2,125	964
• SOLAR ARRAY	750	340
• PROPELLANT	280	127
TOTAL	27,731	12,577

Figure 84. Multibeam Communications Antenna General Arrangement

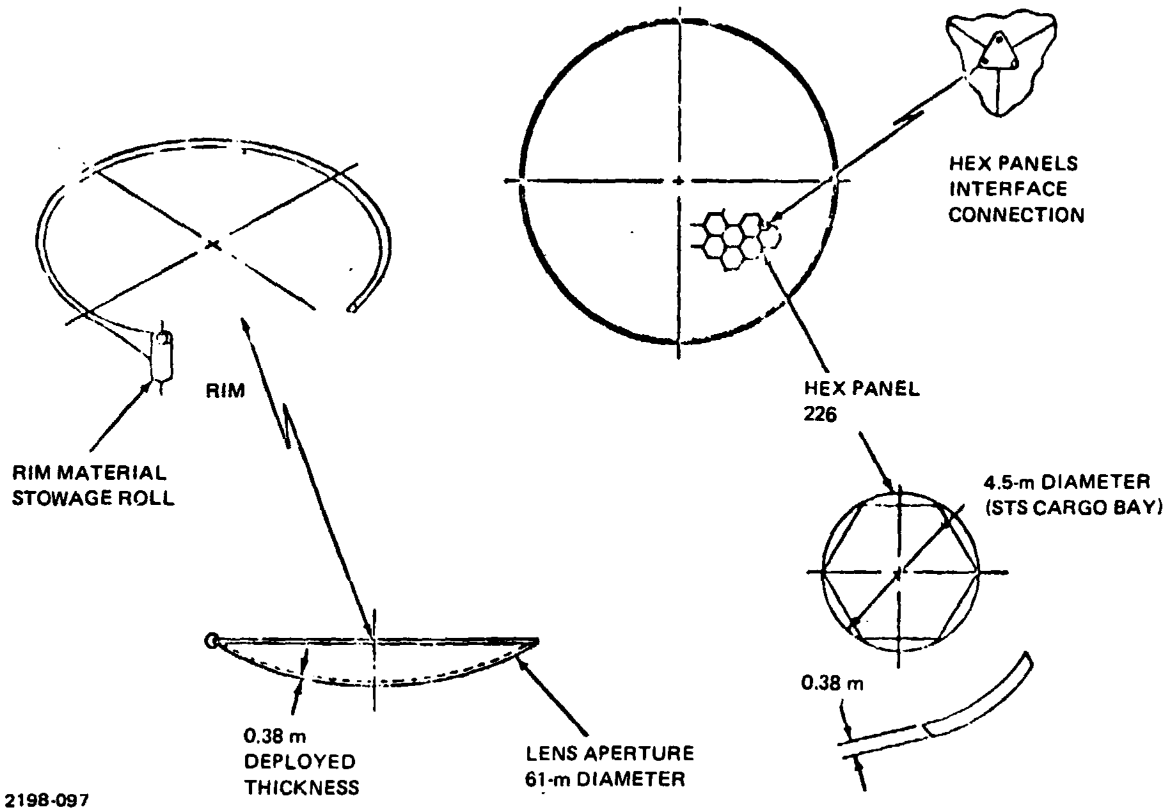


Figure 85. Lens Aperture Structure Design Concept

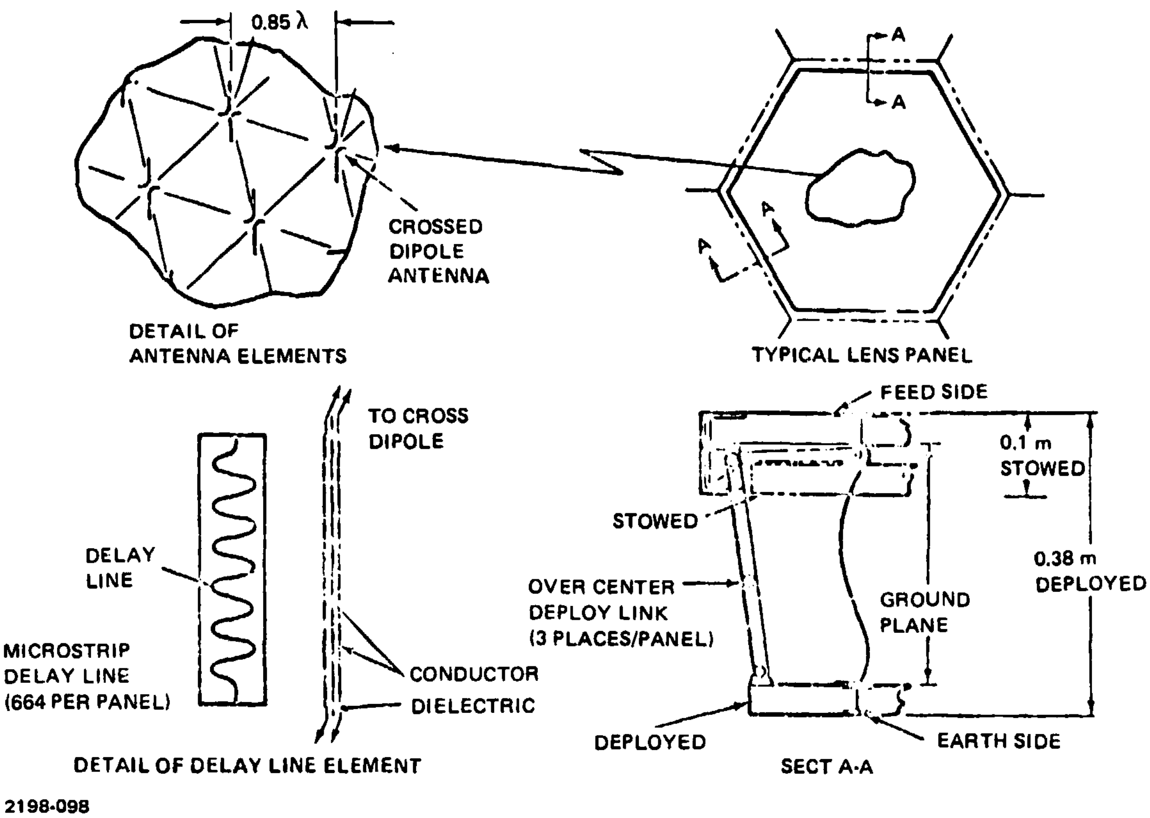


Figure 86. Lens Bootlace Element Design Concept

2.4.3 Support Functions and Mission Scenario

MRWS support functions were established for a railed closed cabin cherry picker operating on the 108m long boom. The functional requirements (Figure 87) are the same as those for the radiometer construction for Functions 1.0 through 6.0. The remaining functions are peculiar to the communications antenna construction and are discussed in the next section.

2.4.4 Task Analysis

Table 22 summarizes the characteristics of the elements being handled and the type fitting used in the antenna or supporting equipment assembly. The characteristics listed under handling requirements generally apply to the stabilizer and those under fittings to the dexterous manipulator.

Table 23 summarizes the tasks performed with the dexterous manipulators along with an estimate of the task time and manipulator functions.

Components for the antenna will be delivered to the construction base by the Shuttle on racks carried in the cargo bay. An arrangement for stowing the required components for the 61-m multibeam communications antenna is illustrated in Figure 88 (Grumman Space Station Analysis Study Report NSS-SS-RE007). The arrangement shows that two Shuttle flights will be sufficient to deliver the required antenna components to the construction base for assembly.

Hexagon-shaped panels containing the bootlace elements will be attached by the MRWS to form the spherical shell making up the lens aperture. Connectors at the apex intersections of the panels provide structural attachment. A cherry picker will be used to handle the components and connectors. The lens structure will be assembled on a turntable fixture attached to the platform structure. The turntable will be rotated as required to bring the work area within easy reach of the rail mounted cherry picker. The rim material is applied and fastened to the edge of the completed lens. Sections of prepackaged structure are deployed and attached end-to-end to form the support struts.

The subsystems module is brought up fully assembled within the Shuttle cargo bay. The module contains the antenna feed system, the transponder

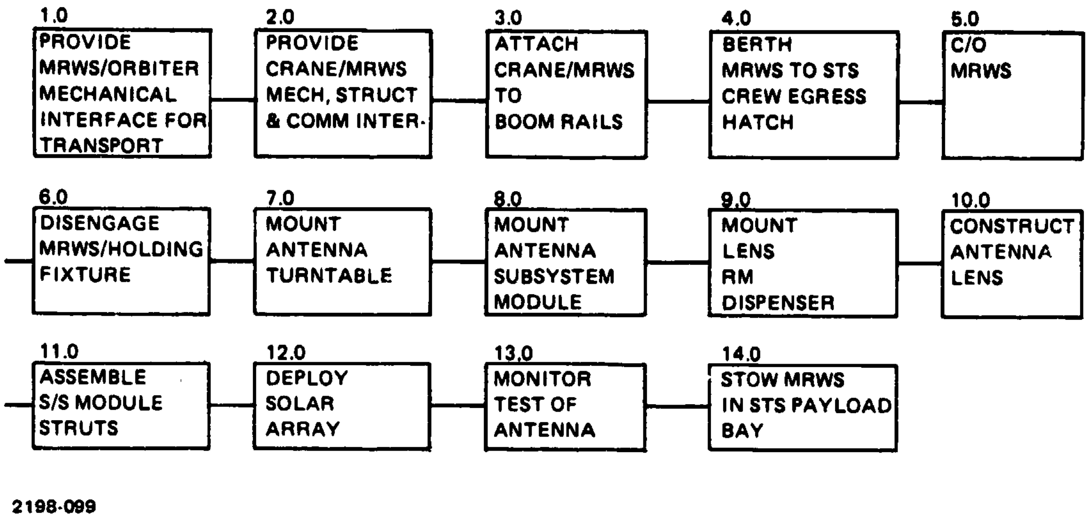


Figure 87. 61-m Communications Antenna Construction MRWS Support Functions – Railed Closed Cabin Cherry Picker

TABLE 22

WORKSITE ELEMENTS – 61-m MULTIBEAM ANTENNA (Sheet 1 of 3)

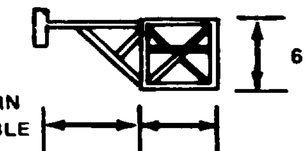
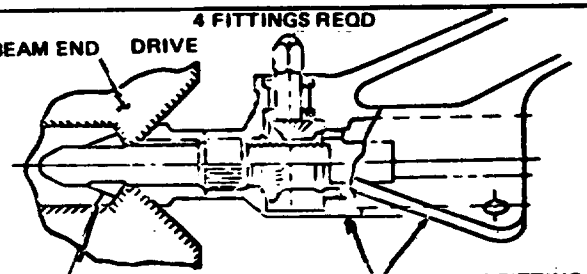
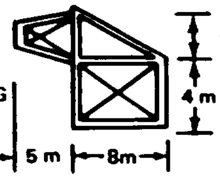
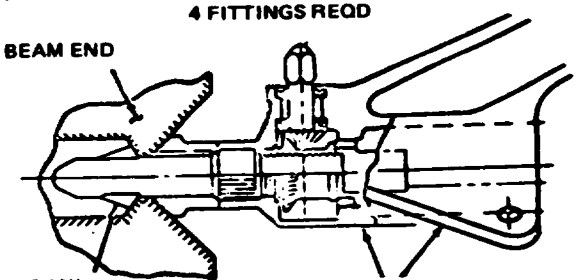
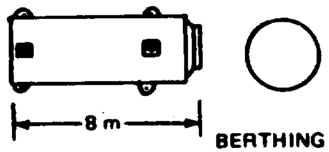
ELEMENT	CHARACTERISTICS	FITTINGS
1 – LENS STRUCTURE HOLDING FIXTURE 	TURNTABLE 2-m DIA BERTHING RING 2-m HIGH MASS 2000 kg (APPROX)	4 FITTINGS REQD 
2 – SUBSYSTEM MODULE HOLDING FIXTURE 	TURNTABLE 2-m DIA BERT' ING RING MASS 2000 kg (APPROX)	4 FITTINGS REQD 
3 – SUBSYSTEM MODULE 	1499 kg MASS	BERTHING RING

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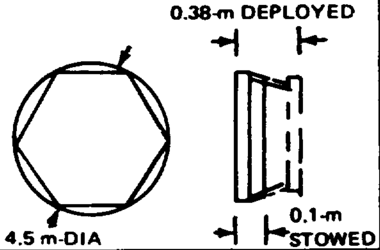
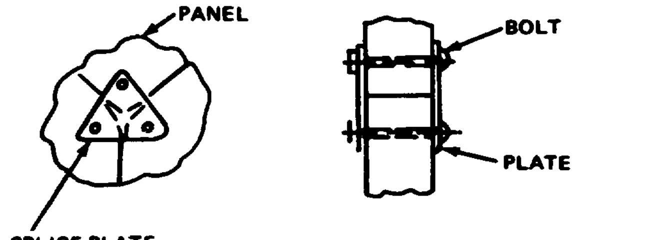
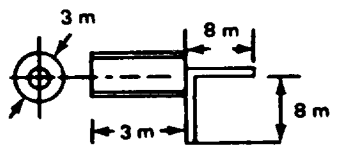
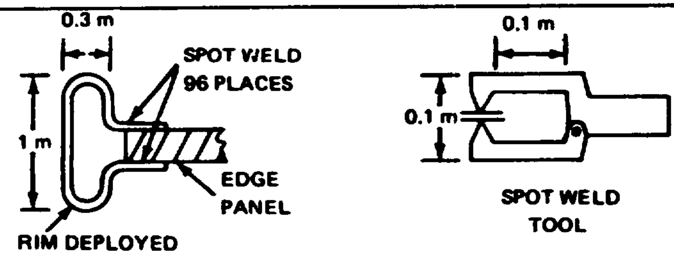
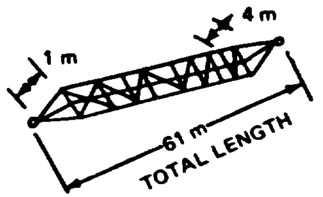
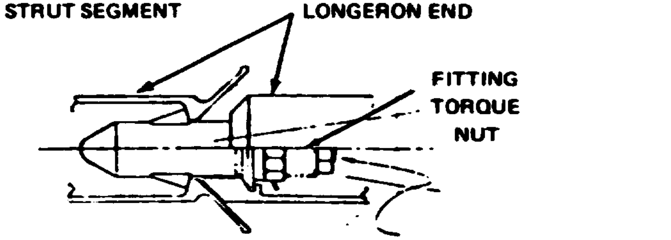
TABLE 22

WORKSITE ELEMENTS – 61-m MULTIBEAM ANTENNA (Sheet 2 of 3)

ELEMENT	CHARACTERISTICS	FITTINGS
4 – LENS PANEL 	35 kg EACH 226 PANELS TOTAL	
5 – LENS RIM DISPENSOR 	936 kg	
6 – LENS SUPPORT STRUTS  3 STRUTS REQUIRED	EACH STRUT MADE UP OF 4 TAPERED SECTION BEAMS 67 kg EACH	INSTALLED ON END OF EACH STRUT SEGMENT 

2198-100(2)

TABLE 22

WORKSITE ELEMENTS – 61-m MULTIBEAM ANTENNA (Sheet 3 of 3)

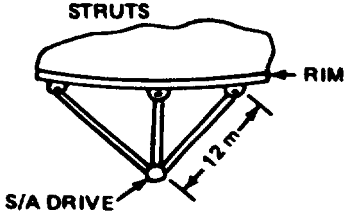
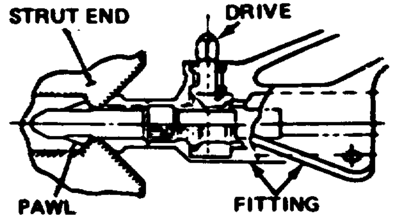
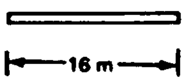
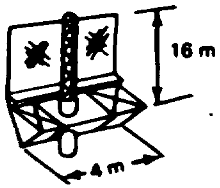
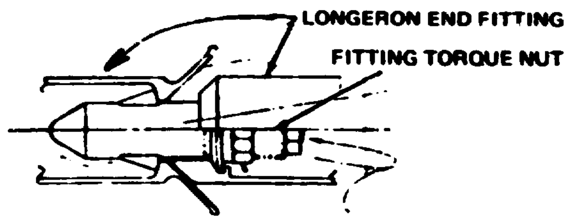
ELEMENT	CHARACTERISTICS	FITTINGS
7 – SOLAR ARRAY STRUTS 	FOUR 1-m BEAMS 12 - m LONG MASS 15 kg EACH	INSTALLED ON EACH STRUT END 
8– SOLAR ARRAY STEM TUBES  TELESCOPING TUBE	SIX TUBES INSTALLED AT ENDS OF SOLAR ARRAY MASS 10 kg EACH	N/A
7 – SOLAR ARRAY ELEMENTS 	340 kg TOTAL ARRAY MASS SIZE ARRAY 16 m x 16 m EACH ARRAY ELEMENT 4-m WIDE	 3 FITTING AT EACH ELEMENT INTERCONNECTION

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TABLE 23

MISSION OPERATION/DEXTEROUS MANIPULATOR FUNCTIONS (Sheet 1 of 3)

MISSION	CHERRY PICKER OPERATIONS USING MANIPULATOR	FUNCTION: GRASP/ VISE	MOVE	PUSH-PULL	INSERT	WITHDRAW	TWIST	HOLD -2 ARM OPERATION	OPERATIONS TIME (hr:min)
61-m COMMUNICATIONS ANTENNA	1.0 MOUNT ANTENNA TURNTABLE								(5:00)
	1.1 DEPLOY TURNTABLE SUPPORT STRUCTURE	●		●					:45
	1.2 ATTACH STRUCTURE TO TURNTABLE	●	●		●		●		:45
	1.3 INSTALL STAYS	●	●		●			●	:30
	1.4 REMOVE TURNTABLE FROM TRANSPORTER	●				●			:30
	1.5 ATTACH TURNTABLE TO PLATFORM & TENSION STAYS	●		●	●		●	●	1:30
	1.6 CONNECT POWER CABLES	●	●		●		●	●	1:30
	2.0 MOUNT SUBSYSTEM MODULE								(4:00)
	2.1 DEPLOY SUBSYSTEM MODULE SUPPORT STRUCTURE	●	●*	●	●		●	●	:30
	2.2 ATTACH STRUCTURE TO PLATFORM	●		●	●		●	●	:30
	2.3 ALIGN STRUCTURE TO ANTENNA TURNTABLE	●		●*					:30
	2.4 CONNECT POWER CABLES	●			●		●		:30
	2.5 REMOVE SUBSYSTEM MODULE FROM FIXTURE								1:30
	2.6 ATTACH TO PLATFORM & CHECKOUT	●			●		●	●	1:00

*MAY BE STABILIZER FUNCTION

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TABLE 23

MISSION OPERATION/DEXTEROUS MANIPULATOR FUNCTIONS (Sheet 2 of 3)

MISSION	CHERRY PICKER OPERATIONS USING MANIPULATOR	FUNCTION: GRASP/ VISE	MOVE	PUSH-PULL	INSERT	WITHDRAW	TWIST	HOLD -2 ARM OPERATION	OPERATIONS TIME (hr:min)
61-m COMMUNICATIONS ANTENNA (CONTINUED)	3.0 MOUNT LENS RIM DISPENSER								(2:30)
	3.1 DEPLOY DISPENSER SUPPORT STRUCTURE	●	●*	●	●		●	●	:30
	3.2 ATTACH STRUCTURE TO PLATFORM	●			●		●		:30
	3.3 ATTACH DISPENSER TO SUPPORT STRUCTURE	●	●*		●		●	●	1:30
	3.4 CONNECT POWER CABLE	●			●		●	●	:30
	4.0 CONSTRUCT LENS								(182:00)
	4.1 LOAD LENS PANELS ON TRAVELLER & TRANSPORT								:30
	4.2 POSITION LENS TO HUB & FASTEN	●		●*	●		●	●	1:00
	4.3 ATTACH LENS PANEL TO HUB PANEL	●		●*	●		●	●	:30
	4.4 REPEAT 224 TIMES								146:00
	4.5 FEED RIM FROM DISPENSER & FASTEN TO PANELS	●		●	●		●	●	29:00
	4.6 MOUNT STRUCT ADAPTERS	●			●		●		3:00
	4.7 MOUNT SOLAR ARRAY FITTINGS	●	●*		●		●		2:00

*MAY BE STABILIZER FUNCTION

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TABLE 23

MISSION OPERATION/DEXTEROUS MANIPULATOR FUNCTIONS (Sheet 3 of 3)

MISSION	CHERRY PICKER OPERATIONS USING MANIPULATOR	FUNCTION: GRASP/ VISE	MOVE	PUSH-PULL	INSERT	WITHDRAW	TWIST	HOLD -2 ARM OPERATION	OPERATIONS TIME (hr:min)
61-m COMMUNICATIONS ANTENNA (CONTINUED)	5.0 ASSEMBLE STUTS								(10:00)
	5.1 DEPLOY STRUT SECTIONS & TRANSPORT	●		●				●	1:00
	5.2 ASSEMBLE STRUT ON PLATFORM	●		●	●		●	●	1:00
	5.3 POSITION STRUTBETWEEN LENS & SUBSYSTEM MODULE								:45
	5.4 ATTACH STRUT TO LENS & SUBSYSTEM MODULE	●		●	●		●	●	5:30
	5.5 ALIGN SUBSYSTEM MODULE TO LENS	●		●*					1:00
	5.6 INSTALL & ADJUST TENSION TIES	●	●	●	●			●	:45
	6.0 SOLAR ARRAY DEPLOYMENT								(7:00)
	6.1 DEPLOY STRUTS (AUTO)								:15
	6.2 ATTACH STRUTS TO SOLAR ARRAY DRIVE	●			●		●	●	:45
	6.3 ASSEMBLE STRUTS TO LENS RIM	●			●		●	●	1:00
	6.4 INSTALL SOLAR ARRAYS & DEPLOY	●			●		●	●	4:30
	6.5 INSTALL POWER CABLE	●			●		●	●	:30

*MAY BE STABILIZER FUNCTION

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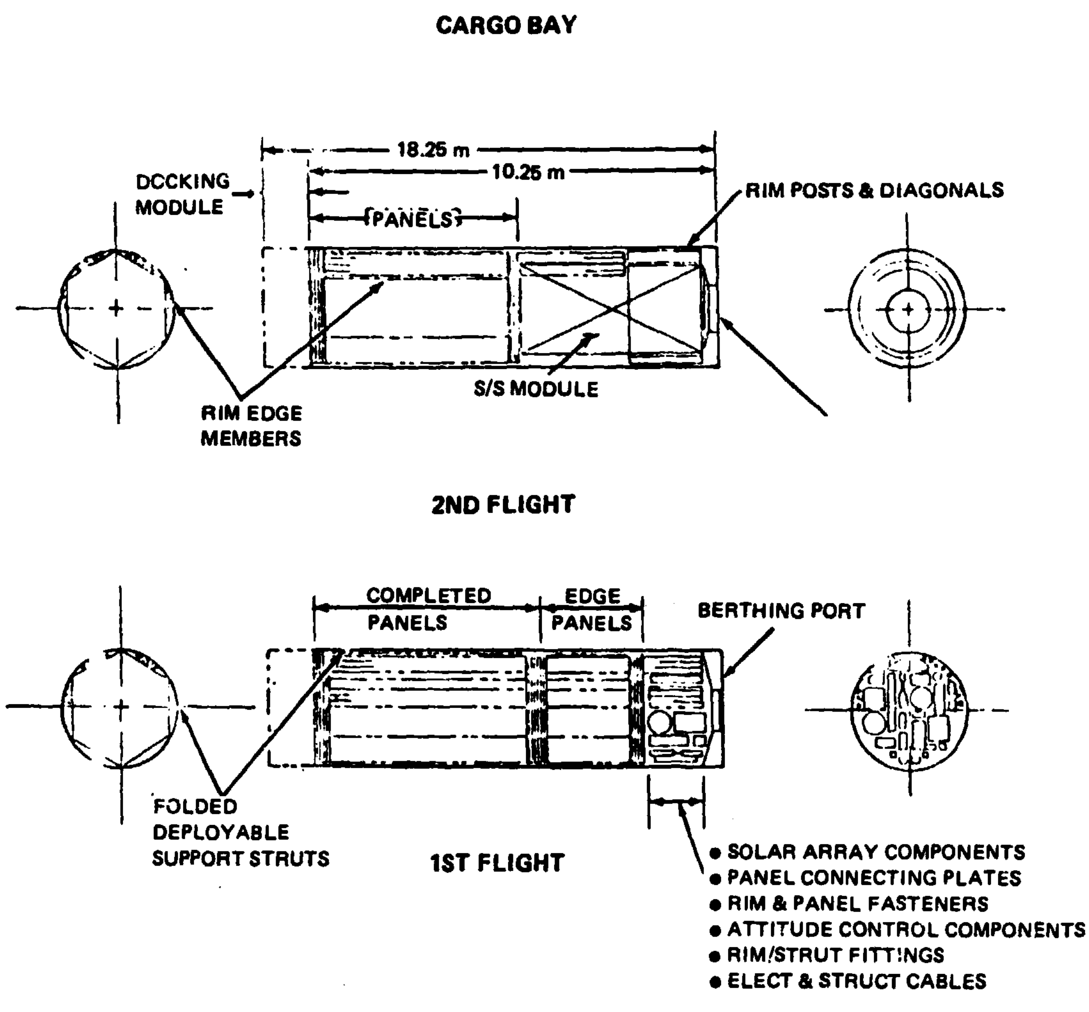

Figure 88. Multibeam Communications Antenna Shuttle Packing

electronics, and the remaining subsystems required to make the multibeam antenna self sufficient. The subsystem module is equipped with a docking provision on one end to allow attachment of a vehicle for orbit change maneuvers and to allow handling during construction and testing.

The support struts are installed between the subsystem module and the lens rim. The ends of the support struts are adjustable to align the axis of the lens to the feed focal point.

2.4.4.1 Antenna Aperature Assembly - The major block of time needed to construct the antenna is the assembly of the aperature (182 hr in Figure 85). Figure 89 defines the dimensions of the hexagon panel handled by the MRWS and the approach path taken by the crane/cherry picker. This function is similar to a docking maneuver in which necessity of the target area is important. The relatively large size of the aperature component makes direct visibility difficult and the need for CCTV with a camera located on a boom for reach around capability is apparent.

Figure 90 illustrates the approach for fastening the hexagon panels. With the joining systems outlined in NAS9-14916, two dexterous manipulators are required. An arm length of 5 to 6 ft appears adequate for this function.

As in most of the tasks analyzed, there is difficulty in grappling the work site to stiffen the MRWS/crane load path. The only location available is at the edge of the hexagon panels themselves requiring as a result, the need for grapple fixtures. The addition of grapple fixtures to the mission article is a mass and complexity penalty that could be avoided if the crane arm were designed with adequate stiffness not to require a stabilizer function.

2.4.4.2 Antenna Rim Assembly - Figures 91 and 92 present a concept for installing the antenna rim. The rim dispenser is located on the edge of the work platform (32-m wide). As the performed rim is unrolled the MRWS welds it to the outer panels of the aperature. From Figure 92, the need for two manipulator arms is shown, one arm for stabilizing the rim and the other to perform the welding operation. The need for a TV camera mounted to a boom is also indicated. In this task, the location of visible grapple points is not apparent.

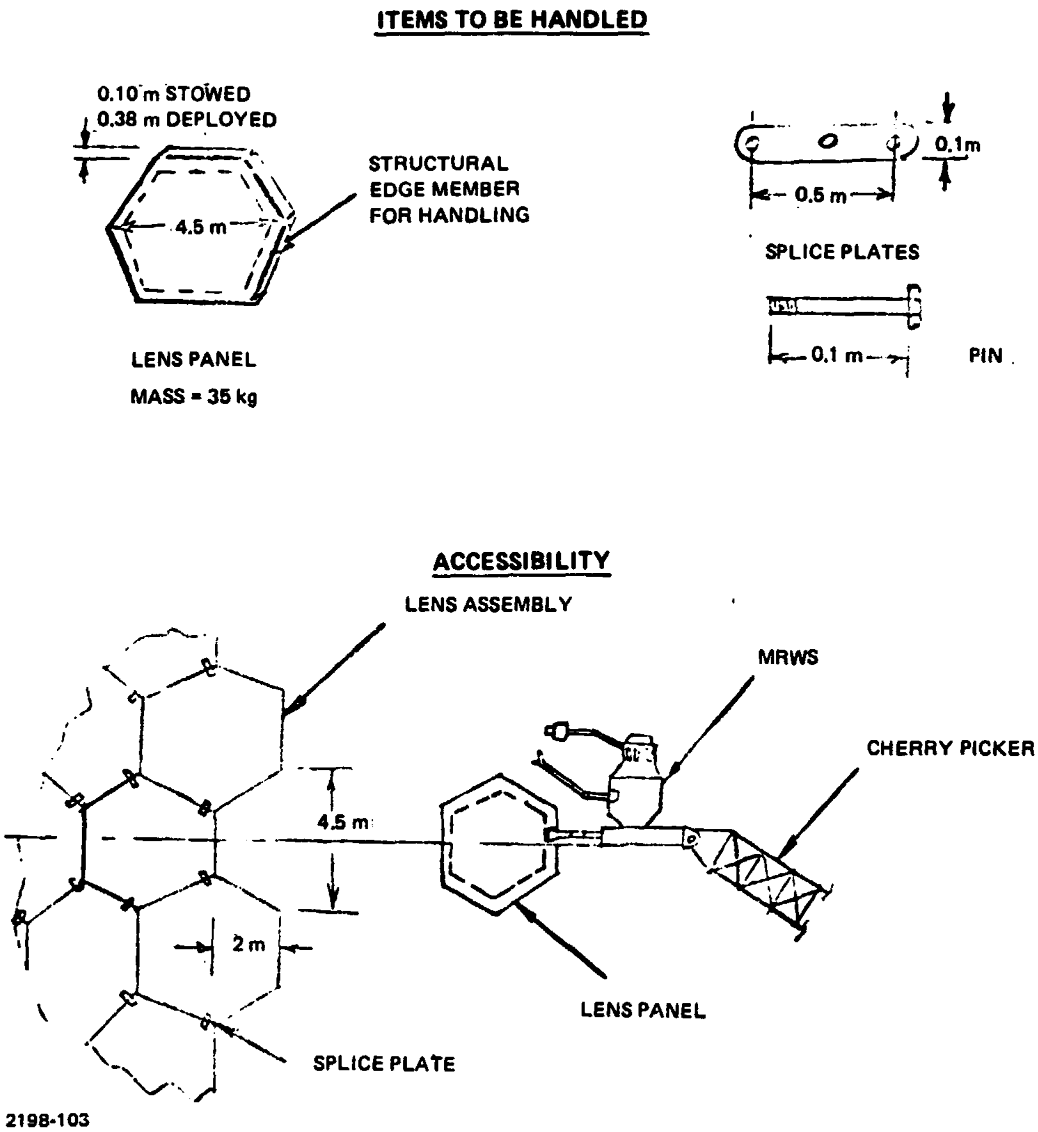

Figure 89. 61-m Communications Antenna Lens Assembly

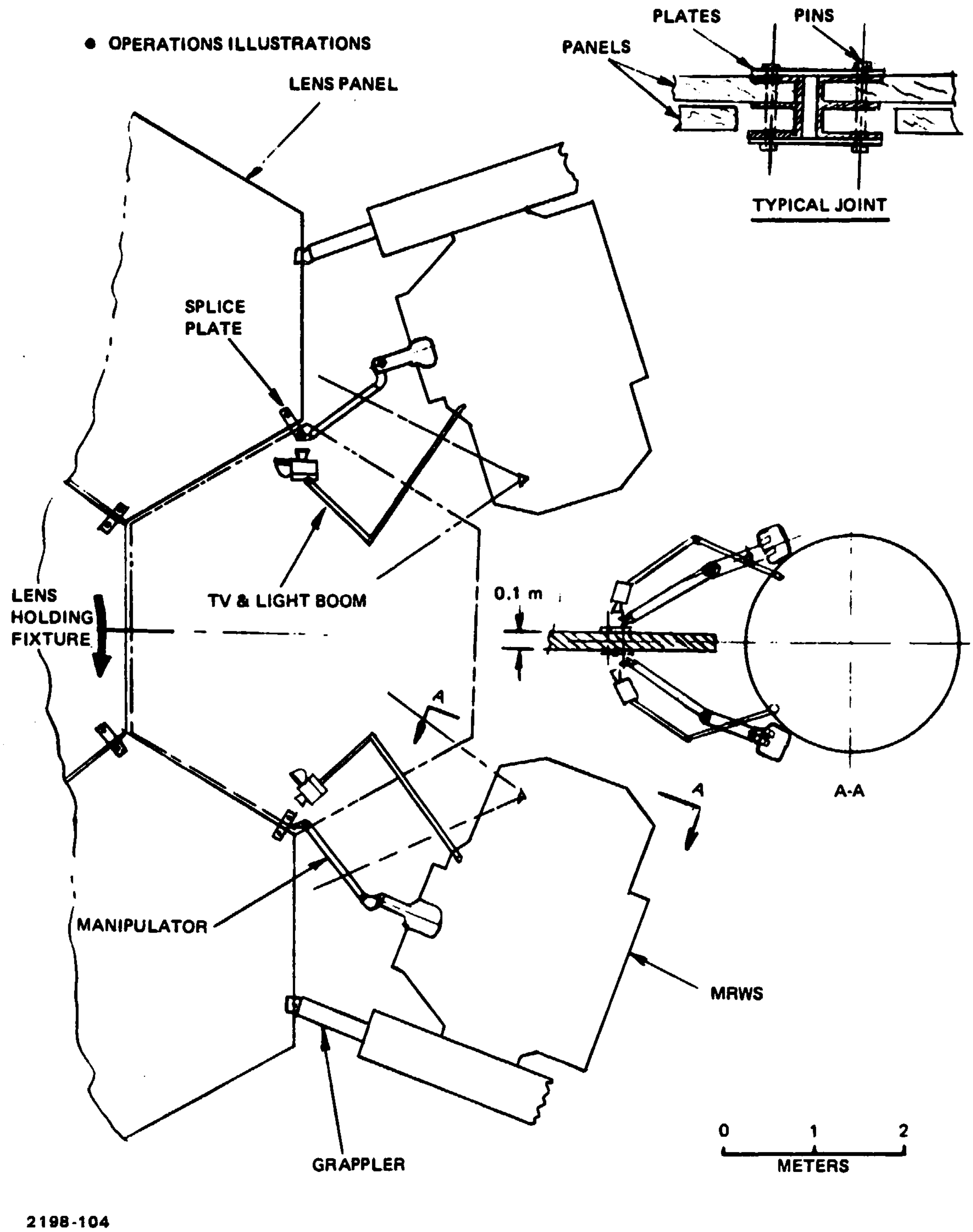

Figure 90. 61-m Communications Antenna Operations

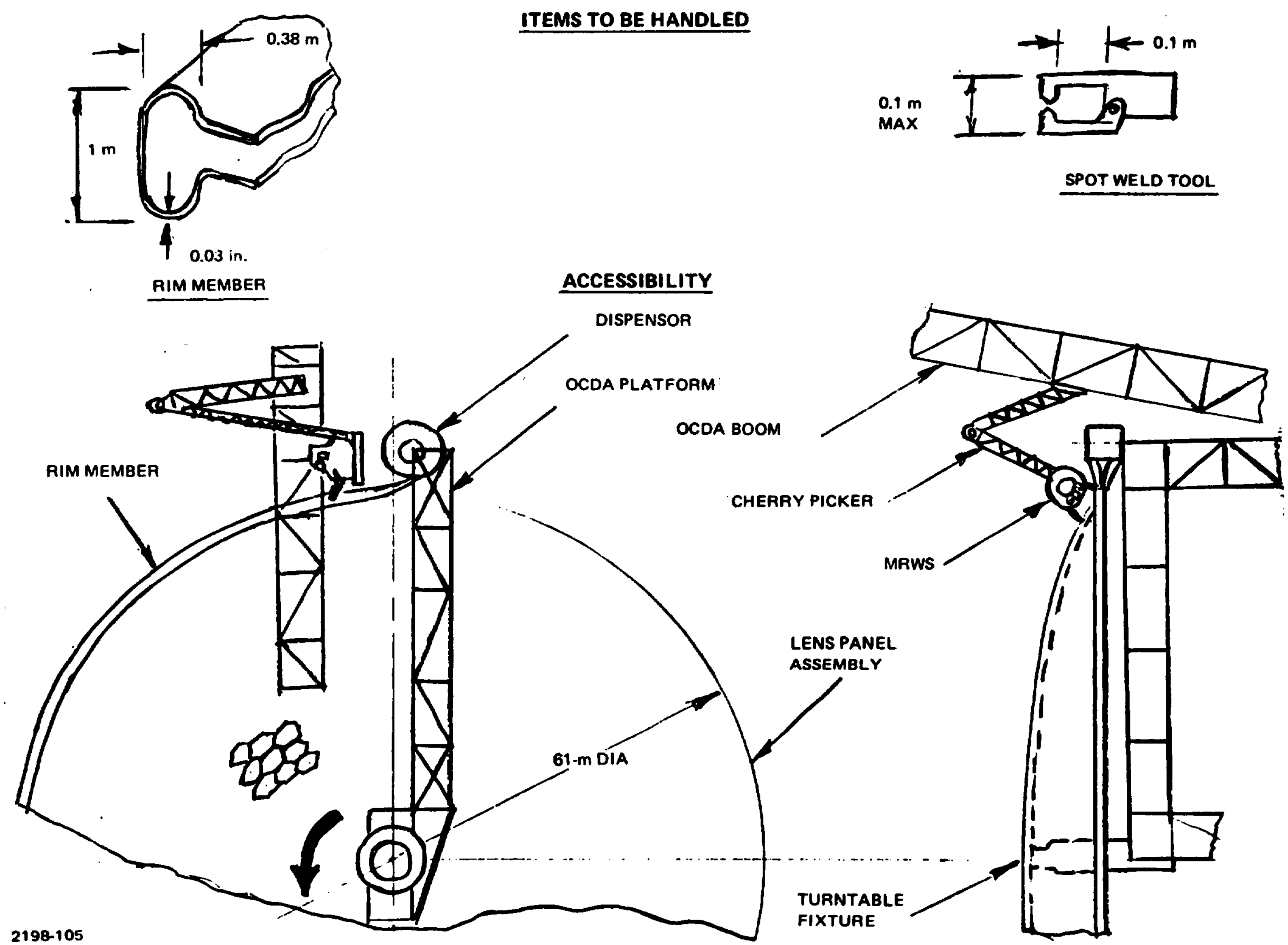

Figure 91. 61-m Communications Antenna Rim Assembly

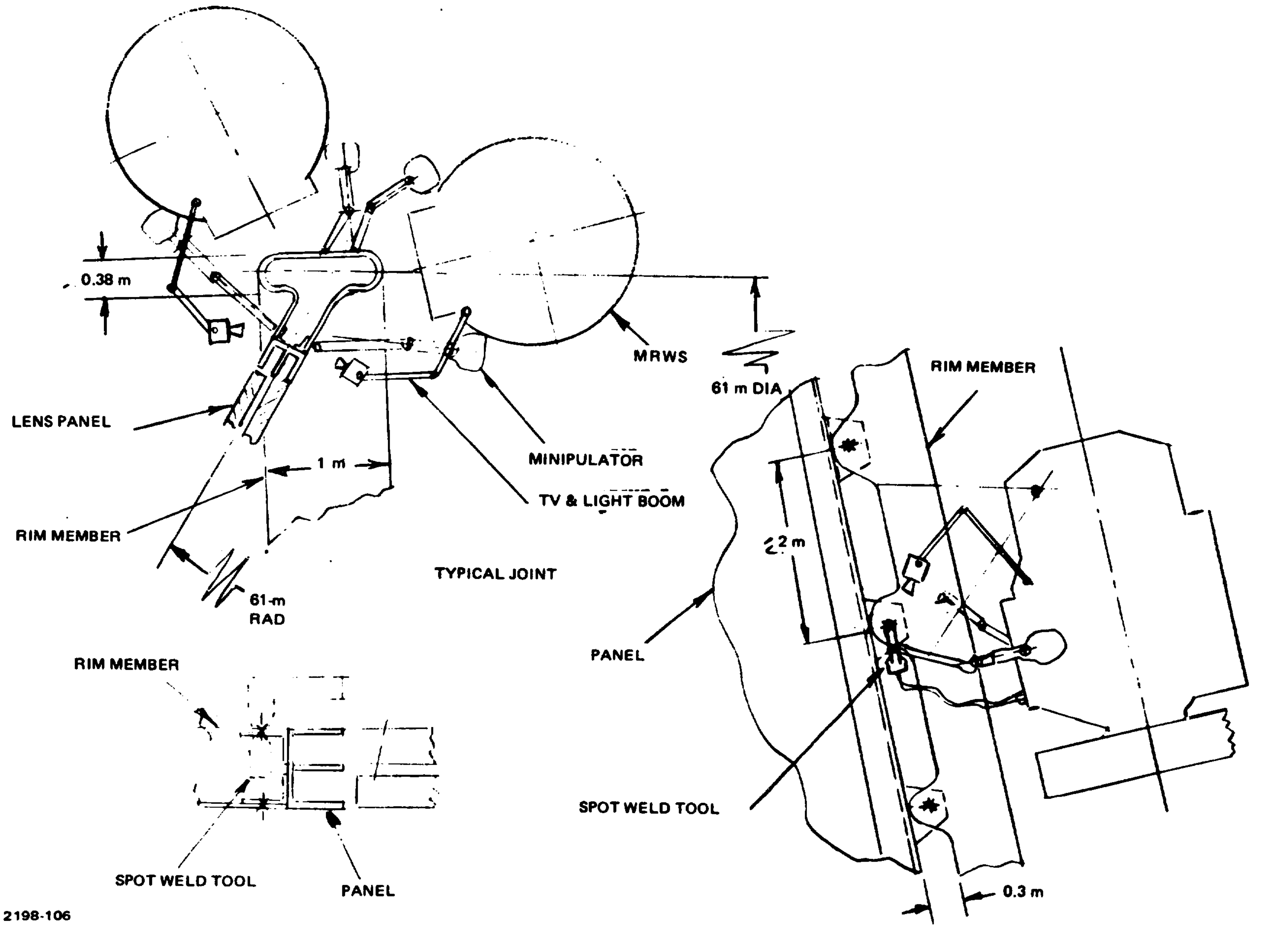

Figure 92. 61-m Communications Antenna Rim Assembly Operations

2.4.5 Closed Cabin Cherry Picker Requirements

2.4.5.1 Cabin Design - The cabin should be of sufficient size to house at least one high fidelity TV monitor.

2.4.5.2 Manipulator/Stabilizer Design - Two dexterous manipulators are required to perform selected tasks in assembly of the communication antenna. Power interfaces must be provided from the csbin, via the manipulator to a weld tool.

2.4.5.3 Controls and Display - A TV control panel is required that contains the switches, controls, etc to position a camera boom.

2.4.6 Issues to be Resolved

- Design definition of the power interface between MRWS and the tools handled by the manipulator
- CCTV design definition.

2.5 PERSONNEL ORBITAL TRANSFER VEHICLE (POTV)

2.5.1 Mission Description

The POTV is a manned vehicle used to transport personnel from one orbit to another, e.g., LEO to GEO. The basic concept requires an air lock for crew transfers from the POTV to other space vehicles. The POTV is also used for servicing geosynchronous spacecraft such as the MMS. This application of the MMS (See Paragraph 1.1.1) involves geosynchronous missions which require module replacement, payload instrument servicing, solar array repair and replacement of gas tanks.

2.5.2 Spacecraft Description

The midterm POTV (Figure 93) is generally a propulsive orbit-to-orbit stage with a minimum crew of four (12 max) designed for up to 90-day stay time. It consists of a propulsion stage, crew quarters, a control cabin and an air lock. The control cabin provides visibility for docking operations with the docking interface being at one hatch of the air lock. Spacecraft servicing involves using the airlock as a closed-cabin cherry picker with dextrous manipulators.

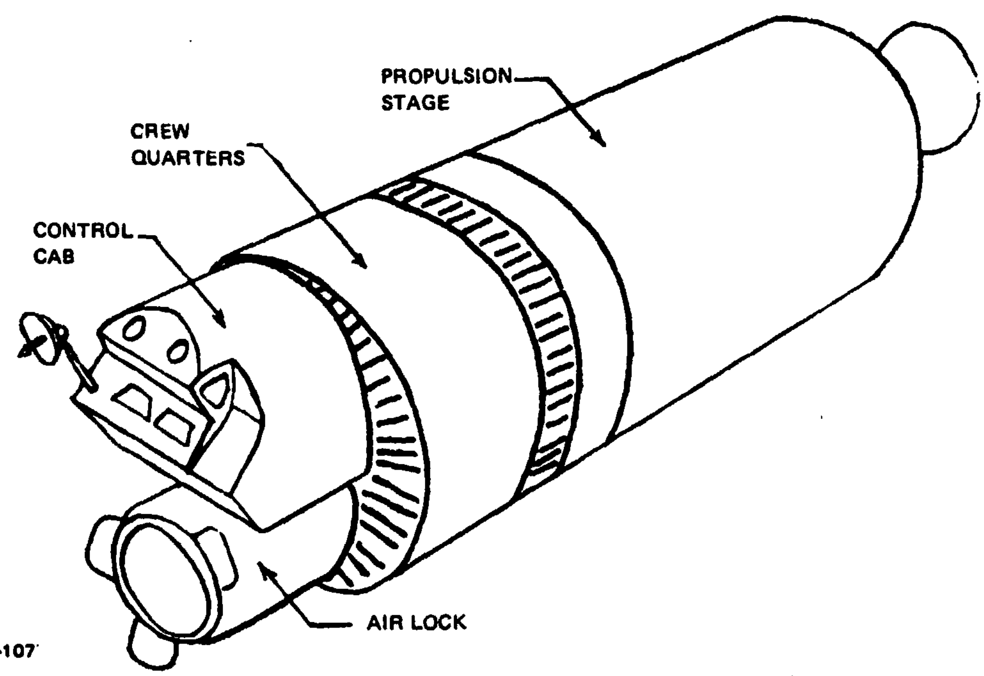

Figure 93. POTV Concept

The basic MMS elements are described in Paragraph 1.1.2. Two particular configurations representative of the geosynchronous application are illustrated in Figure 94. The spacecraft in general consists of the MMS with a propulsion module, a rotating solar array, either roll-up or deployed panels, and an instrument module with mission sensors.

2.5.3 Support Functions and Mission Scenario

Support functions were developed for the MRWS acting in a dual role as both an air lock and a closed cabin cherry picker for the POTV used to service the geosynchronous MMS as shown in Figure 95.

2.5.4 Task Analysis

2.5.4.1 Provide Air Lock for POTV to Space Base -

Accessibility

The MRWS is docked in position on the POTV with the cherry picker arm, the dextrous manipulators and the grappler stowed. The second docking hatch of the MRWS is thus located as the docking interface between the POTV and other space systems such as a construction base.

Items to be Handled

None

2.5.4.2 Cabin Design Requirements -

Operations

Only air lock (pressurization, depressurization) functions are performed as required by the POTV.

Support Equipment

- Compatible docking mechanisms and environmental control system
- Electrical interface equipment between MRWS and POTV.

Issues to be Resolved

Integration of MRWS air lock into specific POTV.

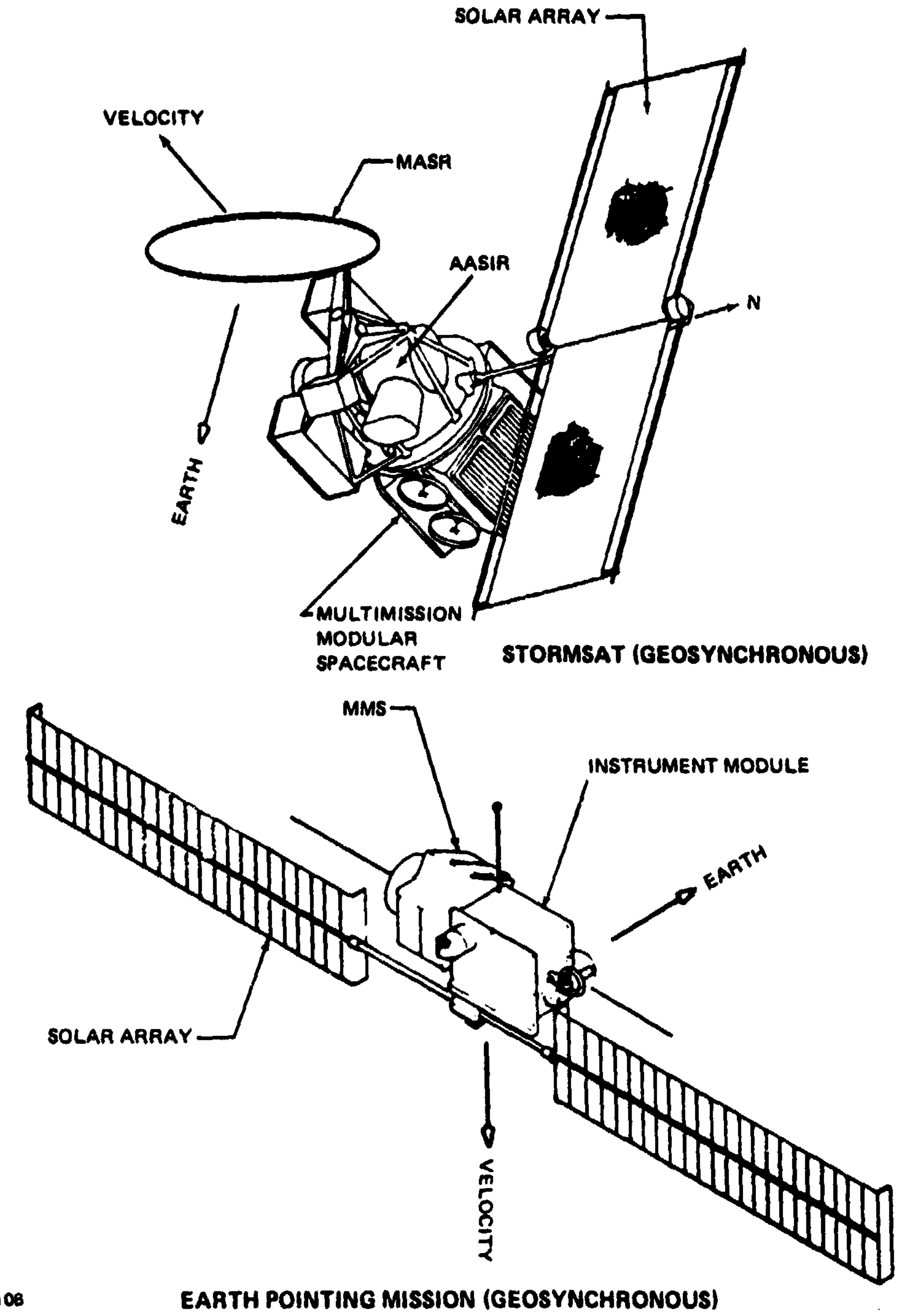

Figure 94. Representative MMS Geosynchroneous Orbit Applications

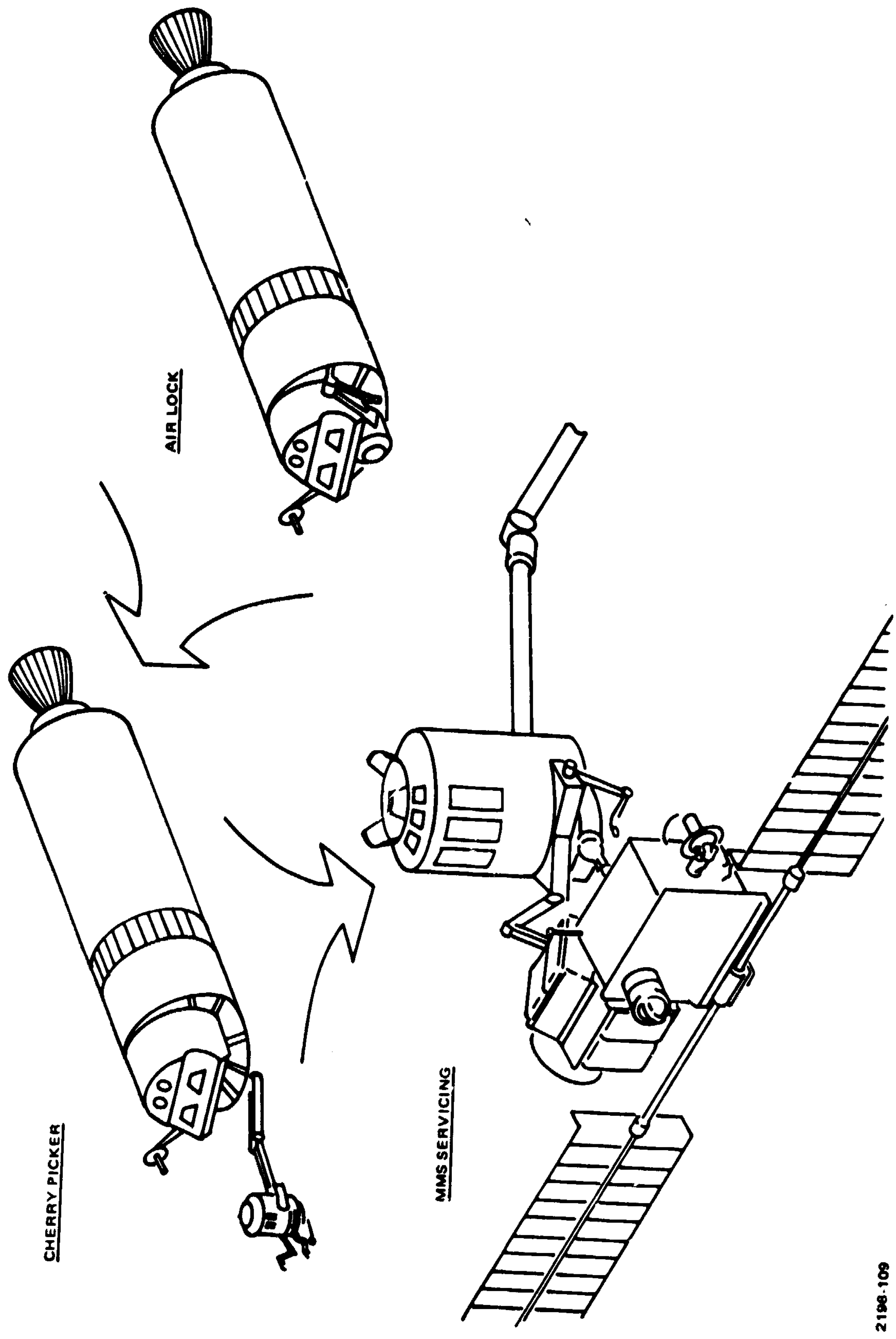

Figure 95. POTV Support Functions

References

- Orbit Transfer Systems with Emphasis on Shuttle Applications 1986-1991. NASA TM X - 73394, NASA/MSFC, April 1977.
- Briefing Charts - Orbit Transfer Systems with Emphasis on Shuttle Applications. NASA/MSFC, August 1977.
- Personnel Orbital Transfer Vehicle (POTV), Design Sizing Synthesis for Geosynchronous Missions, 1st Progress Report. NASA/JSC, Sept. 16, 1976.

2.5.4.3 POTV Servicing of Geosynchronous Spacecraft -

Accessibility

The accessibility depends on the particular MMS application, e.g., Stormsat. In general, the spacecraft consists of the MMS, an instrument module and solar arrays. The preferred approach direction is dependent on the modules and equipment to be replaced.

Items to be Handled

The standard MMS modules are described in Subsection 1.1. Payload instruments, solar arrays and propulsion equipment are assumed to have a mass less than or equal to a single MMS Module with dimensions approximately the same except for the solar arrays. The latter may be either deployed panels or the roll-up type with typical dimensions of TBD.

Operations

It is assumed that the POTV has moved to within 5 m of the spacecraft. The servicing operations are listed in Table 24.

2.5.5 MRWS Design Requirements

Configuration Requirements - The MRWS must be integrated into the POTV design to meet air lock interface requirements. The robust arm, grappler and dextrous arms in the stowed positions must not interfere with docking operations.

TABLE 24

POTV SERVICING TIME-LINE

ΔT (min)	OPERATIONS
10	ALIGN POTV X-AXIS TO DESIRED SPACECRAFT BODY AXIS ROTATE ABOUT POTV
10	X-AXIS TO DESIRED ORIENTATION
1	RELEASE MRWS FROM POTV
5	MOVE MRWS TO SPACECRAFT USING ROBUST ARM
1	GRAPPLE TO SPACECRAFT
10	REMOVE MMS MODULE
5	STOW USED MODULE
5	RETRIEVE MODULE FROM STORAGE
15	INSTALL REPLACEMENT MODULE
10	CHECKOUT MODULE
10	REPOSITION GRAPPLER ORIENTATION
30	REMOVE PAYLOAD INSTRUMENT
5	STOW USED INSTRUMENT
5	RETRIEVE REPLACEMENT INSTRUMENT
30	INSTALL REPLACEMENT INSTRUMENT
15	CHECK OUT INSTRUMENT
95	SOLAR ARRAY REPLACEMENT & CHECKOUT
95	PROPELLENT TANKS REPLACEMENT & CHECKOUT
1	RELEASE GRAPPLER
5	MOVE MRWS BACK TO POTV USING ROBUST ARM
10	SECURE MRWS TO POTV
373	TOTAL

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2.5.5.1 Robust Arm Requirements -

Parameter	Value
Morphology	7 DOF 5 m reach
Maneuver speed - no load	0.2 m/sec
- load	0.02 m/sec
Tip Force	TBD
Torque Capacity	TBD
Position accuracy	0.01 m

2.5.5.2 Stabilizer Requirements - The stabilizer must be capable of interfacing with a standard grapple fitting on the spacecraft.

Parameter	Value
Morphology	8 DOF 3 m reach
Maneuver speed - no load	0.2 m/sec
- load	0.02 m/sec
Tip Force	TBD
Torque Capacity	TBD
Position accuracy	0.01 m

2.5.5.3 Manipulator Requirements -

Parameter	Value
Morphology	7 DOF 3 m reach
Maneuver speed - no load	30 in./sec
- load	TBD
Tip Force	66 N
Torque Capacity	TBD
Position accuracy	0.01 m
Position resolution	0.001 m

2.5.5.4 <u>Support Equipment</u> - The equipment needed to support spacecraft servicing include:

- MMS module handling end effectors for dextrous manipulators
- Mission-unique end effectors for handling payload instruments, solar arrays, and tasks
- Used module stowage racks
- Checkout equipment.

2.5.6 <u>Issues to be Resolved</u>

- Range of variations in spacecraft to be serviced including stabilization status of spacecraft
- Robust arm to POTV interface constraints.

2.5.7 <u>References</u>

- MMS System Specification, S-700-10, May 1977.
- MMS External Interface Specification and Users Guide, S-700-11, May 1977.

Section 3

FAR-TERM MISSIONS

3.1 PHOTOVOLTAIC SOLAR POWER SATELLITE

The purpose of Solar Power Satellites (SPS) is to collect solar energy, convert it to microwave power, and beam it to earth for conversion to useful electrical power. The reference Photovoltaic SPS utilizes solar cells that receive power directly from the sun, without concentration of the sun's energy. The SPS is located in geosynchronous orbit with the solar cells facing the sun and the microwave power transmitting antennas pointed at a specific ground receiving antenna (rectenna).

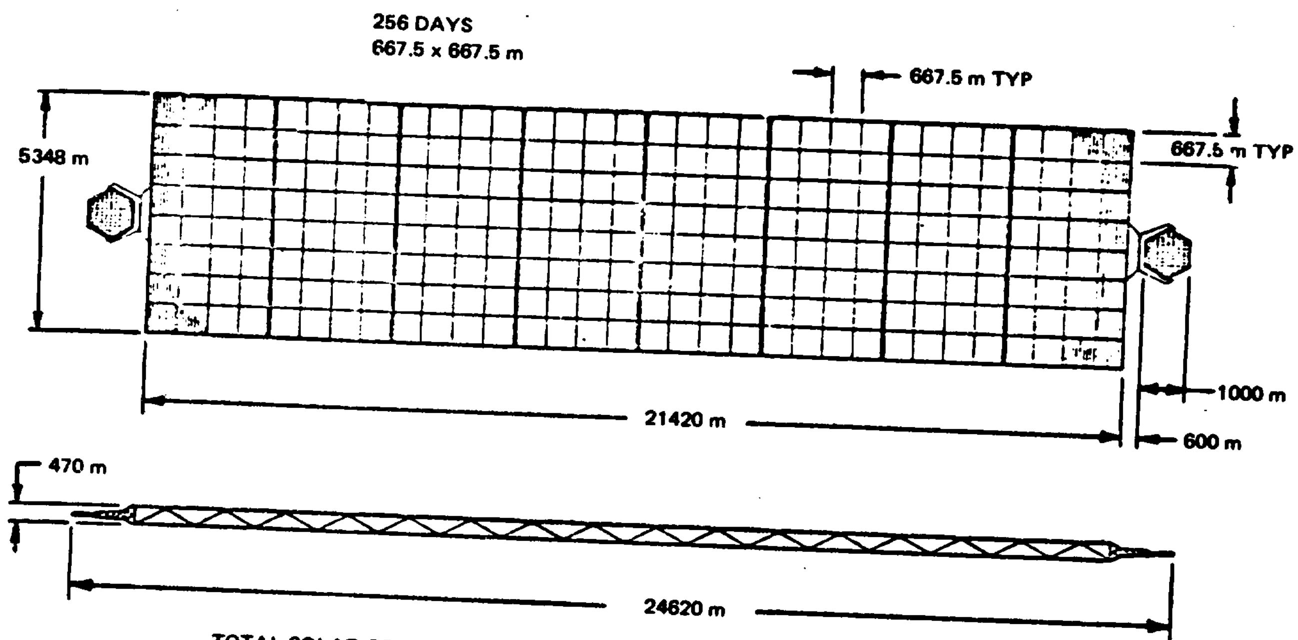
3.1.1 Mission Description

SPS construction commences in low earth orbit where major modular sections are built, and these are then transported to geosynchronous orbit for final assembly. Eventually many SPS's are planned to be in operation, each providing power to specific rectennas. Because SPS's are huge in size compared to any other space venture, large factories must be constructed in space, housing hundreds of workers to construct one SPS per year. It is expected that the first prototype SPS will be constructed by the year 2000, probably transmitting 20% of the full-size (5-10,000 mW) SPS power.

3.1.2 Spacecraft Description

The Photovoltaic SPS (Figure 96) consists of a rectangular-shaped solar collector 5.3 km x 21.4 km, with microwave antennas 1 km in diameter mounted at each end. The primary building element for the solar collector is space fabricated beams joined together (Figure 97). One side of the solar collector structure is covered with solar cells that are connected to power busses located beneath the solar cells. The photovoltaic SPS most probable mass is estimated at 97,500 metric tons.

The microwave power transmitter antenna is cantilevered off the solar collector by support structures (Figure 98). This antenna rotates in two directions using an azimuth rotary joint, yoke, and elevation joint. Slip rings are



TOTAL SOLAR CELL AREA: 101.8 km^2
TOTAL ARRAY AREA: 110.2 km^2
TOTAL SATELLITE AREA: 114.5 km^2
OUTPUT: 16.93 GW MINIMUM TO SLIPRINGS

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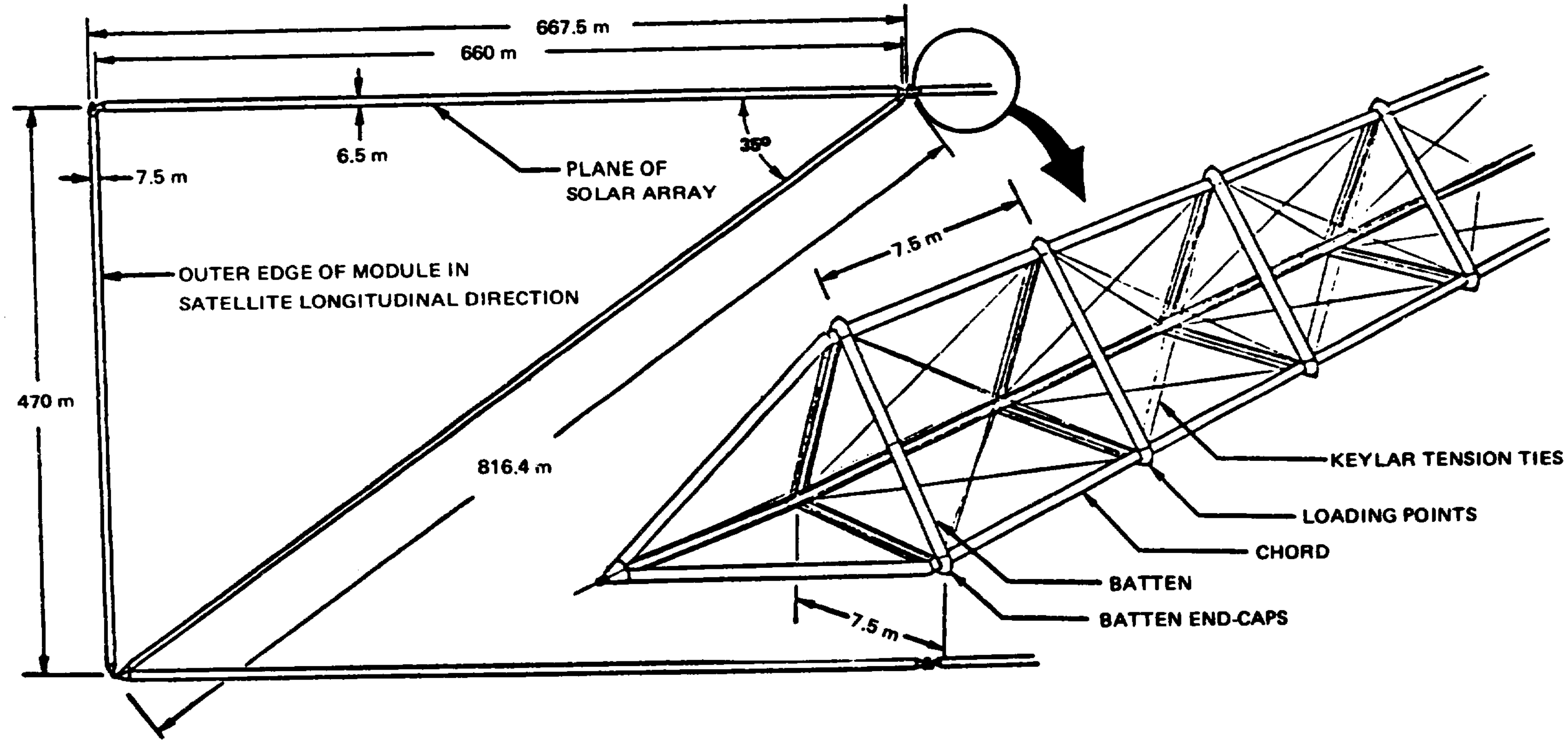
Figure 96. Photovoltaic SPS Reference Configuration



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REFERENCE LENGTHS OF PRIMARY STRUCTURE BEAMS

Figure 97. Solar Collector Primary Structure

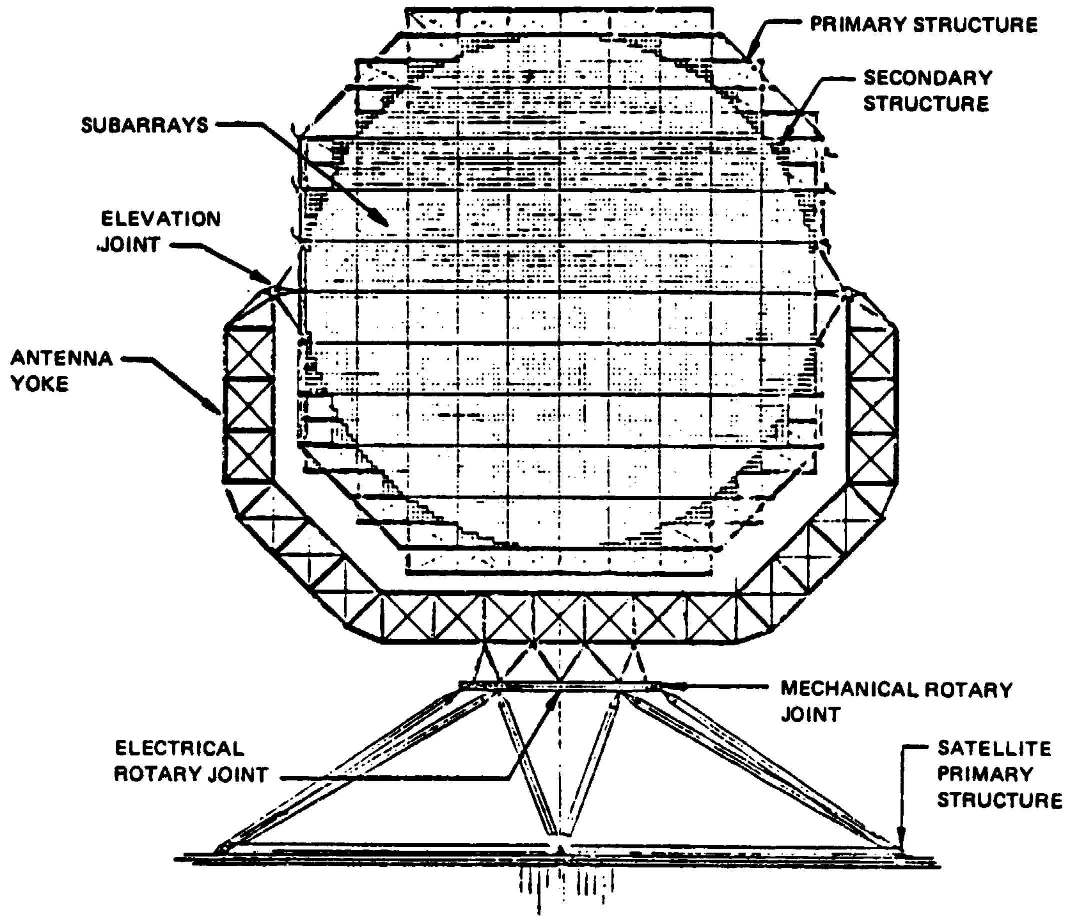

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Figure 98. Microwave Transmission Antenna

provided at each joint for power transmission to the antenna power distribution system. The antenna earth pointing side is covered with wave guides that emit the microwave power from direct current conversion klystrons. The structure plus RF conversion equipment is of higher density than the solar collector, and the mass is estimated at 12,773 metric tons per antenna.

3.1.3 Mission Scenario

The integrated construction, maintenance, and transportation operational concept for Low Earth Orbit (LEO) construction of the CR-1 photovoltaic satellite is shown in Figure 99. Space operations crews and all hardware and consumables required in space are delivered to LEO by launch vehicles. The crew launch vehicle was assumed to be an improved space shuttle with the solid rocket boosters replaced by a reusable liquid propellant booster. The cargo vehicle is a two-stage wing-wing vehicle capable of delivering approximately 400,000 kg of payload per flight. Crew flights occur every two weeks while three cargo vehicle flights are required every two days to each construction facility for the purpose of constructing one 10 GW satellite per year.

The LEO construction base is nominally located in a 478 km circular orbit at 31° inclination. This base houses a crew of 480 with overflow quarters for transients, e.g., those crew members waiting transportation to some other location. The primary purpose of the LEO base is construction of eight SPS power generation modules and two antennas. The satellite construction timeline is shown in Figure 100. The base also serves as a staging depot for orbit transfer vehicles used to carry construction and maintenance crews, crew supplies, and replacement parts to the Geosynchronous Orbit (GEO) base. A construction crew OTV flight to the GEO base normally occurs once every three months. Maintenance crew and replacement components are also transferred to GEO every three months.

The satellite modules are equipped with electric propulsion systems and flight control systems for the self-powered trip to GEO. Figure 101 shows a typical module arrangement as configured for the transfer. Thruster installations are located at the module corners for maximum control authority. Propellant tanks are located at the center of the module. Although the propulsion

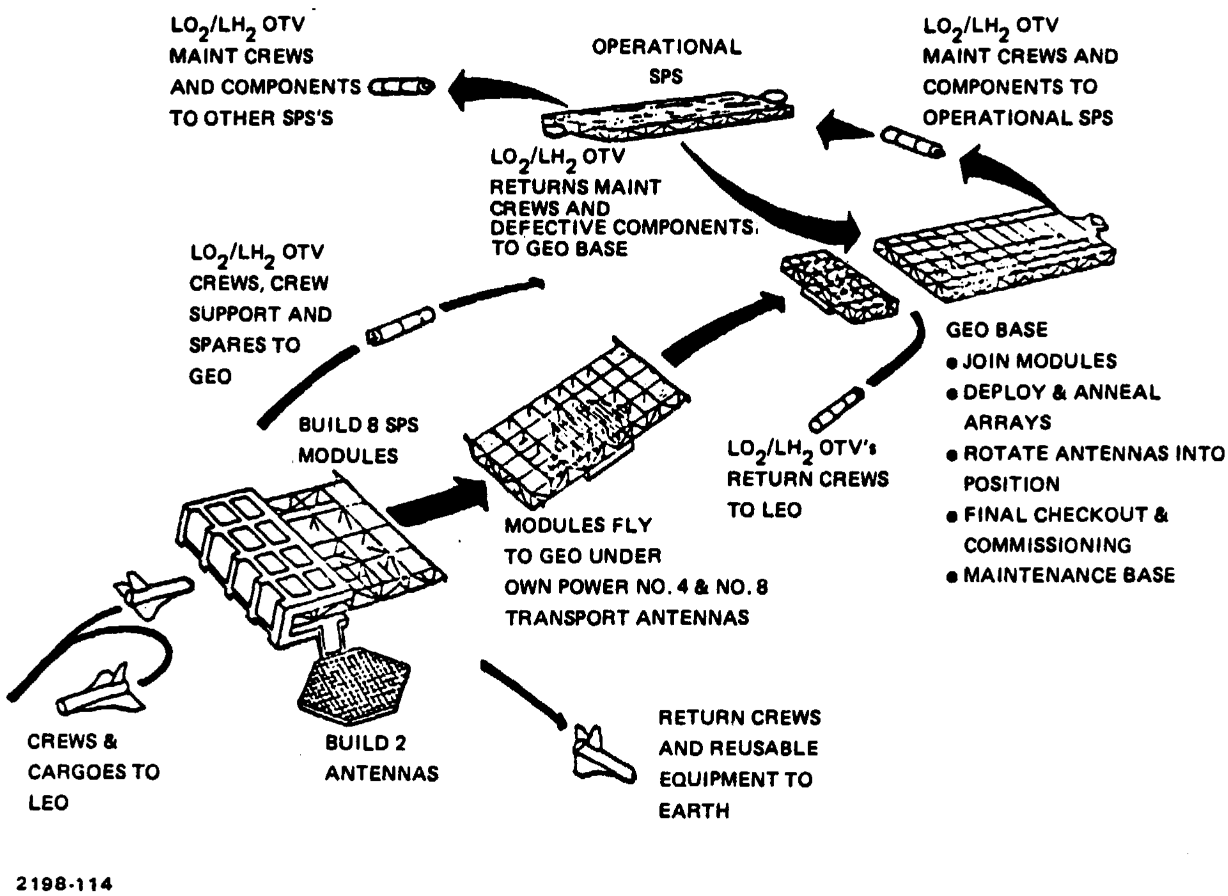

Figure 99. Integrated Space Operations

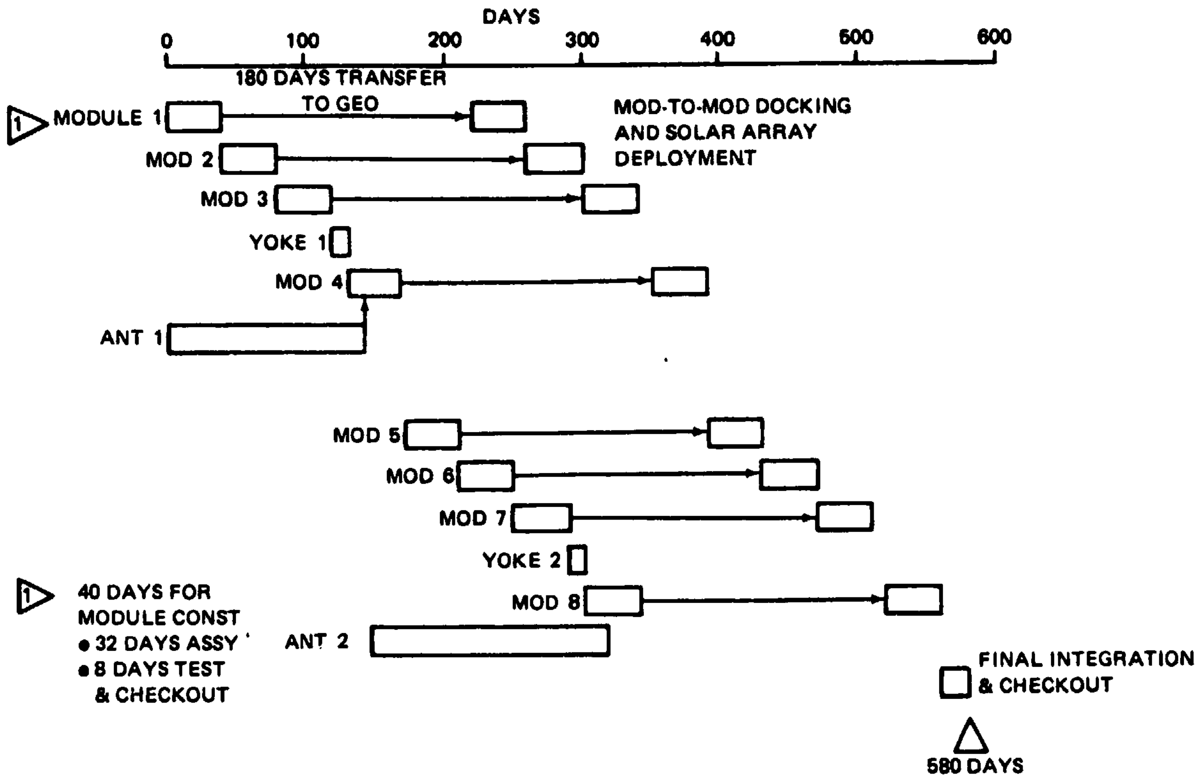

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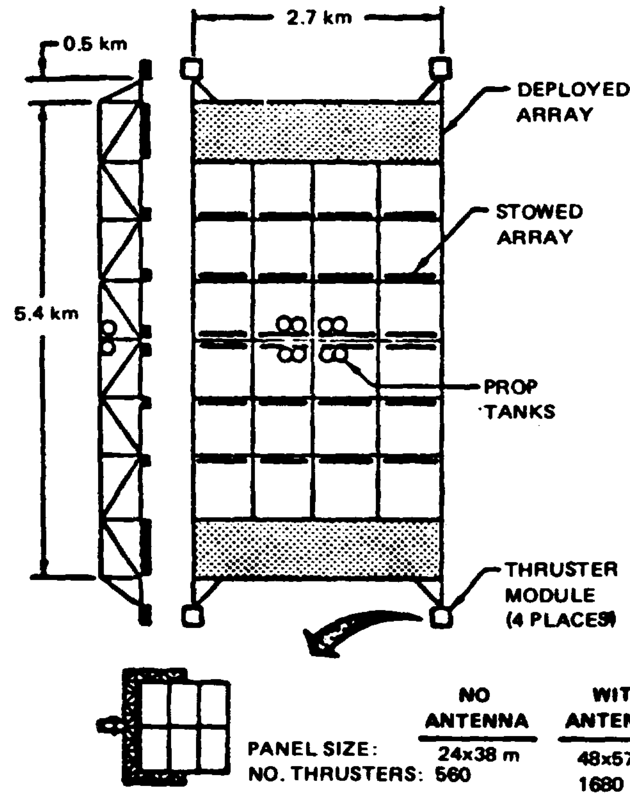
Figure 100. SPS Construction Time-Line



	NO ANTENNA	WITH ANTENNA
PANEL SIZE:	24x38 m	48x57 m
NO. THRUSTERS:	560	1680

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GENERAL CHARACTERISTICS

- 5% OVERSIZING (RADIATION)
- TRIP TIME = 180 DAYS
- ISP = 7000 sec

MODULE CHARACTERISTICS	NO ANTENNA	WITH ANTENNA
• NO. MODULES	6	2
• MODULE MASS (10^6 kg)	8.7	23.7
• POWER REQD (10^6 kW)	0.3	0.81
• ARRAY %	13	36
• OTS DRY (10^6 kg)	1.1	2.9
• ARGON (10^6 kg)	2.0	5.6
• LO_2/LH_2 (10^6 kg)	1.0	2.8
• ELEC THRUST (10^3 N)	4.5	12.2
• CHEM THRUST (10^3 N)	12.0	5.0

Figure 101. Self-Powered Satellite Module

system is primarily solar-electric, some chemical (LO_2/LH_2) thrust capability is also provided so that control authority can be maintained while flying through the Earth's shadow and during periods of high gravity gradient torque.

The GEO base is used for final assembly and maintenance operations. The final assembly operations include module berthing, antenna placement, and deployment of solar array. The maintenance operations include refurbishment of failed SPS hardware. The GEO base is also used as a staging area for the satellite maintenance crews, mobile habitats, space parts LRU's, and their orbit transfer vehicles. The GEO base houses 60 final assembly crew members and up to 240 SPS maintenance crew members.

The maintenance crews are dispatched from the GEO base in an OTV-propelled crew module along with an OTV-propelled replacement parts module destined for an operational SPS that is scheduled for regular maintenance. The maintenance crew will visit each SPS two times per year and will spend four days replacing defective components before returning to the GEO base or proceeding to the next SPS.

3.1.4 Low Earth Orbit Construction Facility

The LEO construction base for the photovoltaic satellite consists of two interconnecting facilities. One of the facilities is used to construct the module and the other is used to construct the antennas (Figure 102).

The module construction facility is an open-ended structure which allows the 4-bay-wide module to be constructed with only longitudinal indexing. There are two sets of internal working bays. The aft bays are used for structural assembly using moving beam machines and crane/manipulators attached to both the "A" and "D" level surfaces of the facility. Solar array and power distribution components are installed from equipment located on the "A" level in the forward bays.

The antenna facility is located with respect to the module facility in such a way that the antenna is constructed at a location where the completed antenna can be mated to the yoke without any vertical movement. The antenna construction facility (also shown in Figure 102) is configured in an open-ended structure that is five antenna bays wide, which allows the antenna to be

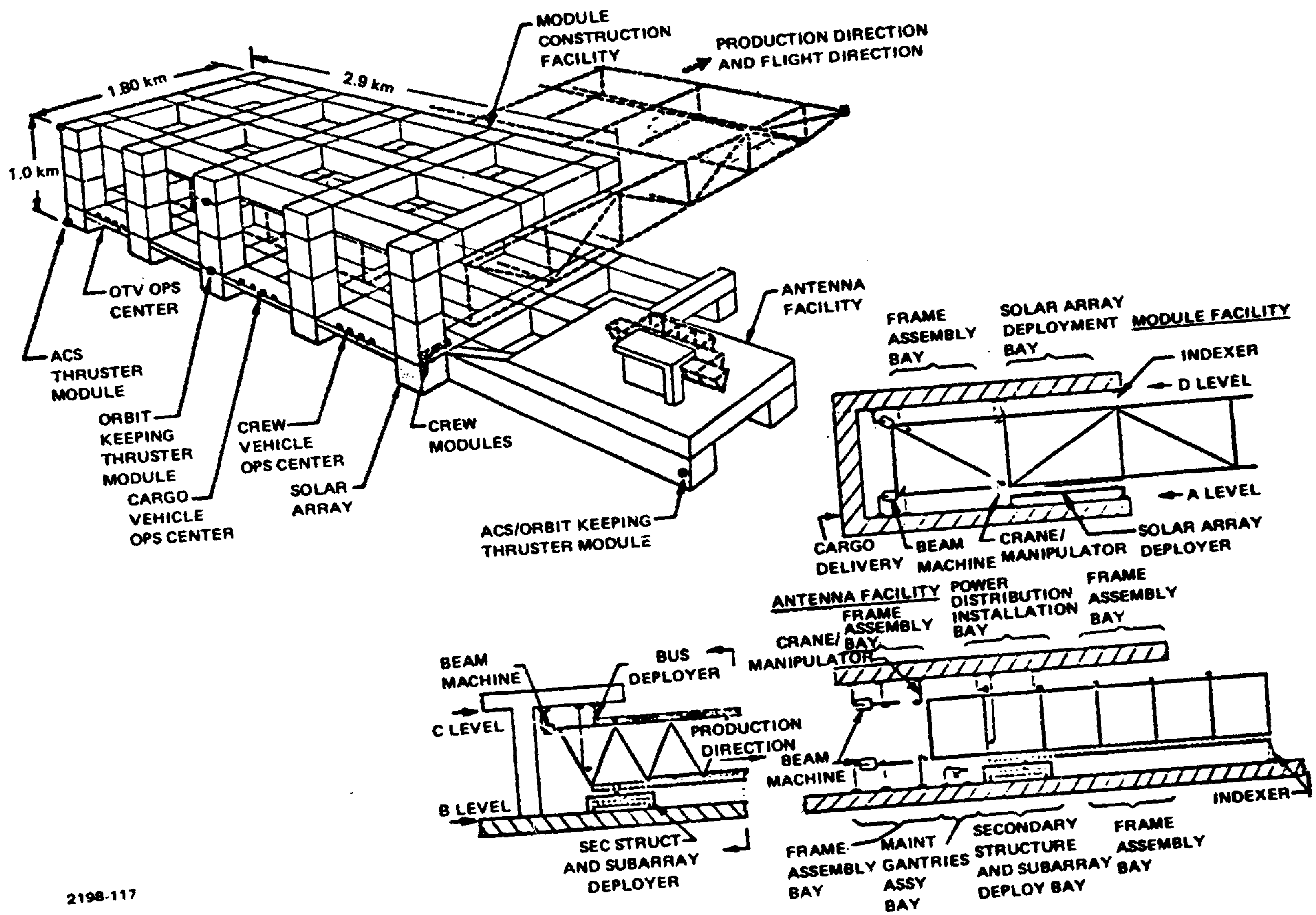


Figure 102. LEO Construction Base

constructed using both lateral and longitudinal indexing. The two end bays are used to assemble the primary structure, and the inner bays are used to deploy the secondary structure and subarrays, and to install the power distribution system and maintenance gantries. Construction equipment operates from both the "B" and "C" levels of the antenna facility.

3.1.5 Low Earth Orbit MRWS Support Functions

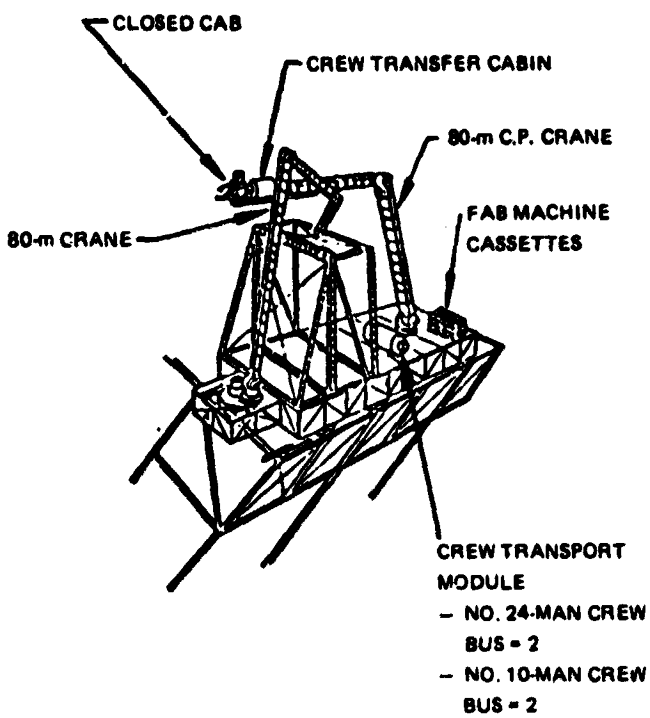
The following support functions are applicable to MRWS roles. Detailed SPS construction data necessary to establish specific MRWS requirements is not available, therefore, design approach assumptions were made to facilitate establishment of MRWS requirements.

3.1.5.1 Base Transporter - Each level of the base has a logistics track network that provides the capability for moving materials and crews from the transportation centers to the warehousing, subassembly, crew habitats, and assembly areas via transporter vehicles. A concept for a base transporter is shown in Figure 103 including MRWS roles/requirements.

3.1.5.2 Articulating Beam Fabricator - The beam fabricator (Figure 104) is configured to allow two beam machines to form all the main module structure (actual assembly machines within framework not shown). Accordingly, it has both translation and rotational capability. The dimensions and mass indicated are for the 15-m segmented beam approach although machines fabricating thermally formed continuous chord structure could be attached to the same frame and used in a similar manner. Two 10-m beam machines are used to fabricate the antenna primary structure. A two-man control cabin is attached to each beam machine.

3.1.5.3 Beam Joining Operations - The primary beam structure of the solar collector are joined at a common nodal point (Figure 105). Also shown are associated MRWS requirements.

3.1.5.4 Bus/Switch Gear Installer - Power bus deployment machines are used to roll out sheet metal bus strips and attach these trips to supporting structures. These machines are used on the "A" level of the module facility and on the "C" level of the antenna facility. Subsequent task analysis provides details of MRWS requirements. (See Paragraph 3.1.4.1).



TRANSPORTER CONCEPT/MRWS ROLES

ELEMENTS TO BE TRANSPORTED

- SUBASSEMBLIES FROM CENTRAL STATION
  - STRUCTURAL JOINTS
  - WAVEGUIDE SUBARRAYS
  - SWITCH GEAR
  - CONTROL PROPULSION DEVICES
- PERSONNEL
- CONSUMABLES
  - 0_2 and N_2 FOR REMOTE WORK STATIONS
  - WATER & FOOD TO REMOTE WORK STATIONS
  - ARGONNE FOR PROPULSIONS
- EQUIPMENTS
  - FAB MACHINES
  - SWITCH GEAR
  - SOLAR BLANKETS ASSEMBLIES
- MATERIAL
  - STRUCTURAL FLAT STOCK
  - FASTENERS

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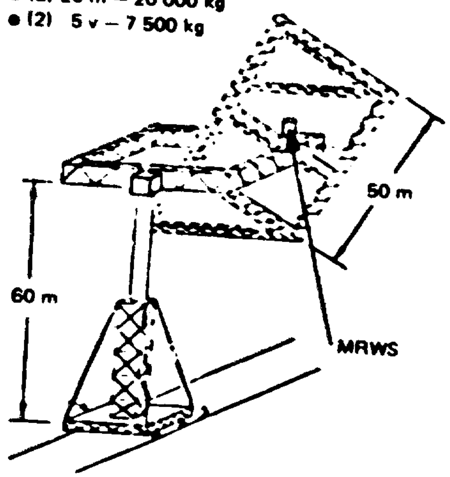
Figure 103. Transporter Requirements

- BEAM MACHINE
  - (2) 20 m – 20 000 kg
  - (2) 5 v – 7 500 kg



MRWS FUNCTIONS

- CONTROL TRANSLATION ALONE RAILS
- CONTROL BEAM MACHINE GIMBAL POSITION
- RESUPPLY MATERIAL CASSETTES
- CONTROL OPERATION OF BEAM MACHINE
- MAINTENANCE & REPAIR

8.25 m min
PRODUCTION RATE

PRODUCTIVITY WITH 2 MACHINES

TYPE BEAM	TOTAL MASS (kg)	TOTAL LENGTH (m)
• FOUR 816-m BEAMS PER DAY	18012	3264
• EIGHT 660-m BEAMS PER DAY	29248	5280
• FIVE 470-m BEAMS PER DAY	8015	2350
TOTAL/DAY	55,275	1089

- MACHINE UTILIZATION PER DAY = (15 hr)
  - – TIME FABRICATING 11 hr
  - – TIME MOVING 2 hr
  - – TIME FOR RESUPPLY 2 hr

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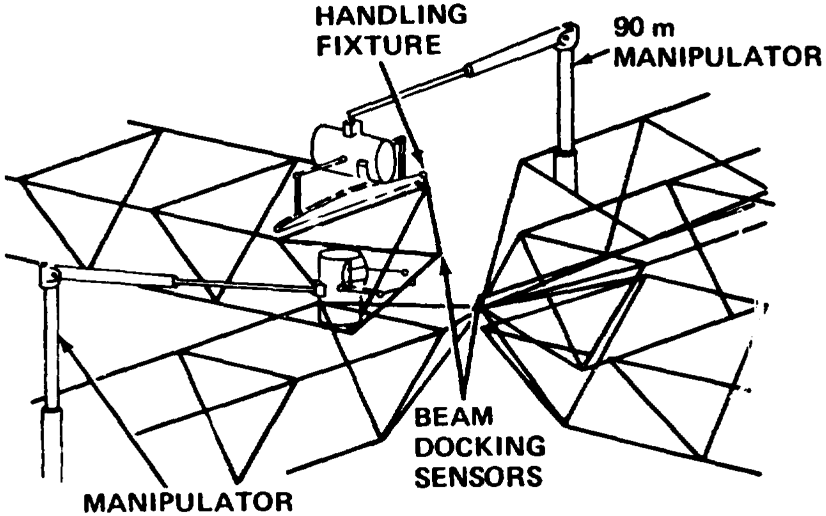
Figure 104. Articulating Beam Fabricator

NOTE: SECOND MANIPULATOR WITH HANDLING FIXTURE AT OTHER END OF BEAM



MRWS REQUIREMENTS

- HANDLE LARGE BEAMS
- POSITION FOR JOINING
- PERFORM ALIGNMENT
- FASTEN
- VERIFY JOINT INTEGRITY

TASK FREQUENCY = 3536 JOINING OPERATIONS PER SATELLITE

TASK TIME = 1 hr PER JOINT

NO. OF MRWS UNITS = 8

SOLAR ARRAY BEAM CHARACTERISTICS

DEPTH, m	LENGTH, m	MASS, kg
7.5	816	4513
7.5	660	3656
7.5	470	2603

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Figure 105. Joint Machines

3.1.5.5 Solar Array Deployment - Four of the solar array deployment machines will be located on the "A" level of the module construction facility. This machine (Figure 106 will deploy the solar array required for self-powered transit to GEO. The non-deployed array will be installed on the structure in radiation-protective containers by this machine.

3.1.5.6 Antenna Secondary Structure Deployment Platform - The antenna deployable secondary structures and the subarrays are installed by the deployment platform (Figure 107). The most significant unique piece of equipment on this deployment platform is the subarray installer. This machine lowers subarrays onto the structure and makes the structural and electrical interfaces.

3.1.5.7 Power Cable Connection Manipulator - Microwave modules are installed on the secondary structure of the antenna. These modules are connected to the antenna power distribution system (Figure 107).

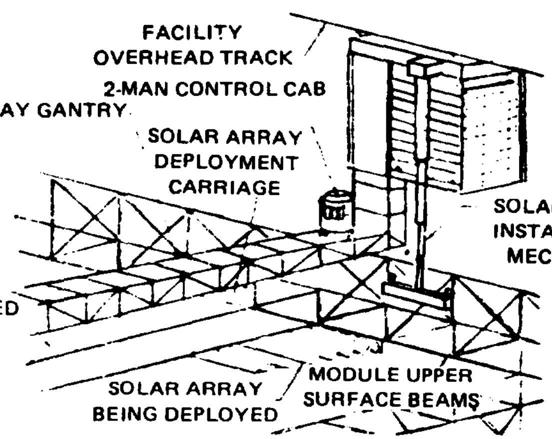
3.1.5.8 Rotary Joint Assembly - The microwave antenna-to-satellite interface requires 360° rotation about the spacecraft central axis with limited motion for elevation steering, while maintaining structural and electrical integrity. Paragraph 3.1.4.2 shows the MRWS support of this operation and lists functional requirements.

Crane/manipulator systems are primarily used to form the structural joints of the satellite frame. Two 250-m units are required in the construction of the antenna yokes as well as several 20-m cranes. Control cabins with manipulators are located at the end of the crane, which in itself attached to a moving platform.

3.1.5.9 Quick Repair and Rescue Module - This mode of operation is discussed in depth in task analysis, Paragraph 3.1.8.4.

3.1.6 Geosynchronous Orbit Assembly Base

The overall configuration of the GEO final assembly base is shown in Figure 108. The base has overall dimensions of 1500 m x 1600 m x 100 m with two decks of operation. The upper deck supports the crew and maintenance modules and docking facilities for transportation systems and payloads.

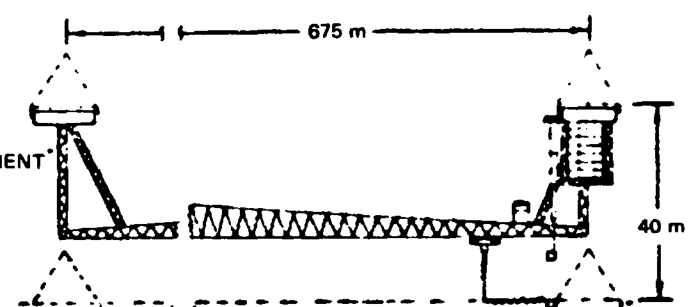


MRWS FUNCTIONS
- REMOTE CONTROL OF RESUPPLY HOIST/SOLAR ARRAY INSTALLER
- REMOTE CONTROL OF SOLAR BLANKET DEPLOYER
- CONTROL OF CROSS-BAY GANTRY
- CONTROL OF BLANKET DISPENSER
- TEST & CHECKOUT
- CONSTRUCTION MONITORING

MRWS EQUIPMENTS
- CCTV – STEREO (2)
- DIGITAL/GRAPHIC DISPLAYS (4)
- CONTROLLERS (SWITCHES)

MRWS CREW (2-MAN)

- SOLAR ARRAY DEPLOYMENT
  - 4 UNITS
  - 12 000 kg (Ea)



- HOIST/DISPENSOR/ BLANKET DEPLOYER OPERATOR
- SYSTEMS TEST ENGINEER

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Figure 106. Solar Array Deployment Machine

MRWS TASKS

- CONTROL/MONITOR SUBARRAY DEPLOYMENT
- MATE ELECTRICAL CONNECTIONS
- FASTEN WIRING TO STRUCTURE

TASK REPETITION 6932/ANTENNA
TASK FREQUENCY 2.5/hr

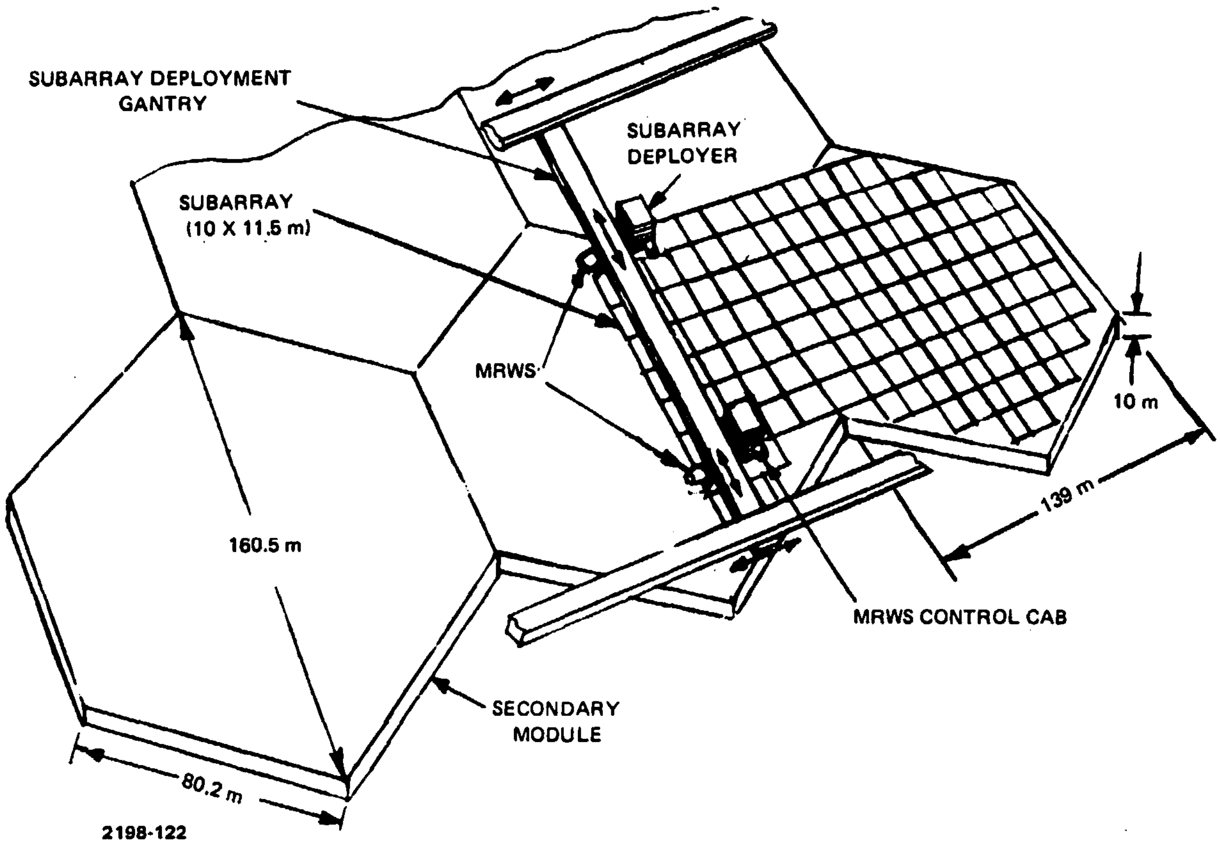

Figure 107. Microwave Antenna Subarray Installation and Wiring Connections

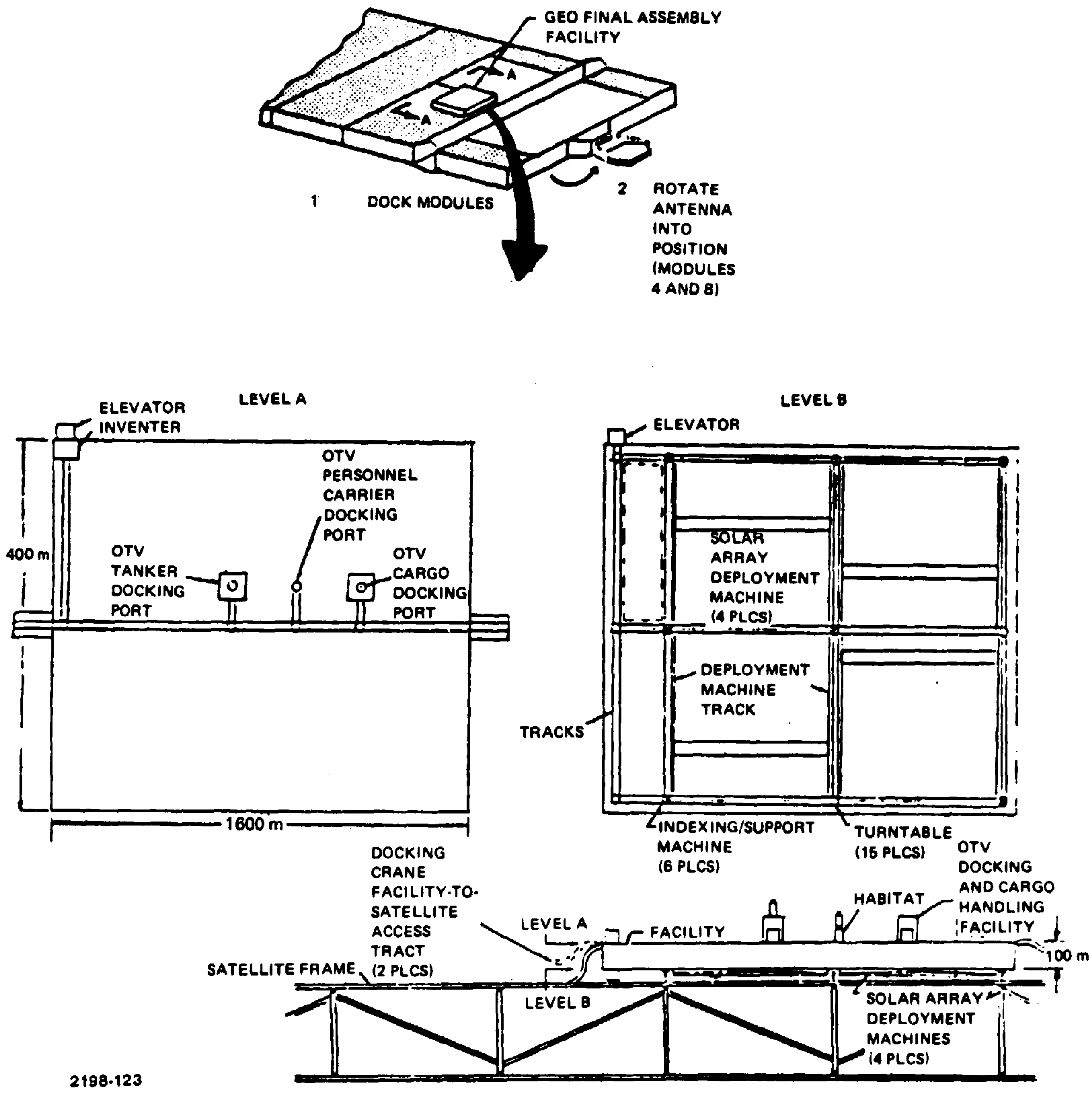

Figure 108. GEO Final Assembly Base

The lower surface of the facility supports the four solar array deployment machines. Docking cranes used in berthing the modules are also attached to the base when not in use or when the GEO base is transferred to another longitudinal location.

3.1.7 Geosynchronous Orbit MRWS Support Functions

The first task to be performed after modules reach GEO is that of their berthing (docking) to form the complete satellite. The concept employed to perform this operation is illustrated in Figure 109 and along with associated MRWS requirements.

Four docking systems are used with each, involving a crane and three control cables. Tension applied to the cables allows the modules to be pulled in and provides stopping control and attitude capability. Also required in this concept is an attitude control system, including thrusters which are not shown.

This operation is the only one that requires special equipment over that previously identified for GEO support.

3.1.8 Task Analysis

3.1.8.1 Install Solar Collector Power Busses -

Accessibility

The main busses consist of flat aluminum sheets 1-mm thick suspended by cables in the solar collector primary structure just below the solar arrays. Figure 110 shows three parallel busses that lie along the longitudinal center of the solar collector, near the slip ring end of the satellite. The three point spring/cables are tied to the main structure, and tension ties that react the bus magnetic repulsion forces are shown in the figure. Each bus is divided into several parallel segments. The common bus increases in steps from a meter in width to over 32 m. The bus is rolled up for transportation to orbit and, because a single roll would exceed HLLV launch capability, it is divided into four segments, each approximately 8 m wide. The individual 8-m wide busses are joined by stretchers at the bay sides which support and tension them, and at intermediate points by tension ties. The structural bays are open boses in configuration, 667.7 m on two sides and 470-m high, permitting good access to the installation area.

MRWS FUNCTIONS

- EXTEND CRANE AND ATTACH CONTROL CABLES TO MODULE
- TRANSLATE MODULE BY RETRACTING CRANE
- ALIGN MODULE FOR DOCKING

MRWS EQUIPMENT

- CRANE TRAVEL 2.7 km
- CRANE REACH 400 m

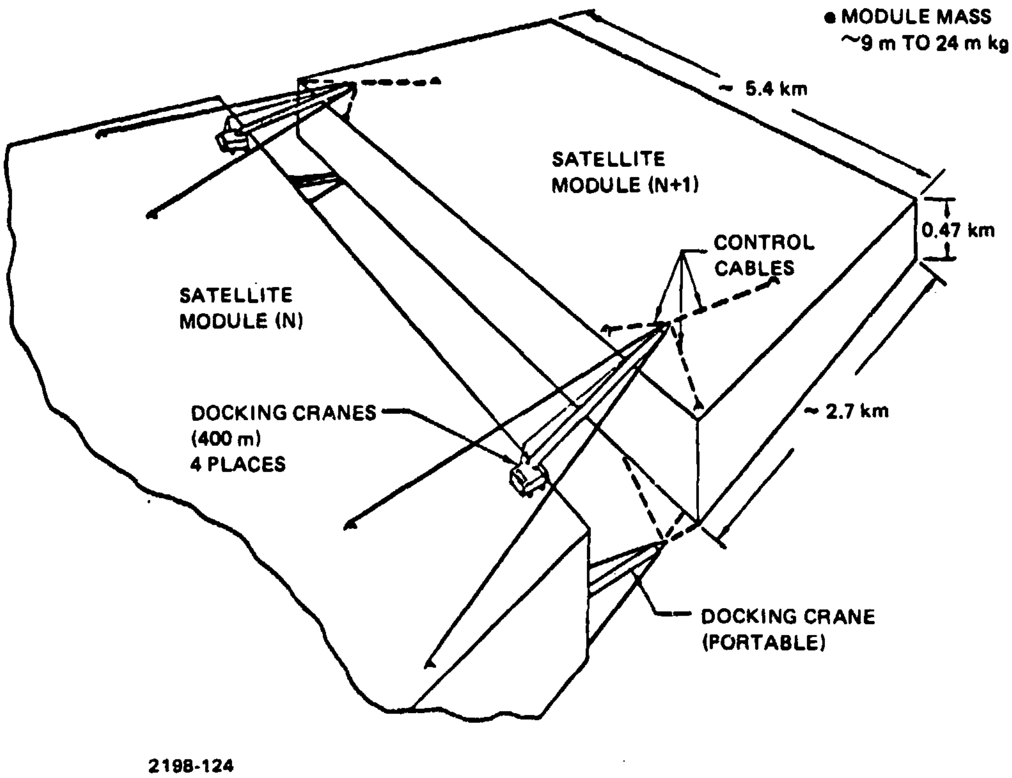

Figure 109. Berthing Concept

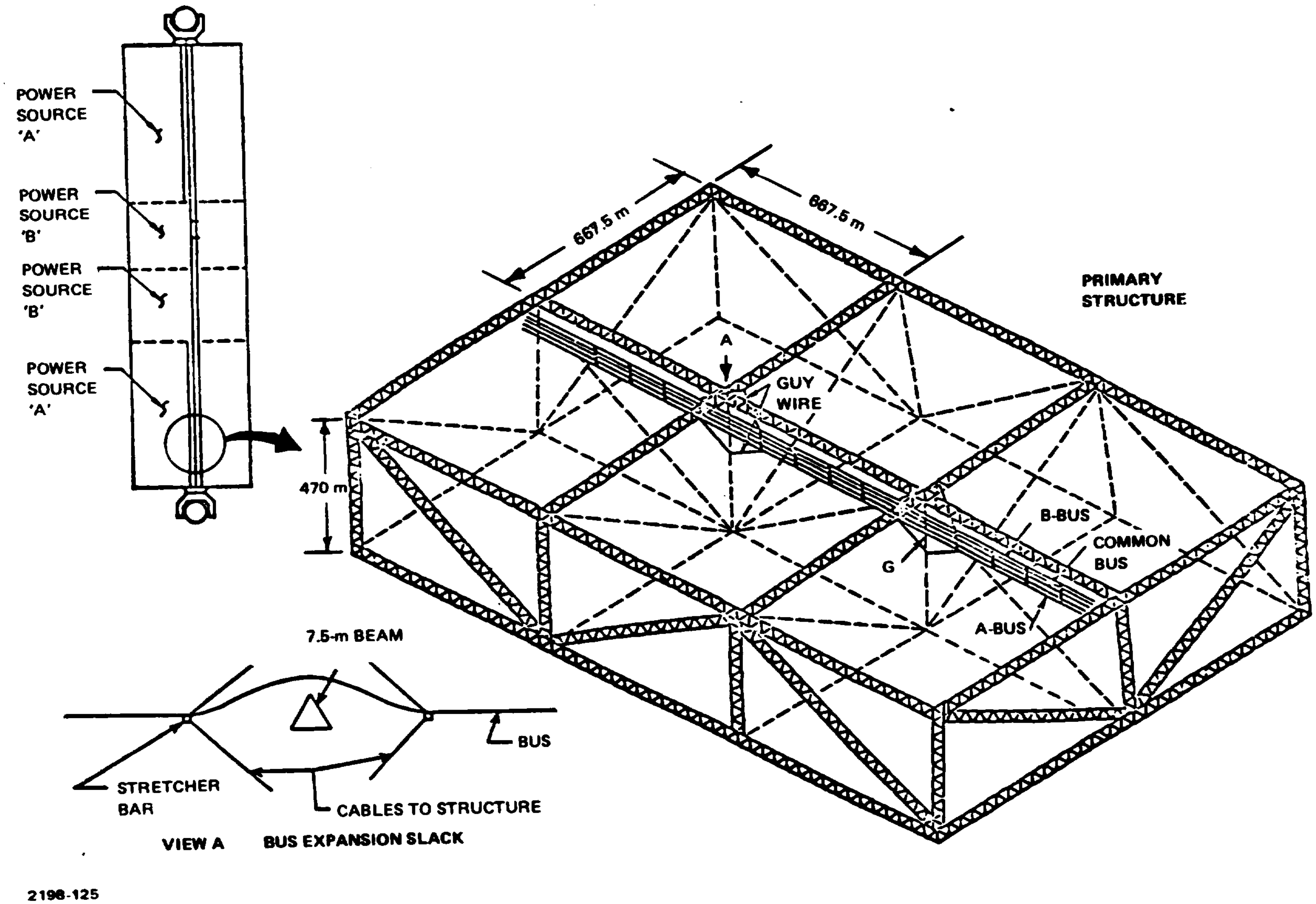

Figure 110. Main Bus Location in Solar Collector Primary Structure

Items to be Handled

The main bus rolled segments' (8-m long) mass is 180,000 kg for 8010-m long power source A bus. These are removed from the HLLV and mounted in a conductor dispensor (Figure 111) by a facility crane MRWS. The cherry picker MRWS is required to attach tension ties and stretch cables to the stretcher bars. Stretcher cables are attached to the structure via a cable tensioning winch. Winch mass and attachments are assumed to be 5 kg.

Operations

Attach tension ties (3720) times and install tension cables (192 times), Table 25.

Tracked Cherry Picker Requirements

Figure 112 contains the requirements for the crane, stabilizer, and dexterous manipulator.

Support Equipment

It is assumed that the winch is installed on a mounting bar, which must be fastened to the structure. Depending on the type of structure and fastening method selected, this requires an end effector that allows welding, adhesive heat curing, or mechanical fastening. Controls, displays, and illumination must be provided for positioning the grappler and dexterous manipulators.

Issue to be Resolved

Provide candidate design for the winch so that manipulator loads may be determined.

References

Solar Power Satellite System Definition Study, Part III
D180-24071-1 Preferred Concept System Definition.
Boeing Aerospace Co., March 1978, pp. 43-46.

3.1.8.2 Microwave Antenna Rotary Joint Assembly -

Accessibility

The microwave antenna is attached to the satellite primary structure by the use of an antenna yoke, yoke support structure, a mechanical rotary joint,

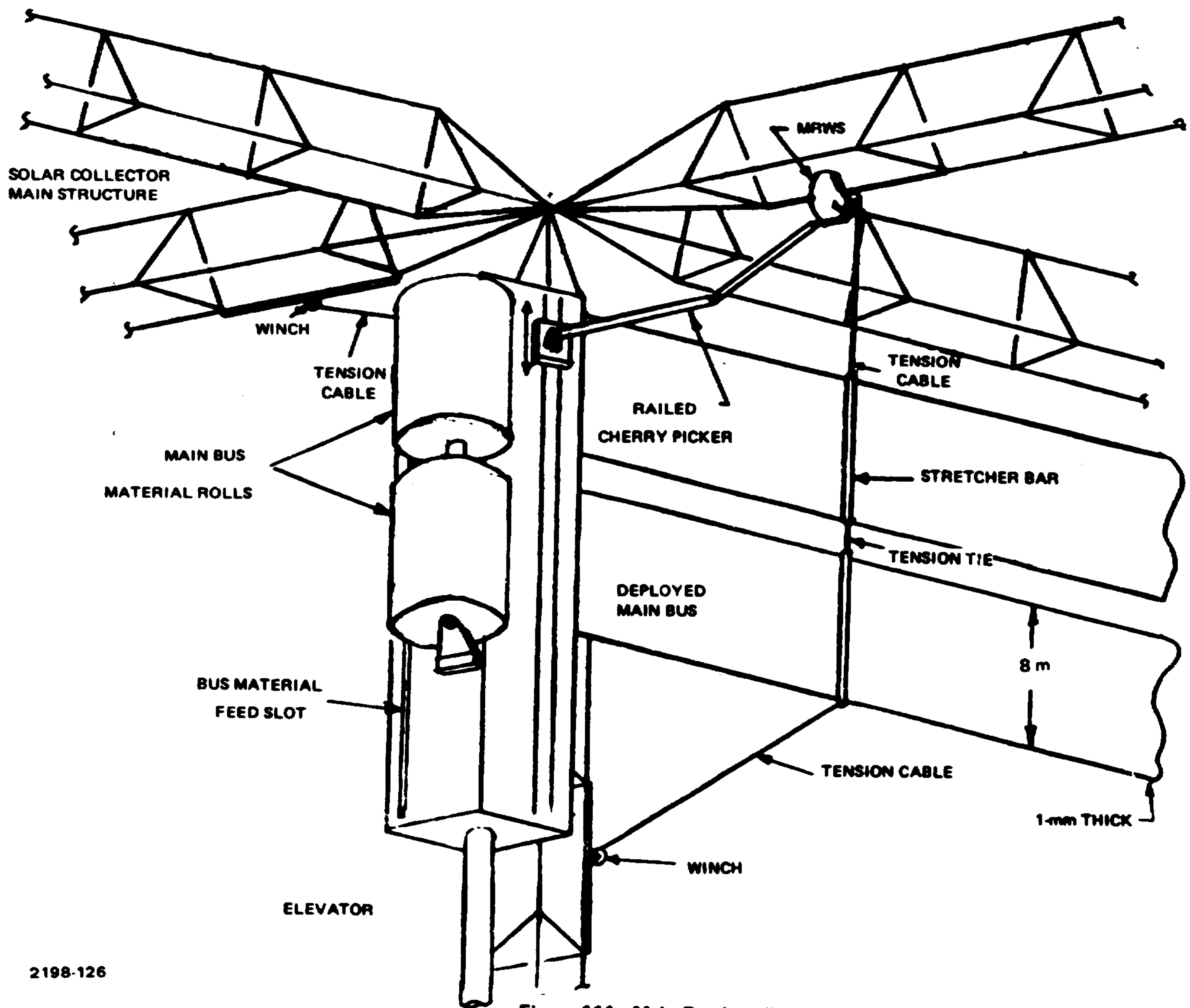

Figure 111. Main Bus Installation

TABLE 25

SOLAR COLLECTOR POWER BUSSES INSTALLATION TIME-LINE

ΔT (min)		OPERATION
		NOTE: STRETCHER BARS PREVIOUSLY ATTACHED TO CONDUCTORS
660		MONITOR CONDUCTOR UNROLLING (1 m/min)
40		SNAP FASTEN TENSION TIE TO STRETCHER BAR (4 TIMES/END)
40		STRETCH TENSION TIE TO OTHER CONDUCTOR & FASTEN (4 TIMES/END)
180		LOCATE WINCH SUPPORT STRUCTURE ON BEAM & FASTEN (3 TIMES/END)
60		STRETCH CABLE FROM WINCH TO CONDUCTOR STRETCHER BAR & SNAP FASTEN (3 TIMES/END)
90		OPERATE WINCH TO TENSION CABLE TO REQUIRED VALUE (3 TIMES/END)
1070	(18 hr)	TOTAL/BAY

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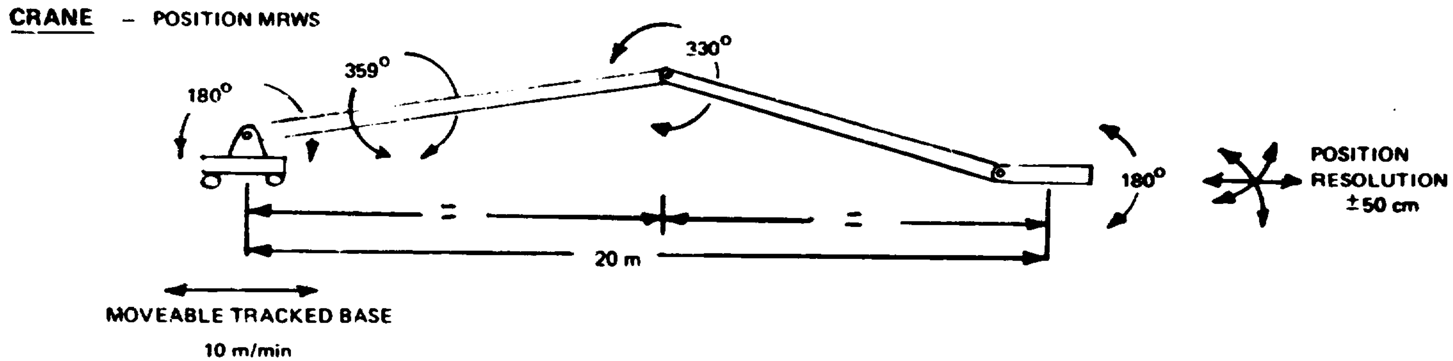

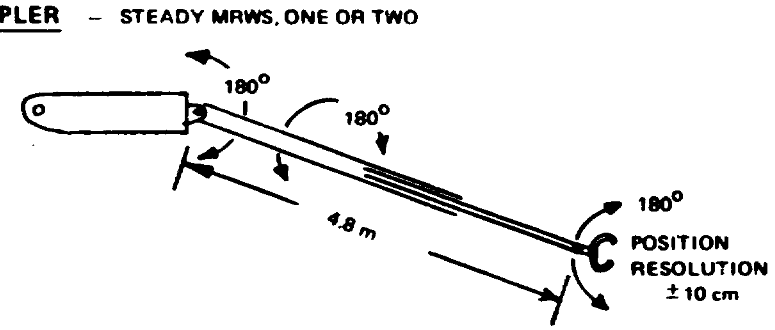

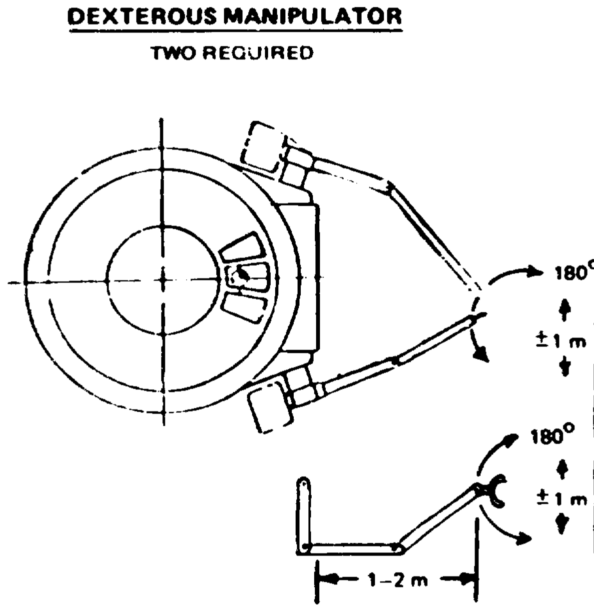

TASK	TIP FORCE (N)	TORQUE (m/kg)	VEL (m/sec)	ACC (m/sec^2)	POSITION RESOLUTION (cm)
MOUNT WINCH	50	–	0.1		±1.0
INSTALL CABLES	10	–	0.1		±1.0
TENSION CABLES	–	0.05	0.1		±2.0

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Figure 112. Power Bus Installation – Cherry Picker Requirements

and an elevation joint (Figure 113). The entire antenna support structure is hinged at the edge of the satellite structure for LEO/GEO transport configuration (Figure 98).

The yoke support structure is composed of the 7.5-m beams baselined for the satellite primary structure (Figure 97). The support structure beams joint to form a hexagonal interface that provides eight support points for the mechanical rotary joint circular beam (Figure 113). On the satellite side, these beams join to the hinged platform that will allow the complete antenna and support system to rotate under the end modules of the satellite.

The mechanical rotary joint is composed of two segmented circular beams (one on the satellite side and one on the yoke side), a section of which is shown in Figure 114. Each circular beam is supported at eight points, every 45°, to its adjacent support structure. The inner and outer base chords of each circular beam are arranged adjacent to each other. Between each set of base chords, a drive ring and roller assembly is attached (Figure 115) to provide relative movement between the satellite and antenna system. The antenna yoke attaches to its circular beam in a similar method as described for the yoke support structure.

The yoke is composed of 100-m trusses made up of the same beams as those for the antenna primary structure. At the antenna end of the yoke, a special end fitting is provided to interface with the antenna elevation joint. The elevation joint (See Figure 113) provides for a small pointing angle adjustment (approximately 7°) of the antenna system for alternate rectenna transmission capabilities. There is an electrical rotary joint at the interface of the yoke and yoke support structure. The electrical connection across the elevation joint uses flex cables because of the small angle adjustment involved.

Access for the MRWS to the mechanical joint is good (Figure 115); however, attachment of the drive ring and roller assembly presents a challenge to the manipulator design due to the limited space (35 cm) between circular beams. Although the structure for the electrical joint is 2.1 m apart, access for the MRWS is difficult due to the tension cables attaching at the same points as the outer slip ring motor drive. Access tp the middle and inner slip rings appears

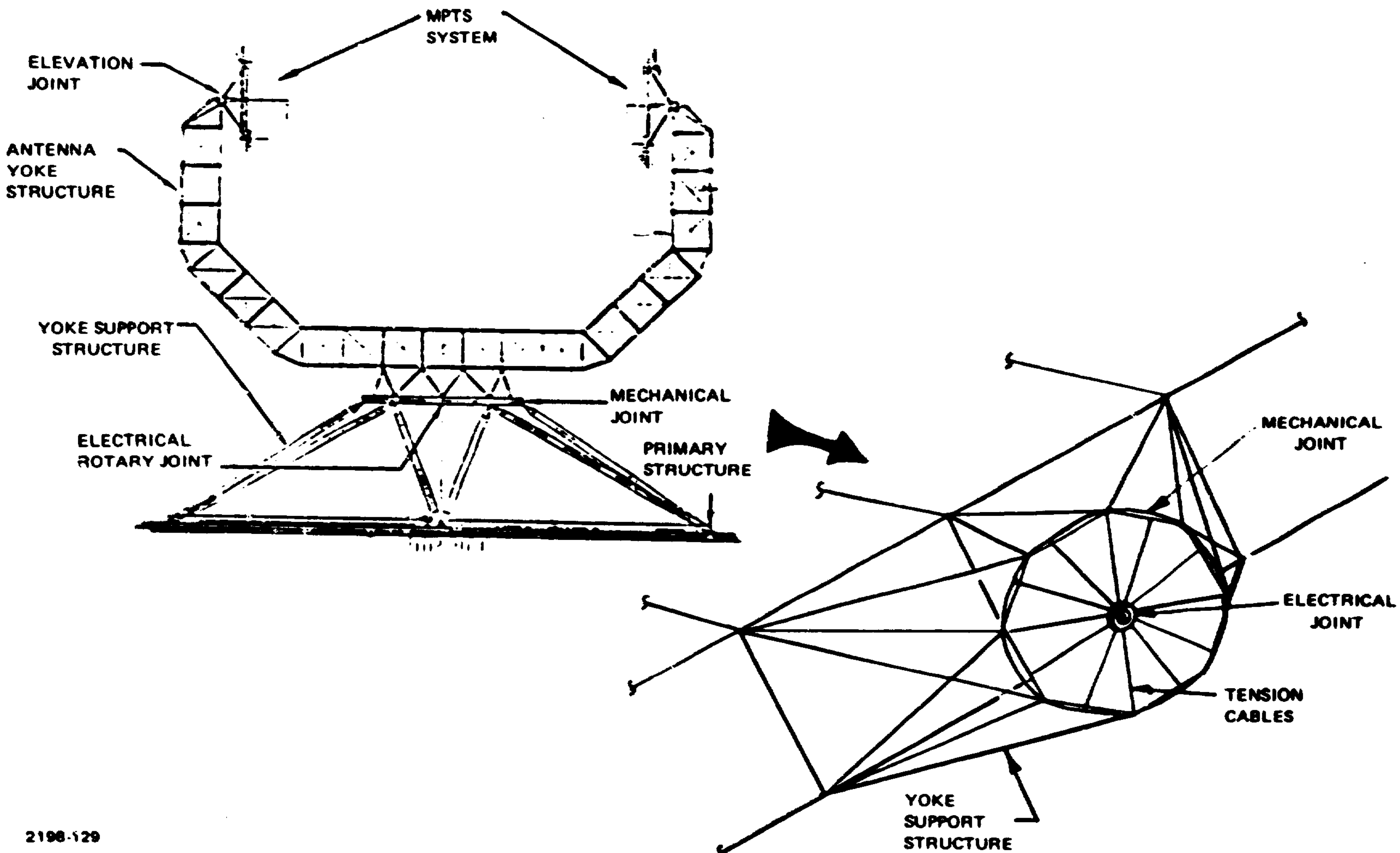

Figure 113. Antenna Yoke and Support Structure

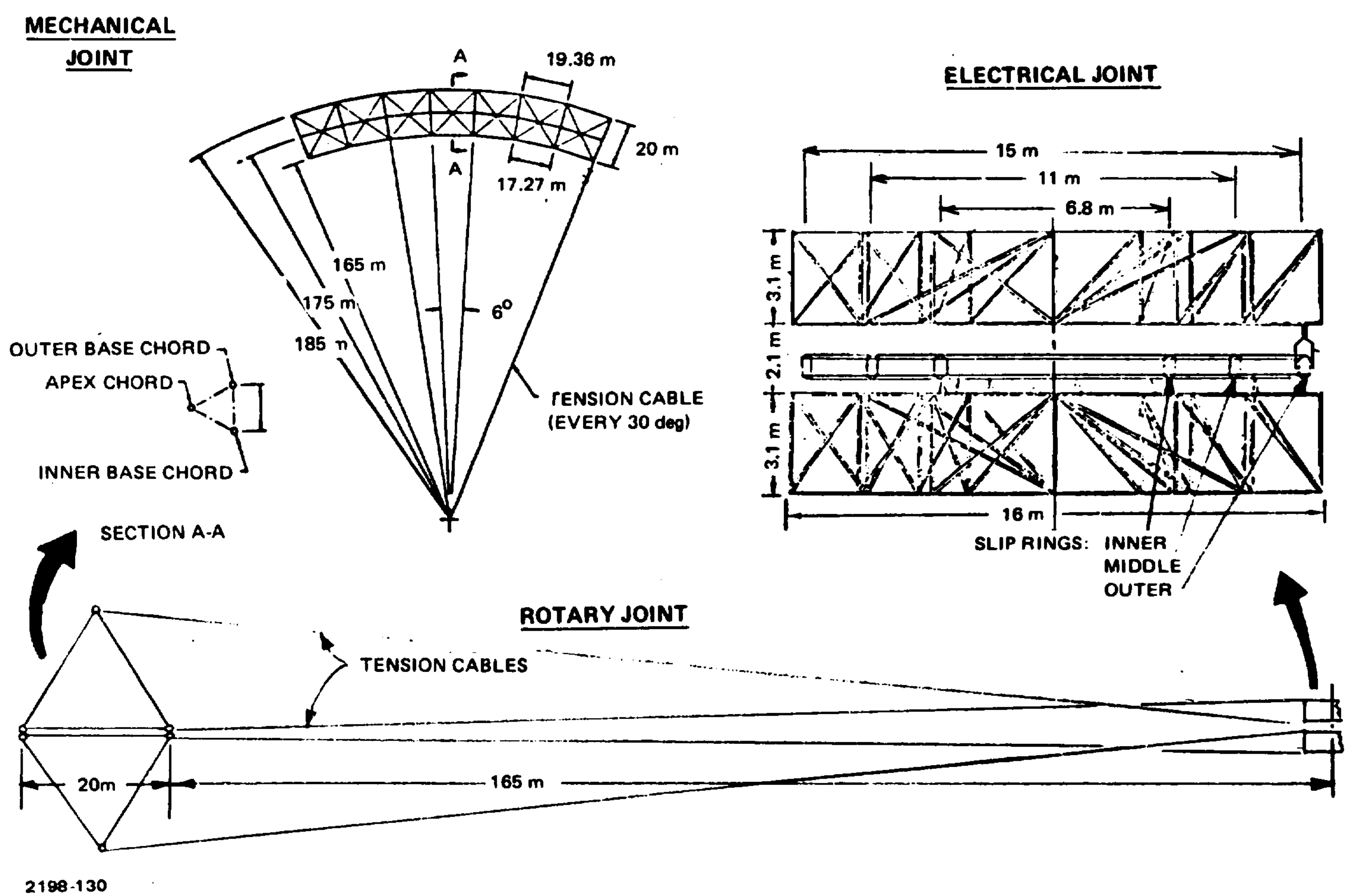

Figure 114. Rotary Joint Configuration

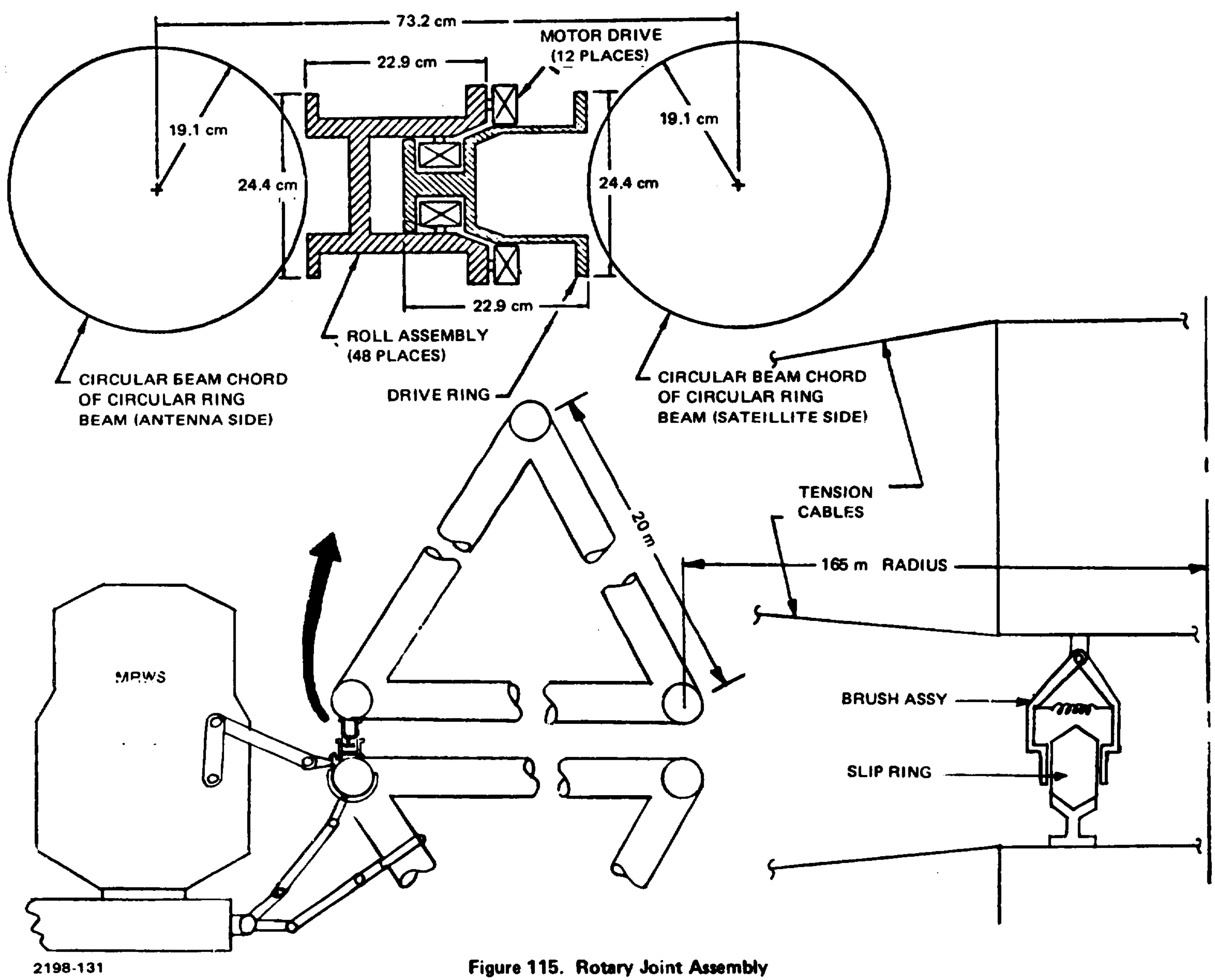

Figure 115. Rotary Joint Assembly

impractical for a MRWS-type vehicle. The route in is past the outer slip ring or through the slip ring/brush support structure. It appears this requires EVA astronaut capability for servicing. Possibly during construction, the slip rings and brush assemblies could be mated and installed as a completed assembly by attaching the tension cables. Alternatively, the brush jaws could be opened, slip ring assembly positioned during mechanical joint assembly, and then the brushed closed after verifying joint alignment.

Items to be Handled

Assuming the electrical joint is mated during mechanical joint assembly, the individual electrical assemblies must be positioned in the center of the mechanical rotary joint for attachment of the tension ties. This requires cranes to position an assembly of 19,620 kg for the slip ring (solar collector) side of the rotary joint and assembly of 4840 kg for the brush (antenna) side of the rotary joint. Tension cables 157-m and 167-m long on deployment spools are transported for cable installation. Winches are required on each cable for tensioning purposes.

Two approaches are available for the mechanical joint assembly. The drive ring could be attached to the antenna side of the rotary joint and the roller assemblies mounted on the antenna support structure (solar collector side). After the joint is mated, the rollers could be inserted, thereby mechanically locking the joint. Alternately, the roller assemblies are mounted to the drive ring during subassembly and the roller assemblies are fastened to the antenna support structure. This later approach only requires the MRWS to handle the fastening hardware.

Operations

Attach 24 tension cables and 48 roller assemblies, Table 26.

Cherry Picker Requirements

Figure 116 contains the requirements for the crane, stabilizer, and dexterous manipulator.

TABLE 26

TENSION CABLES/ROLLER ASSEMBLIES ATTACHMENT TIME-LINE

ΔT (min)	OPERATION
120	SNAP FASTEN TENSION CABLES TO INNER BASE CORD (24 TIMES)
360	STRETCH CABLE TO ELECTRICAL JOINT STRUCTURE (24 TIMES)
720	ATTACH CABLE TO WINCH & TENSION (24 TIMES)
720	ALIGN & CENTER ELECTRICAL JOINT BY ADJUSTING TENSION CABLES (24)
720	POSITION ROLLER ASSEMBLY TO STRUCTURE (48 TIMES)
1440	FASTEN ROLLER ASSEMBLY (48)
180	ATTACH POWER CABLE TO MOTOR DRIVE (12)
60	VERIFY ANTENNA DRIVE
4320	(72 hr) TOTAL

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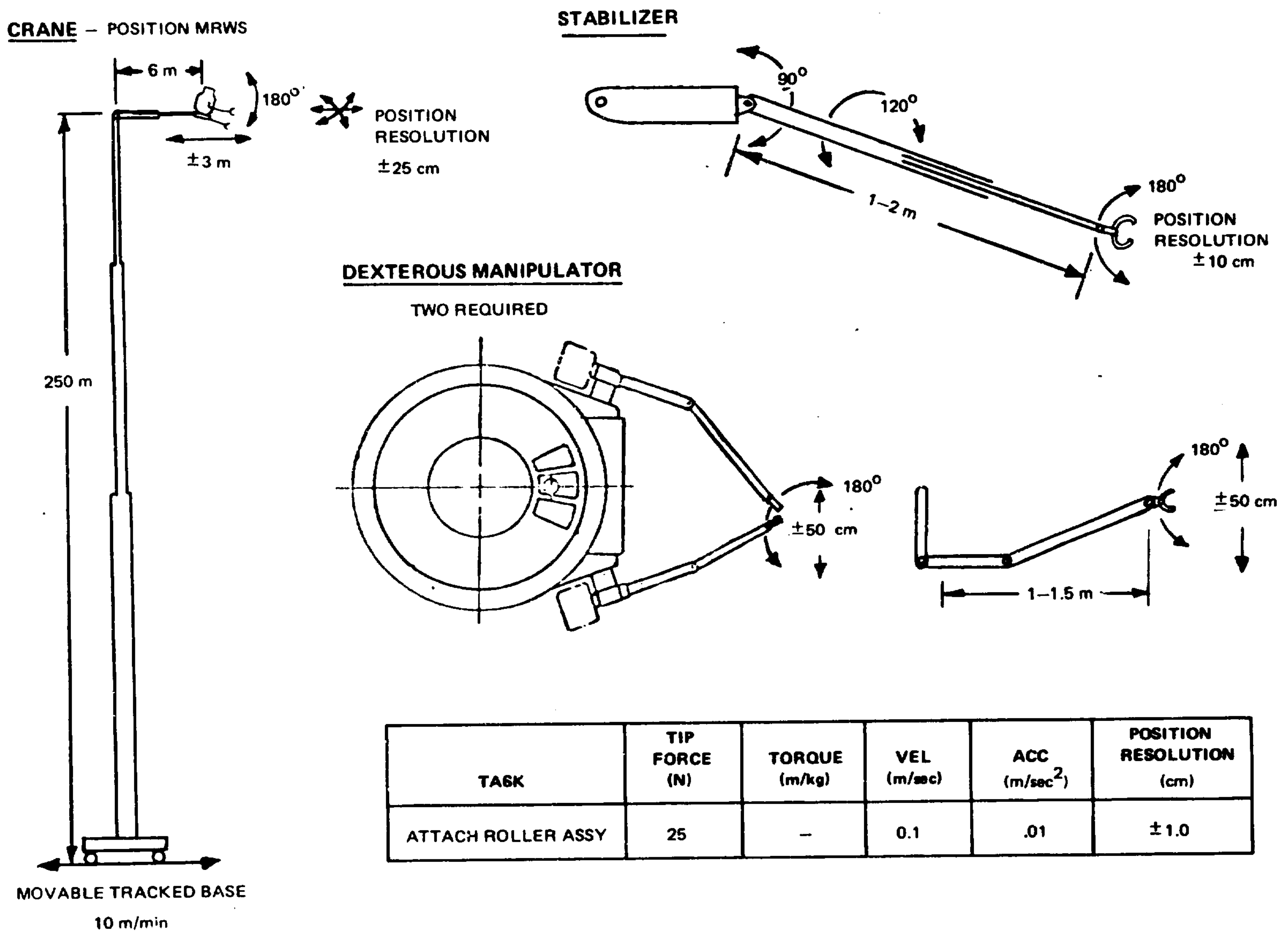

TASK	TIP FORCE (N)	TORQUE (m/kg)	VEL (m/sec)	ACC (m/sec^2)	POSITION RESOLUTION (cm)
ATTACH ROLLER ASSY	25	–	0.1	.01	±1.0

2198-133

Figure 116. Cherry Picker Requirements

Support Equipment

- End effector to fasten roller assembly to circular beam
- End effector to grapple circular beam
- Crane attachment fixture for electrical rotary joint structure
- Position and alignment tools for centering mechanical and electrical joints.

Issues to be Resolved

- Design and method of assembling rotary joint
- Means of access to the electrical and mechanical joints
- Alignment equipment and procedures
- Joint attachment tool design and operation.

References

Solar Power Satellite System Definition Study Part III, D180-24071-1 Prefered Concept System Definition. Boeing Aerospace Company, March 1978, pp. 22-26, 47-51.

3.1.8.3 Assemble Primary Joints of Microwave Antenna -

Accessibility

The Primary Structure of the MPTS antenna is an A-frame open truss structure 130-m deep, with a quasi-octagonal shape in excess of 1000-m width and length. The A-frame elements of the Primary Structure are made up of 7½-m continuous chord beams composed of graphite polysulfone composite structure. See Figures 98 and 117.

The antenna Primary Structure is fabricated and assembled using the LEO Construction Base. Figure 118 shows the Construction Base and the fabrication and assembly sequence of the antenna structure. The structure is assembled by use of "joint plugs" at beam intersections, and by using a probe/drogue-type connector at each beam chord end, the beams are joined to the plug. The lateral and longitudinal beams are handled and assembled by

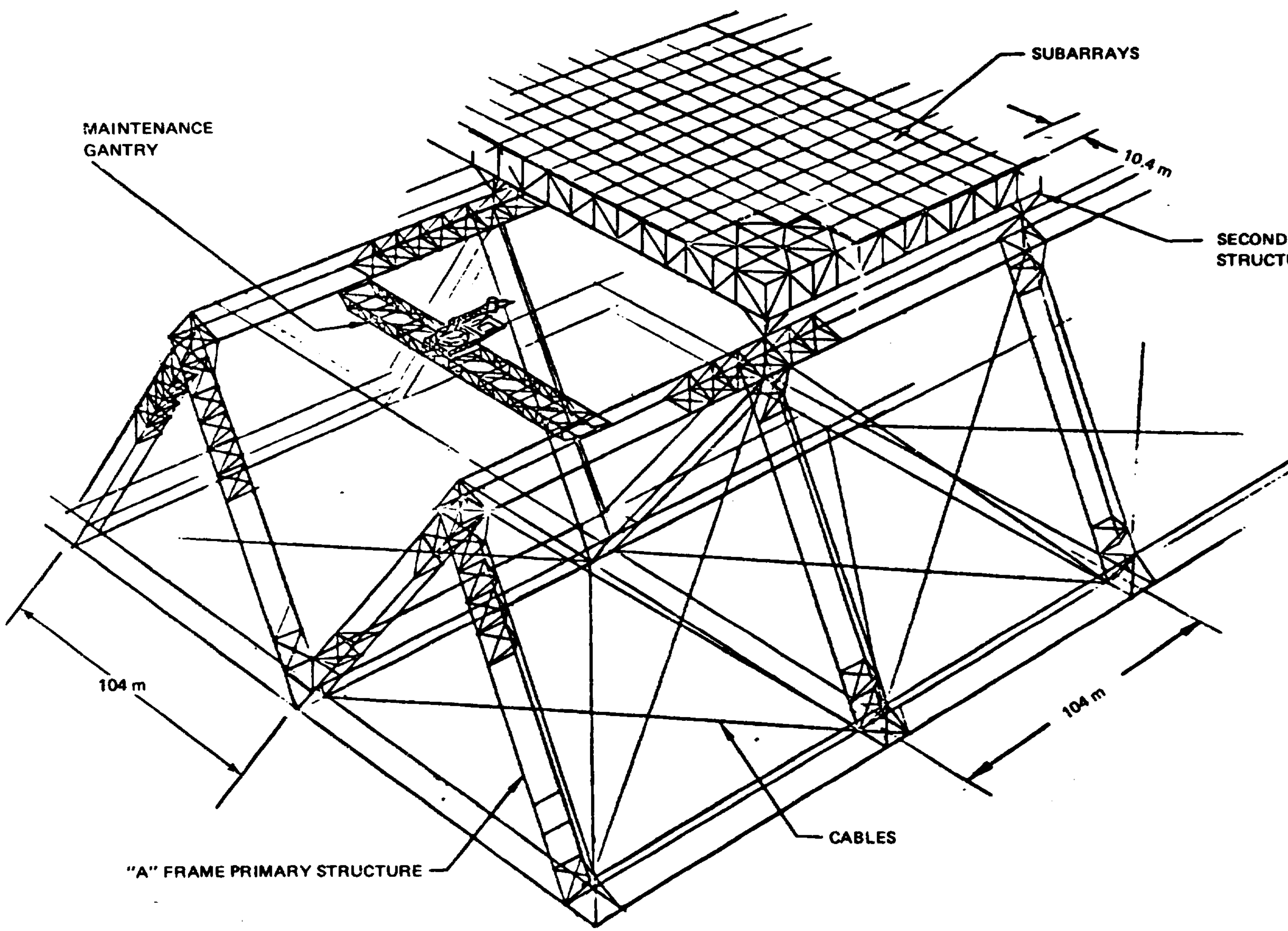

Figure 117. MPTS Structural Configuration

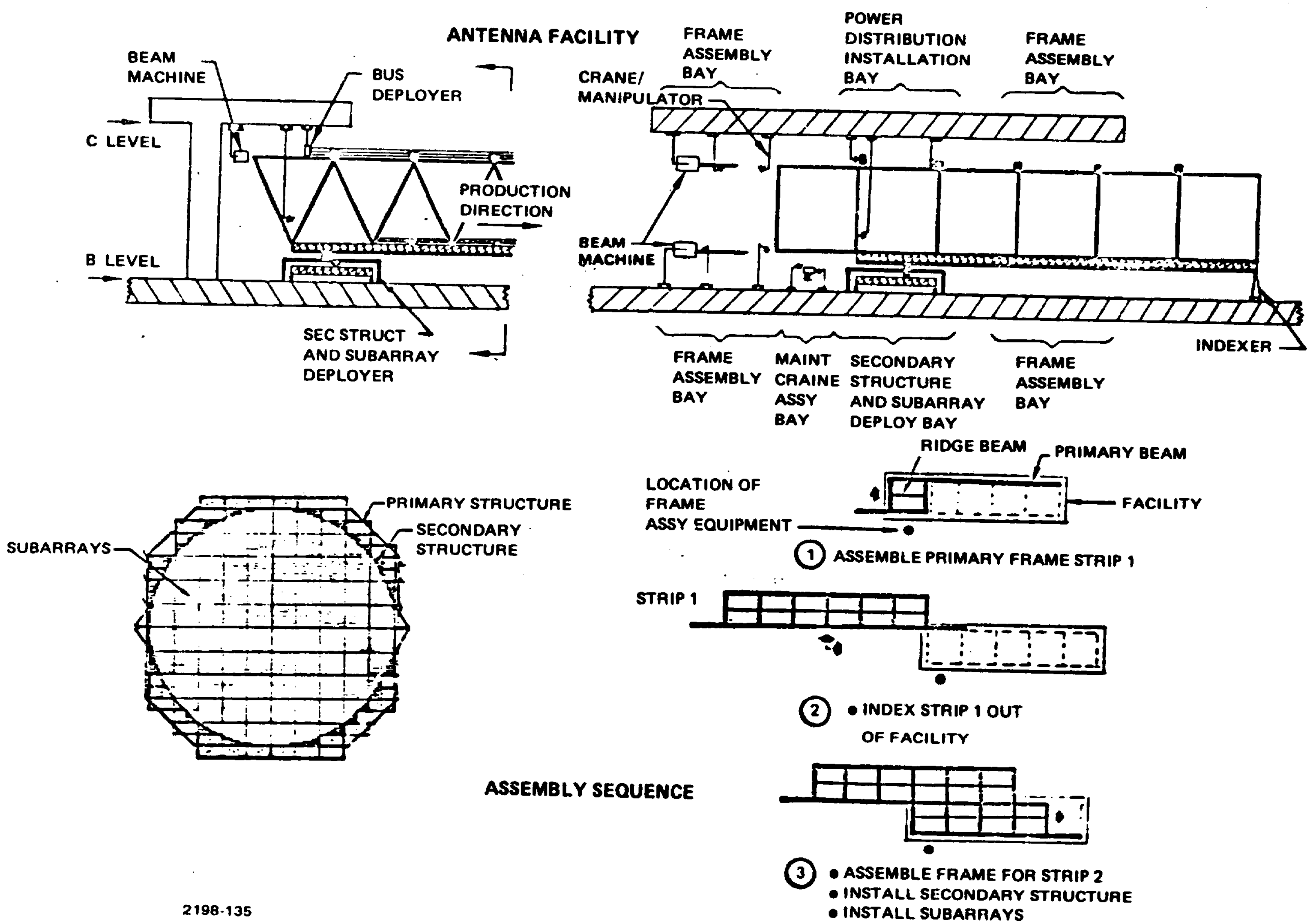

Figure 118. LEO Construction Base

two railed MRW's on the same construction base level. The diagonal beams are handled and assembled by one MRWS from each construction base level (Figure 119). A gimballed automatic beam fabrication machine is located at each level of the construction base. The structural "A" frame is an open framework and allows easy access to all the beam end connections (Figure 120).

Items to be Handled

- Lateral and Longitudinal Beams - Triangular Shaped, 7.5 m x 104 m, 575 kg
- Diagonal Beams - Triangular Shaped, 7.5 m x 140 m, 770 kg
- Joint Plug - 15 m x 15 m x 15 m, 250 kg.

Operations

Position joint plugs (207 plug joints) and assemble beam ends to joint plugs (3138 beam connections) Table 27.

Tracked Cherry Picker Requirements

Figure 121 contains the requirements for the crane, grappler, and dexterous manipulator.

Support Equipment

Figure 122 shows the necessary construction base support equipment required to fabricate and assemble the structural joints. Special end effectors will be required for the stabilizer arms to grasp the beams for transporting and aligning. Special tools for manipulator end effectors are required to grasp and fasten probe/drogue beam connectors. CCTV and illumination will be required, mounted on the MRWS for grappler and manipulator operation. Provisions for transporting MRWS operators from construction base crew living module to work site, and transferring them to the MRWS are required.

Items to be Resolved

- Numbers of crew in MRWS, one or two
- Configuration and location of stabilizer arms on MRWS to hold beams
- End effector design for grappler to grasp beam chords
- End effector design for dexterous manipulator for grasping beam connectors and holding tools for locking up beam connectors

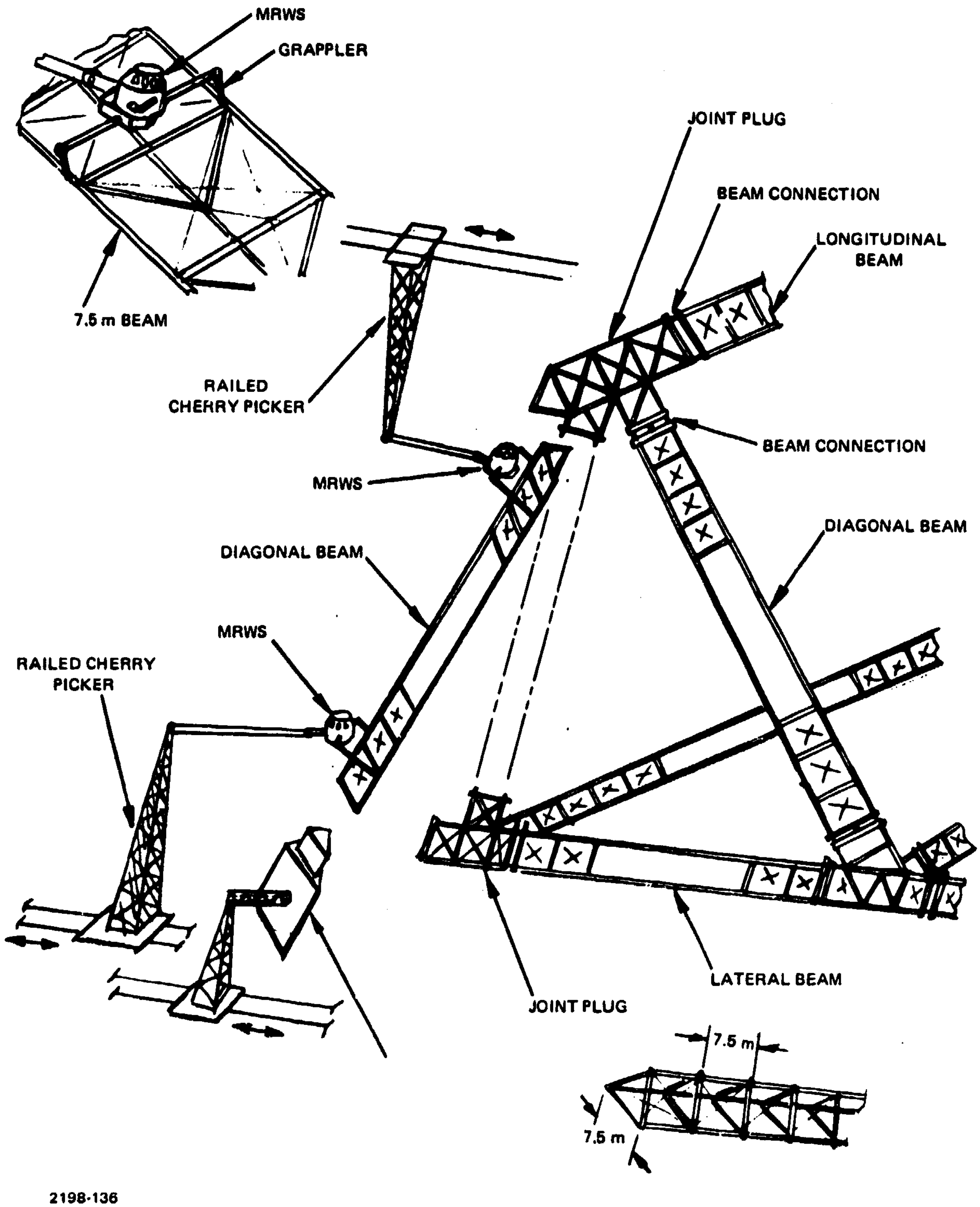

Figure 119. Assembly Operations

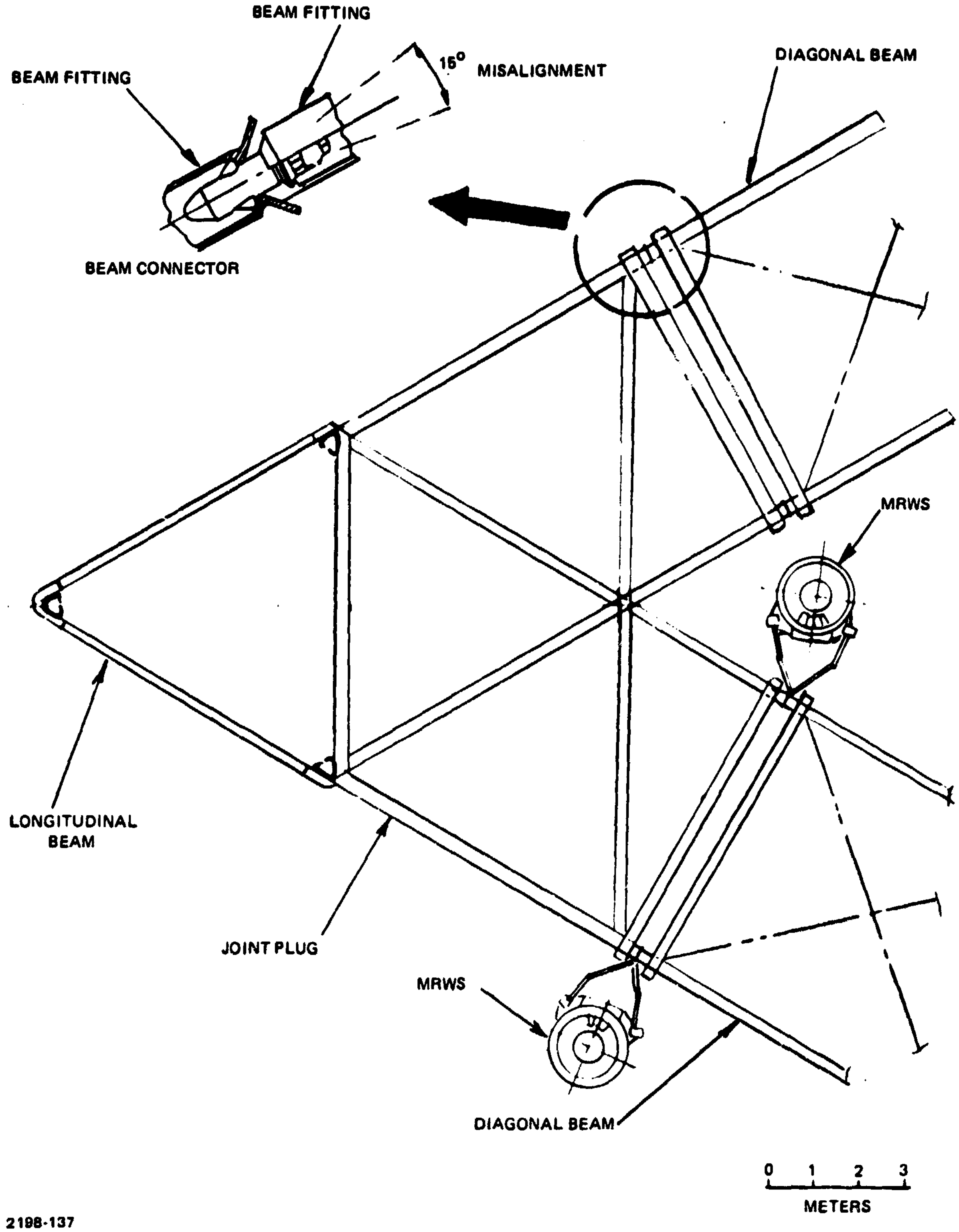

Figure 120. Beam Connections

TABLE 27

MICROWAVE ANTENNA PRIMARY JOINT ASSEMBLY TIME-LINE

ΔT (min)	OPERATION
:10	GRAPPLE PLUG JOINT & TRANSPORT TO ASSEMBLY POINT
:05	POSITION PLUG & CLAMP TO SUPPORT JIB
:05	MRWS GRAPPLE BEAM & REMOVE IT FROM BEAM MACHINE
:10	TRANSPORT & ALIGN BEAM WIDTH EACH PLUG JOINT
:05	MRWS ALIGN'S & SOFT DOCKS ONE CHORD CONNECTOR
:02	MRWS UNGRAPPLES & MOVES 7.5-m TO NEXT CONNECTOR
:05	MRWS ALIGNS & SOFT DOCKS SECOND CHORD CONNECTOR
:07	REPEAT FOR THIRD CONNECTOR
:19	ABOVE IS REPEATED BY MRWS AT OTHER END OF BEAM
:15	EACH MRWS THEN DOCKS UP ON EACH OF THE 3 BEAM CONNECTIONS
:83	(1:23) TOTAL

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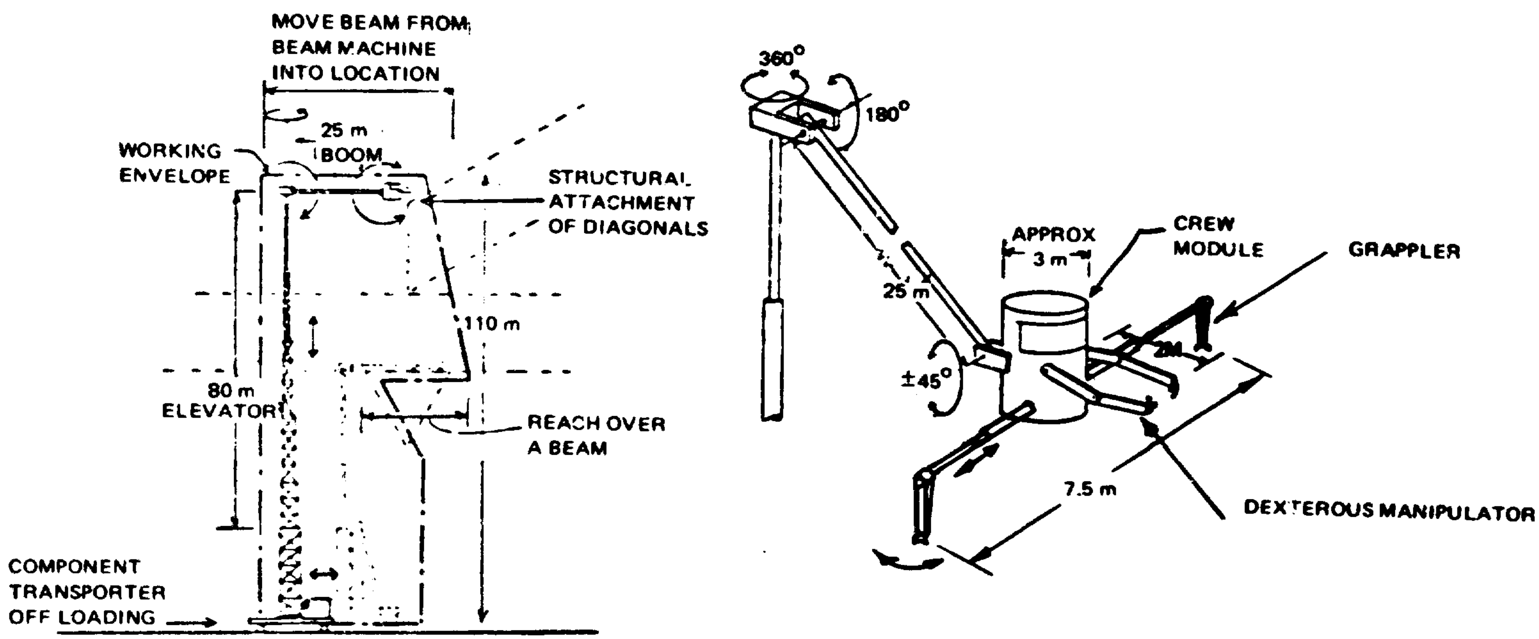

PARAMETER	CRANE	GRAPPLER	DEXTROUS MANIPULATOR
REACH, m	NOTED	NOTED	NOTED
MORPHOLOGY	NOTED	NOTED	SHOULDER JOINT PR WRIST JOINT PRY ELBOW JOINY P
VELOCITY, m/sec	10	0.1	0.1
TIP FORCE, N	–	22	22
POSITION RESOLUTION, m	0.5	0.1	0.01

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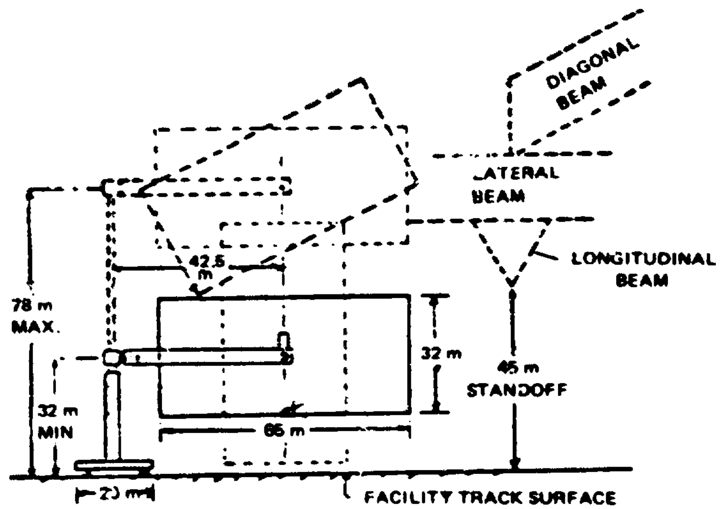
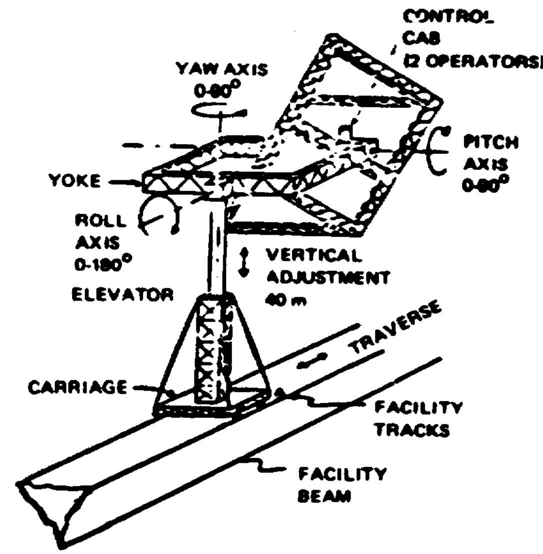
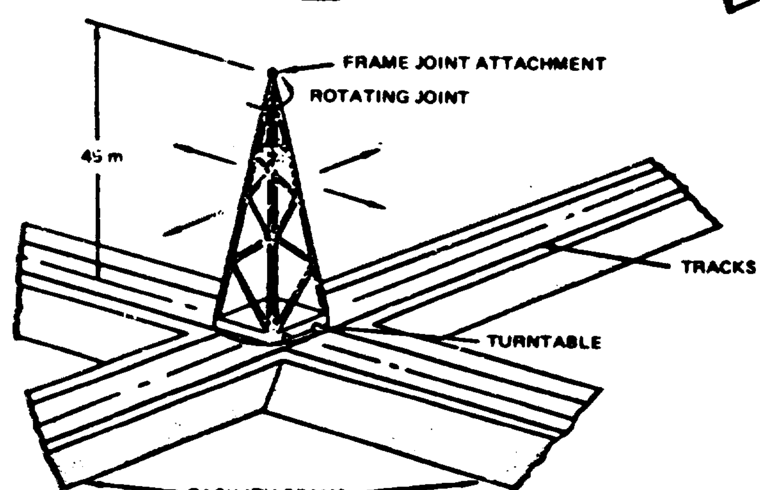
Figure 121. Railed Cherry Picker MRWS



BEAM MACHINE





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INDEXING/SUPPORT ASSEMBLY

Figure 122. Support Equipment

- Method of control of crane/cherry picker arm to limit acceleration of the tip
- Type of controller and displays to operate grappler and dexterous manipulator
- Visibility requirements for assembly tasks and collision avoidance
- Location of CCTV and illumination on MRWS module and stabilizer arms
- Safety considerations such as arm joint lockout in case of malfunctions, rate limiting of crane to reduce impact energy, method of rescuing crew from MRWS
- Method of transporting and transferring MRWS crew from crew living module to MRWS cabin
- Ability of one MRWS to handle, align, and fasten one end of 7½-m beam, might require two MRWS at each beam end.

References

- Solar Power Satellite System Definition Study Part III, D180-24071-1. Boeing Aerospace Company, March 1978.
- Solar Power Satellite System Definition Study Part II, Volume V, D180-22876-5. Boeing Aerospace Company, March 1978.

3.1.8.4 Solar Collector - Repair Crane Upper Joint - The MRWS support functions for the free-flyer were established based on a repair/rescue role involving the construction crane/manipulator illustrated in Figure 108. This role was selected because it encompasses all the generic tasks except transport over large distances (> 1 km), which is considered separately.

The repair/rescue scenario (Figure 123) involves transport to the crane location by a tracked-vehicle MRWS which becomes the free-flyer by separating from the locomotive section. The free-flyer then translates to the crane crew module where the stranded personnel are rescued via EVA transfer to the MRWS. The malfunction drive assembly is then replaced and the crane personnel are

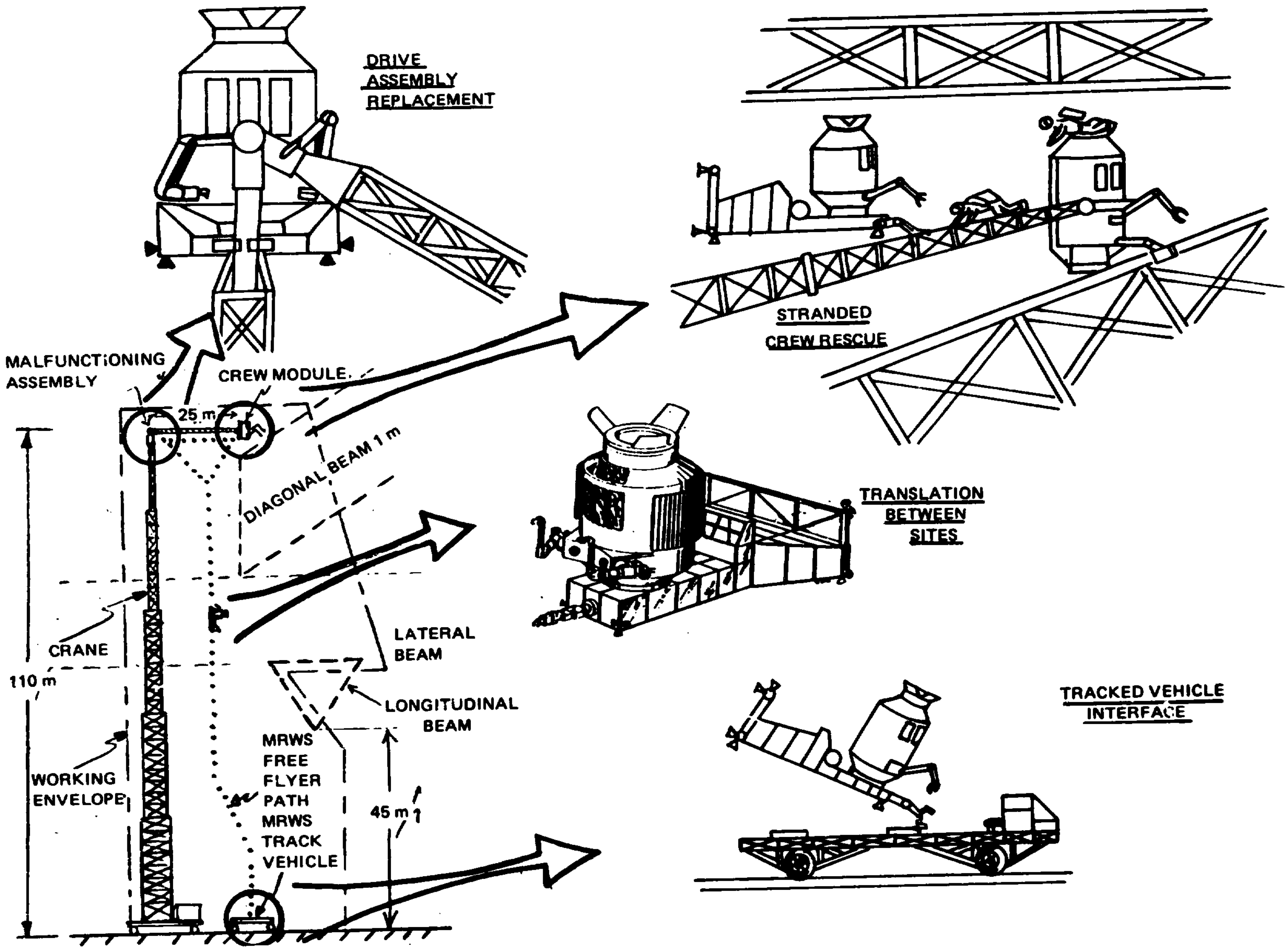

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Figure 123. SPS Repair/Rescue Scenario

returned to the crew module. The free-flyer then translates back to the tracked vehicle where it docks, attaches mechanically and electrically, and is transported back to the repair base.

Accessibility (refer to Figure 123)

Crew Module - The crane crew module is located in tight quarters in the SPS structure preventing the MRWS from docking with it for direct crew transfer. The MRWS grapples to the crew module boom as close as possible to the crew module emergency hatch. The crew EVA escape path is along the boom with tethered transfer aided by MRWS dexterous manipulators.

Drive Assembly - The crane upper joint drive assembly is an integrated double-gimbal, replaceable unit located at the intersection of the crane mast and crew module boom. In normal operation it does not come near any SPS structure nor other support equipment and is, therefore accessible from any direction.

Tracked Vehicle - The tracked vehicle is designed as an MRWS transporter with docking performed using the stabilizer. An approach path for docking is required at a 30° angle above the rear of the vehicle.

Items to be Handled

There are two major items to be handled: the joint drive assembly and the crew module mast.

The joint drive assembly is estimated to be 300 kg and measures 0.5 x 0.5 x 1.0 m. The end fitting on the crew module boom is inserted into the boom coupling adapter on the drive assembly and held in place while the cover plate is put in position and attached. A similar coupling concept is used in attaching the drive assembly to the crane mast.

The crew module boom assembly consists of the 25-m boom structure with the crew module at one end and the end fitting for attaching to the drive assembly at the other end. The crew module boom weight is estimated at between 1000 and 1500 kg and the crew module is 3500 kg. Two handling conditions must be considered. First is the case where the crew module is tethered or attached via its stabilizer to SPS structure. The MRWS at the drive assembly location must then be able to move the boom end fitting while the other end of the boom is being held. In the second case, the crew module is free with the only support through the boom to the drive assembly. In this case, the MRWS must support the entire boom/crew module assembly through the end fitting and must secure it while the drive assembly is being replaced. The latter functions may require a mission-peculiar stabilizer or mini-crane on the MRWS.

The removal, installation, checkout, and monitoring of the drive assembly will require handling a number of special test fixtures and fastening tools.

Operations

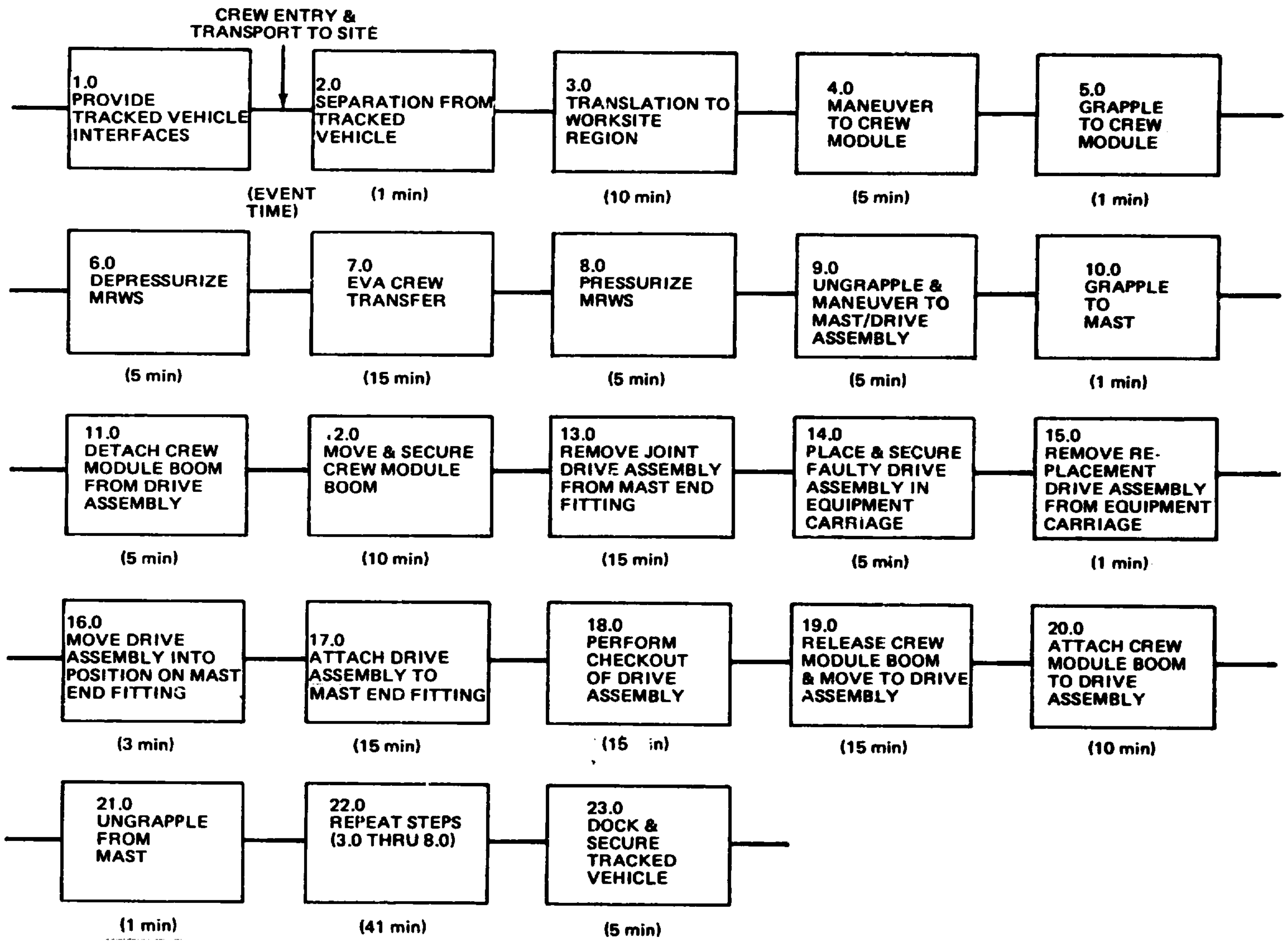
The temporary removal of crew module personnel and removal and replacement of the mast drive assembly involves the support functions shown in Figure 124. The operations are summarized in Table 28.

These free-flyer operations are represented of the mission to be performed once per week.

Stabilizer Requirements

The stabilizer must be capable of interfacing with the boom structure, the top section of the crane mast, and the tracked vehicle docking fixture. In general, the grapple region is the lower quadrant in front of and below the MRWS. Because the designs of the elements to be grappled are conceptual, only ROM requirements can be generated at this time:

Grappler Parameter	Value
Morphology	8 DOF (min) 3 m reach
Maneuver speed - no load	0.2 m/sec
- loaded	0.02 m/sec
Tip force	TBD
Torque Capacity	TBD
Position accuracy	0.01 m



*Excludes tracked vehicle support functions, e.g. locomotion control.

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Figure 124. Free Flyer Functions* – SPS Repair/Rescue

Manipulator Requirements

The primary manipulator tasks are positioning and installing the joint drive assembly, and removing and securing the crew module boom. The latter operation suggests the need for a special-purpose, mission-peculiar manipulator possibly carried as a tool on the equipment carriage as illustrated in Figure 125.

The following requirements have been established for the positioning and installing of the joint drive assembly:

Manipulator Parameter	Value
Morphology	7 DOF 3 m reach
Maneuver speed - no load	30 in./sec
- load	TBD
Tip force	66 n
Torque capacity	TBD
Position accuracy	0.01 m
Position resolution	0.001 m

Support Equipment

The equipment needed to support free-flyer operations includes:

- Tracked vehicle attachment clamps and connectors
- Cargo, tie-downs for replacement units, installation tooling, etc.
- Special-purpose manipulator (described above)
- Special end effectors for grappling and handling crew module boom and mast
- Miscellaneous tools and hardware for drive assembly removal and installations
- Drive assembly installation tooling and checkout equipment.

TABLE 28

CREW AND MAST DRIVE ASSEMBLY REMOVAL TIME-LINE

ΔT (min)	OPERATIONS
17	MANEUVER TO CREW MODULE
25	CREW REMOVAL
6	MANEUVER TO DRIVE ASSEMBLY
95	REMOVE, REPLACE & CHECKOUT DRIVE ASSEMBLY
31	RETURN TO CREW MODULE
15	RETURN TO TRACKED VEHICLE
189	(3:09) TOTAL

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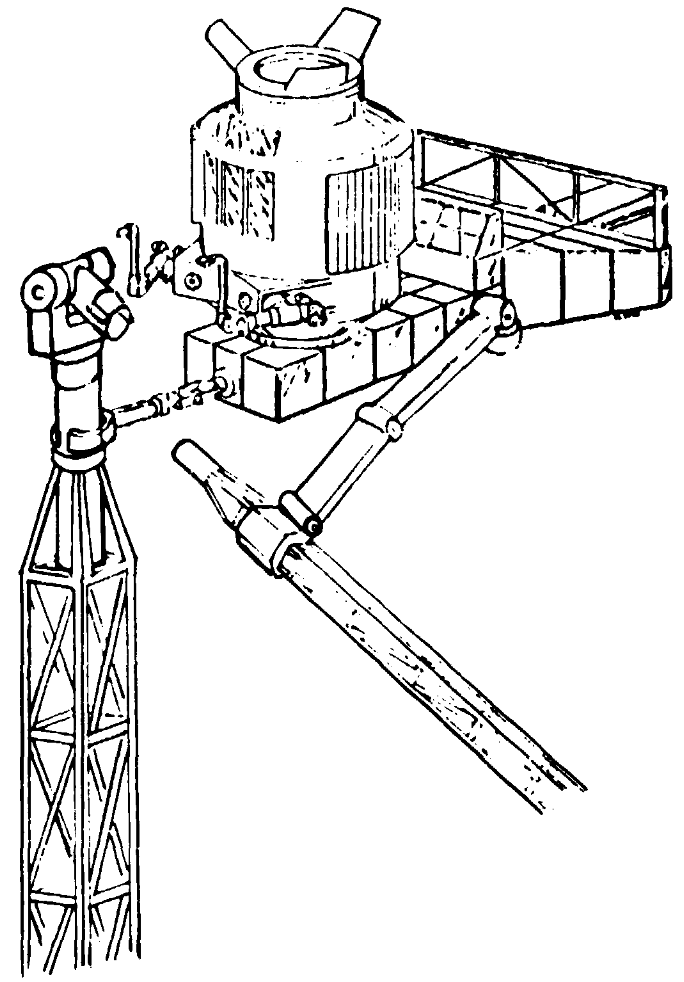

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Figure 125. Drive Assembly Repair – Boom Handling Manipulator

Issues to be Resolved

- Division of subsystem equipment between the cabin and carriage and between the inside and outside of the cabin
- Crew/passenger accommodation number and requirements
- Translational and rotational control system sizing
- Manipulator and grappler subsystems requirements and internal and external integration
- Displays concept for free-flyer role
- Life support subsystem sizing
- Electrical power subsystem sizing
- GN&C subsystem definition and sizing for transport tasks.

References

SPS System Definition Study, Vol V, Boeing, December 1977.

3.2 THERMAL ENGINE SOLAR POWER SATELLITE

The purpose of Solar Power Satellites (SPS's) is to collect solar energy, convert it to microwave power, and beam it to earth for conversion to useful electrical power. The Thermal Engine SPS utilizes solar reflectors that concentrate energy and reflect it into thermal cavities where heat exchangers absorb the thermal energy for subsequent transfer to turbine generators. Electrical power from the turbine generators is routed to microwave power transmission antennas for conversion to microwave energy and beamed to earth for collection, conversion, and distribution.

3.2.1 Mission Description

SPS construction commences in low earth orbit where major modular sections are built, then transported to geosynchronous orbit for final assembly. Eventually many SPS's are planned to be in operation, each providing power to specific rectennas. Because SPS's are huge in size compared to any other space venture, large factories must be constructed in space, housing hundreds of workers to construct one SPS per year. It is expected that the first prototype SPS will be constructed by the year 2000, probably transmitting 20% of the full-size (5-10,000 mw) SPS power.

3.2.2 Spacecraft Description

The Thermal Engine SPS (Figure 126) consists of 16 saucer-shaped concentrators joined together at their perimeter in three rows (5-6-5). Thermal cavities, which have rotating turbine generators mounted on their external shell, are suspended above each concentrator. Power busses run between the cavity assemblies to collect the electrical power and route it to microwave antennas located at each end of the longest (6) concentrator row.

3.2.3 Mission Scenario

The construction approach philosophy is similar to the photovoltaic previously discussed. Individual concentrator assemblies are constructed in low earth orbit (Figure 127) and transferred to goosynchronous orbit for final assembly. The Solar Engine Thermal SPS Microwave Antenna is constructed in LEO and transported to GEO in a similar manner to the photovoltaic SPS, and the final assembled SPS orbital parameters are also the same. Comparison of the two SPS construction approaches in Figure 128 shows that the thermal engine SPS requires more massive construction equipment although thermal engine SPS most probable mass 96,800 metric tons is about the same as the photovoltaic SPS.

3.2.4 Support Functions

The construction tasks were reviewed for MRWS functions as shown in Figure 129. Although the overall configuration of the thermal Engine SPS is vastly different from that of the photovoltaic SPS, many of the MRWS functions are similar:

- Material and personnel transported
- Large mass assemblies positioned and aligned
- Long beams maneuvered
- Automated operations monitored
- Joint integrity verified.

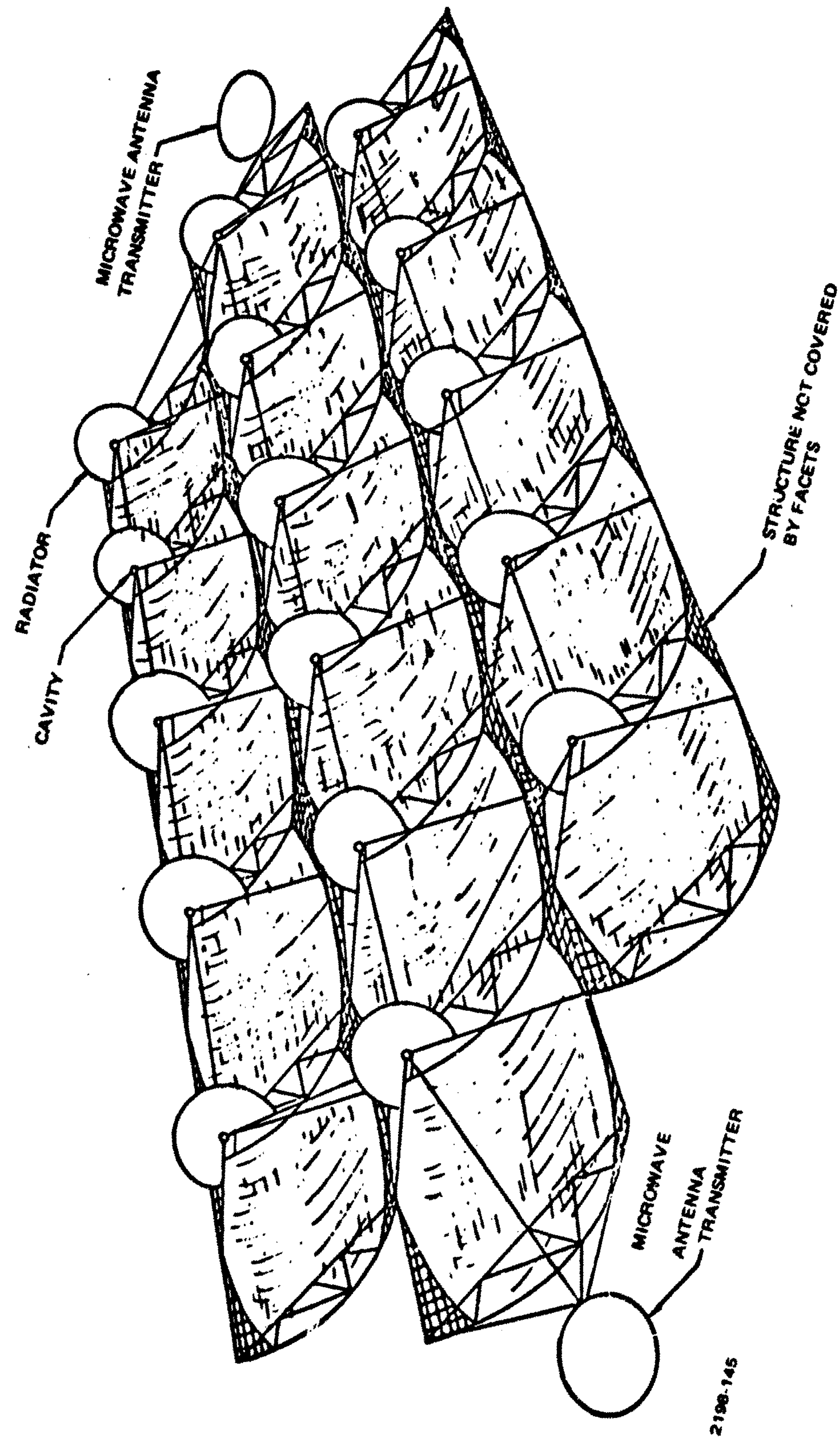

Figure 126. Thermal Engine SPS

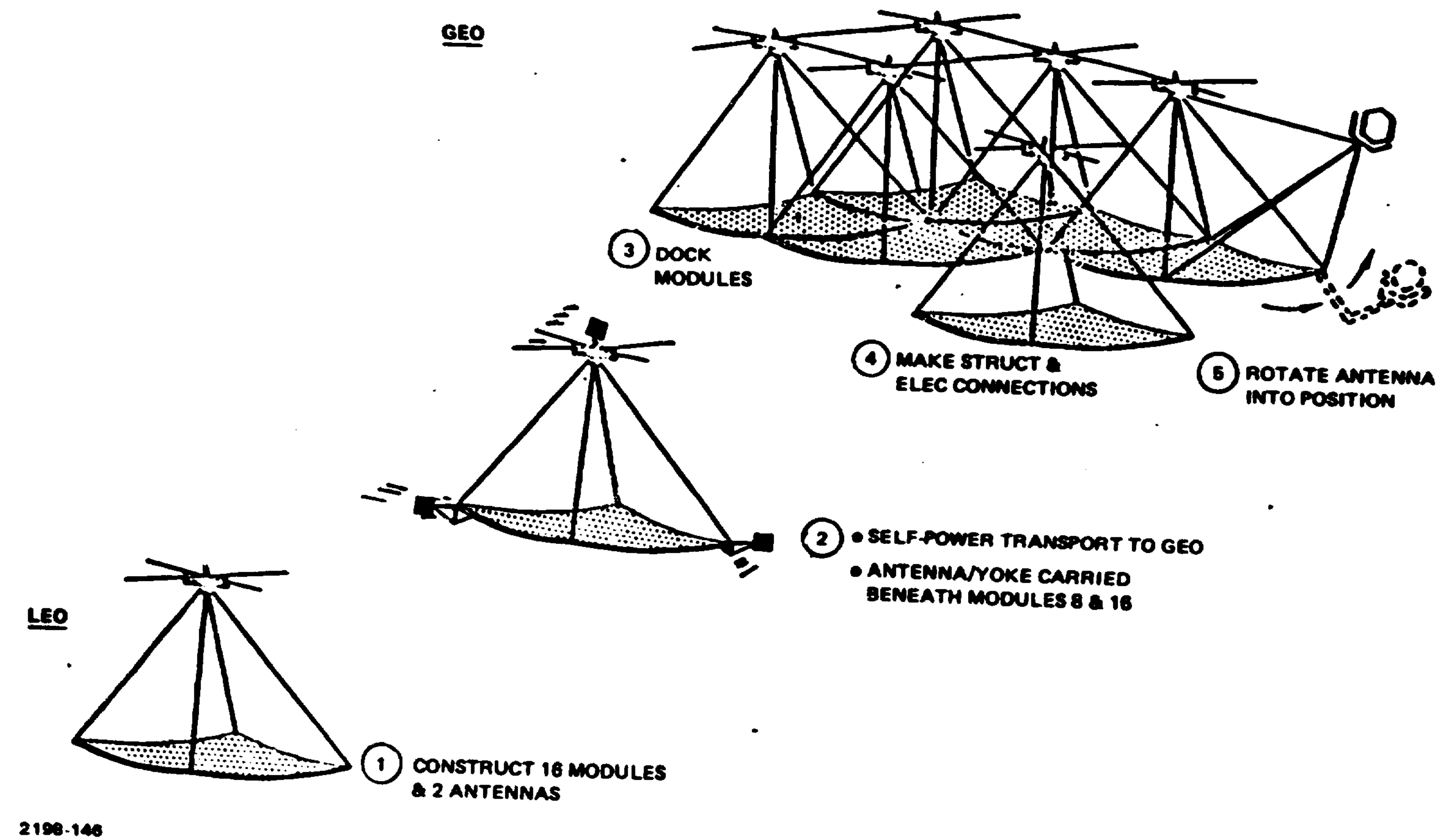

Figure 127. Thermal Engine SPS Construction Scenario

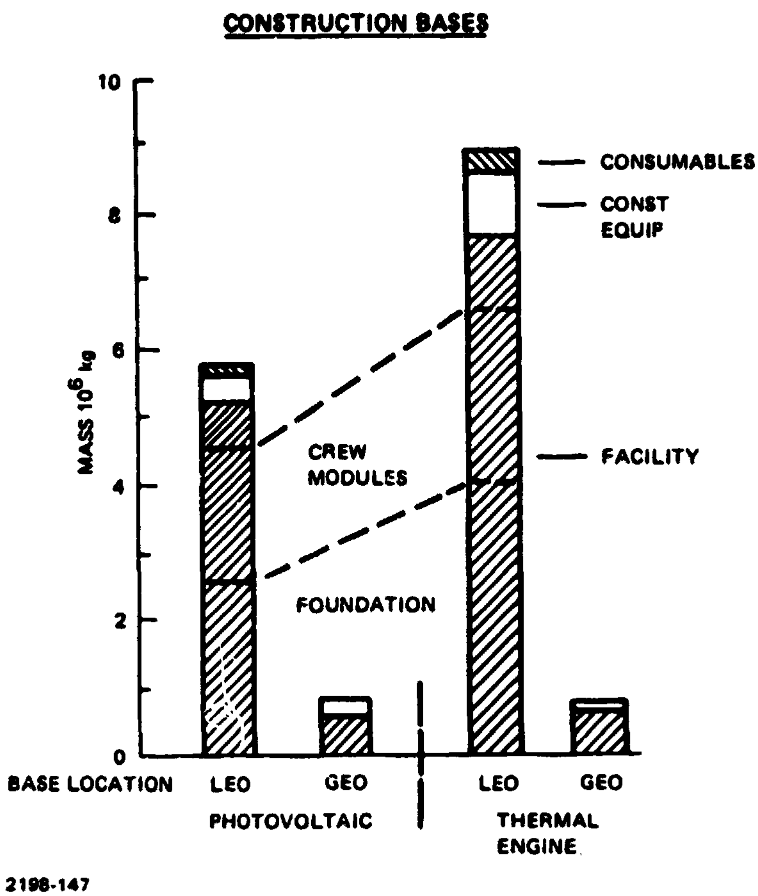

Figure 128. Construction Base Mass Photovoltaic and Thermal Engine SPS

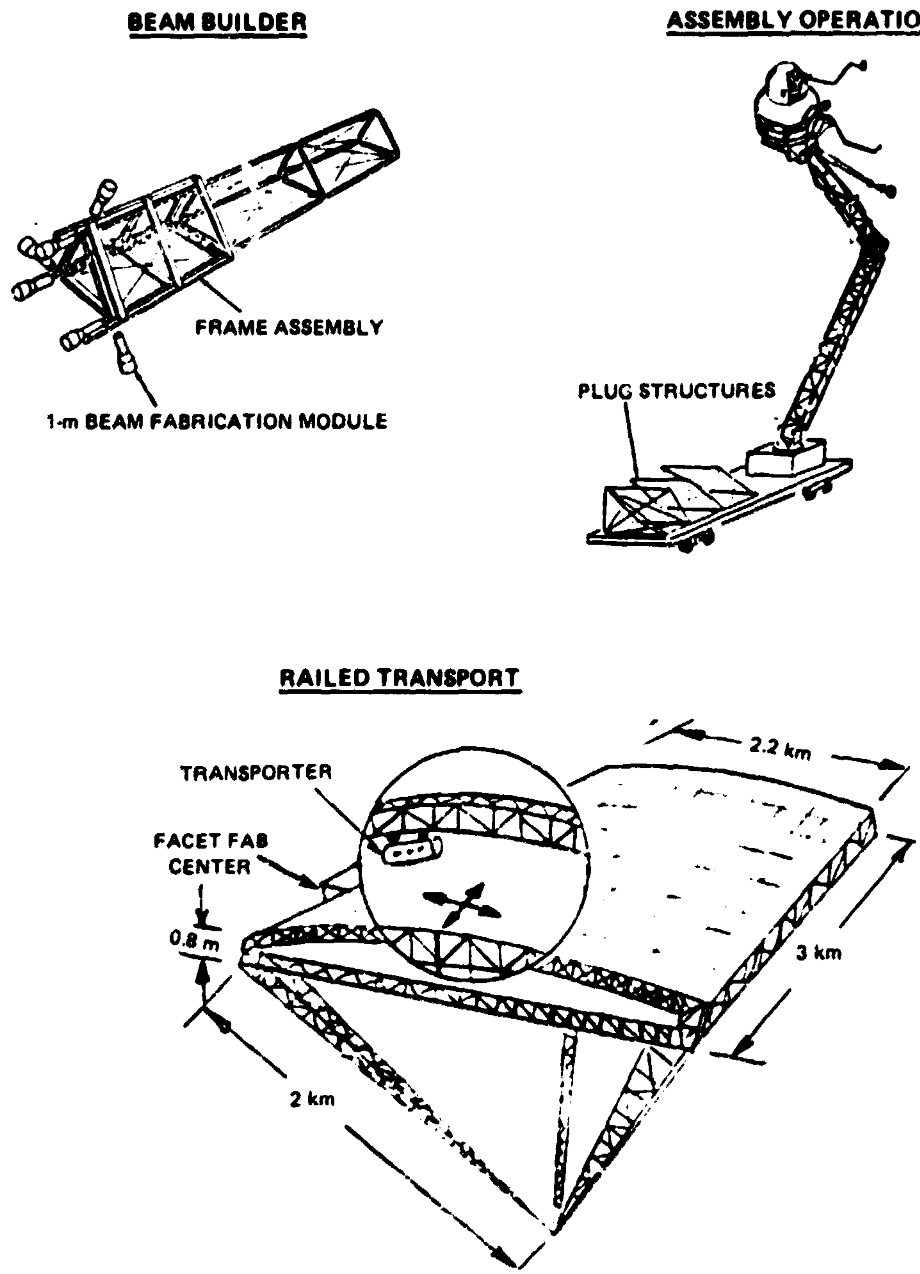

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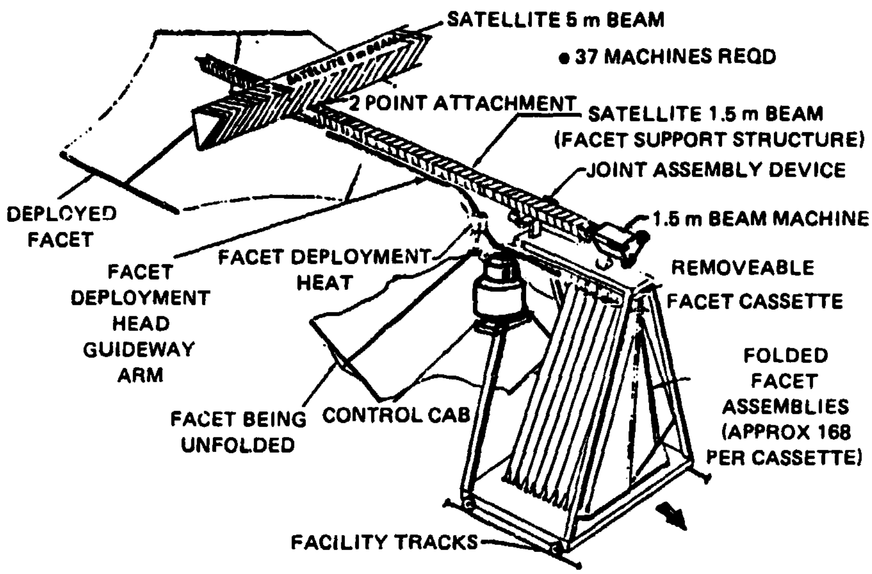
Figure 129. Thermal Engine SPS MRWS Functions (Sheet 1 of 4)

FACET DEPLOYMENT



FACET ASSEMBLY

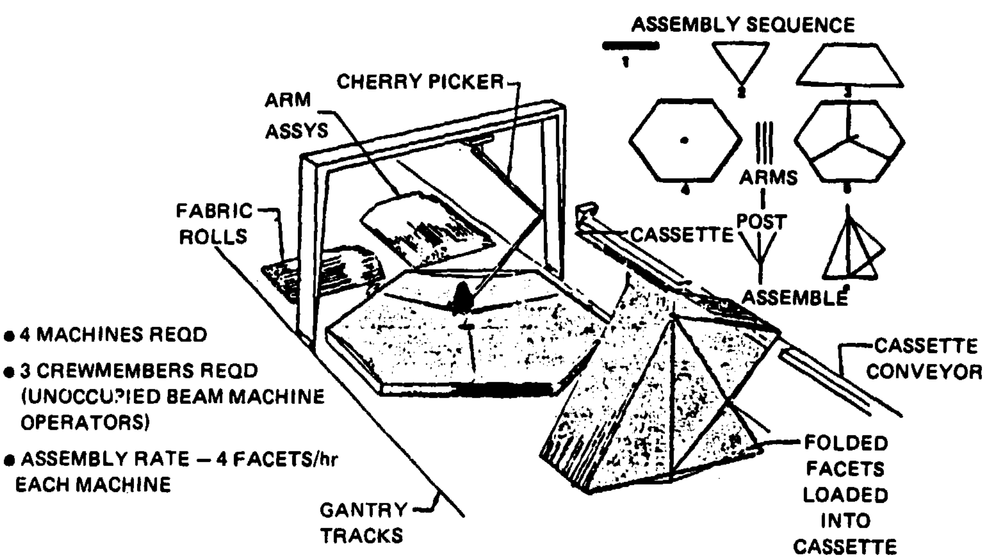
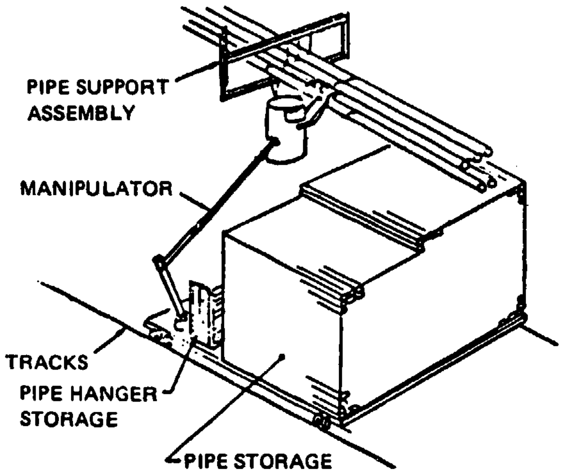


Figure 129. Thermal Engine SPS MRWS Functions (Sheet 2 of 4)

MANIFOLD INSTALLATION



CAVITY ASSEMBLY

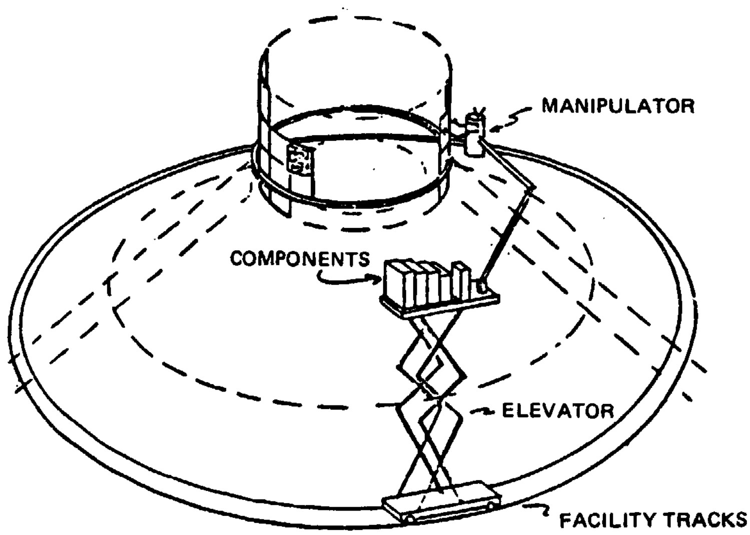


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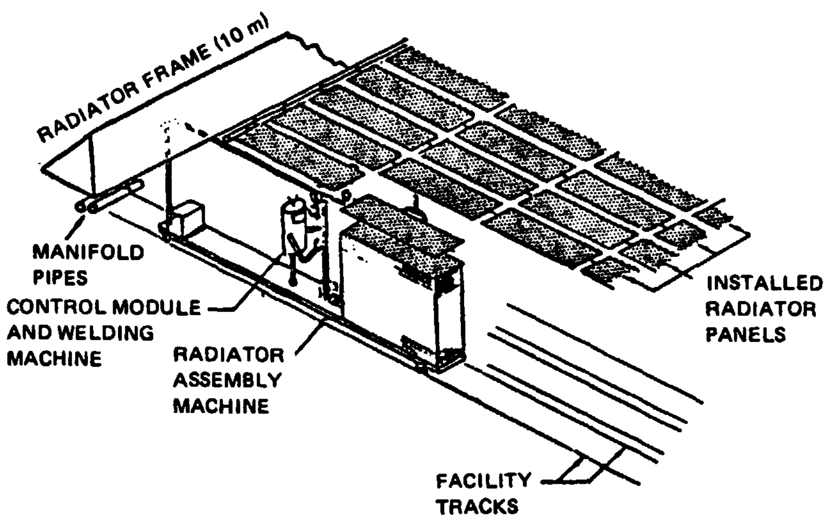
Figure 129. Thermal Engine SPS MRWS Functions (Sheet 3 of 4)

RADIATOR ASSEMBLY



SPINE ASSEMBLY

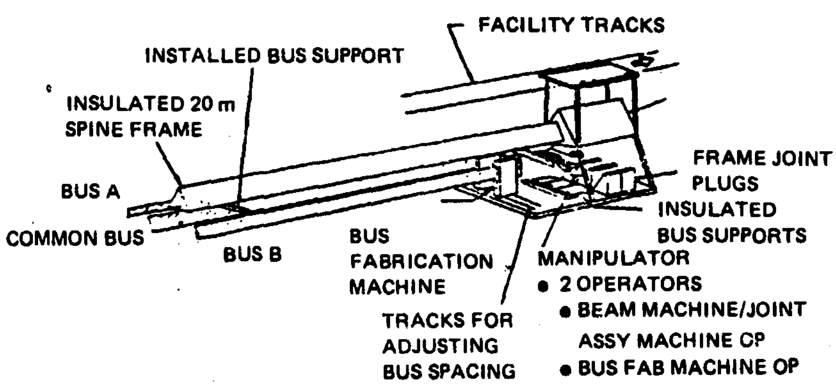


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Figure 129. Thermal Engine SPS MRWS Functions (Sheet 4 of 4)

The various construction tasks for each major assembly of the satellite module (reflector assembly, focal point assembly, and spline assembly) are described and the MRWS functions and requirements indicated for each assembly.

3.2.4.1 Reflector Assembly - The reflector structure is a spherical disc constructed from tetrahedral structural units which are fabricated and assembled with the structure assembly machine. This machine incorporates strut assembly machines and joint fitting installation mechanisms, similar to those used in the construction of the photovoltaic satellite. The MRWS construction functions are to transport, align, and join beams to form pyramids which are in turn joined to the main structure. Socket-type nodial joints are used for assembling beams.

The reflector facets are hexagons of thin aluminized Kapton. The Kapton is 3 μ m thick and are tensioned by three rigid end members pulled outward by bridles. This tensioning system causes the three edge members to be coplanar so that a flat reflector is produced. The Kapton film and arms are delivered to the facet assembly area. The Kapton roll is unfolded into the hexagonal shape and the arms and post and tensioning cables installed (Figure 129, Sheet 2). The facets are then folded and loaded on a casette conveyor and moved to the facet deployment machine. The railed cherry picker MRWS attached to a railed gantry will unfold plastic film; install arms, posts, and tension devices; and fold facets and attach them to the conveyor.

The facet deployment machine will fabricate 1.5-m satellite structural beams, attach them to existing 5-m beams and deploy facets (Figure 129, Sheet 2). The MRWS construction functions during this operation are to monitor beam fabrication machines, deploy structural joints, join beams, deploy and install facet assemblies to reflector structure.

3.2.4.2 Focal Point Assembly - Each of the satellite modules focal point is equipped with a radiator assembly, a cavity assembly and a spline assembly. The radiator assembly operations are shown in Figure 129, Sheet 4. The radiator panels and pipe supports are transported to the assembly area. The

MRWS deploys the panels and pipe supports into position and welds the panels and pipe supports. After the welds are inspected, the radiator assembly machine (which is self propelled) moves to the next position and attaches the next panel.

The manifold installation machine concept is shown in Figure 129, Sheet 3. The MRWS attached to a railed cargo vehicle must transport and install pipe hanger assemblies. The MRWS then transports and holds the pipes in position and welds pipe assemblies together. After the welds are inspected, the machine (which is self propelled) moves to the next assembly station.

The construction of the cavity assembly is shown in Figure 129, Sheet 3. The MRWS is attached to a vehicle which moves on a circular track. The vehicle, which has an elevator platform, also carries the components necessary to assemble the cavity. The MRWS must transport, align, and fasten ring support components together to form the cavity structure and fasten them to adjacent segments of the radiator leg frames. The turbogenerator pallets must be transported, positioned, and attached to the support ring by use of the MRWS.

3.2.4.3 Spline Assembly - The splies are 20-m beams which connect the focal point assemblies of each module together. The beams act as supports for the electrical buses. The spine assembly machine (Figure 129, Sheet 4) automatically fabricates the 20-m beams and buses. The MRWS, located on the assembly machine, monitors the automatic fabrication operation and installs and joins the bus supports to the beam. The MRWS will also transport, align, and join joint plugs to the beams. The buses are welded together at the joints by the MRWS.