MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

NASA CR-160462

FINAL REPORT — EXECUTIVE SUMMARY

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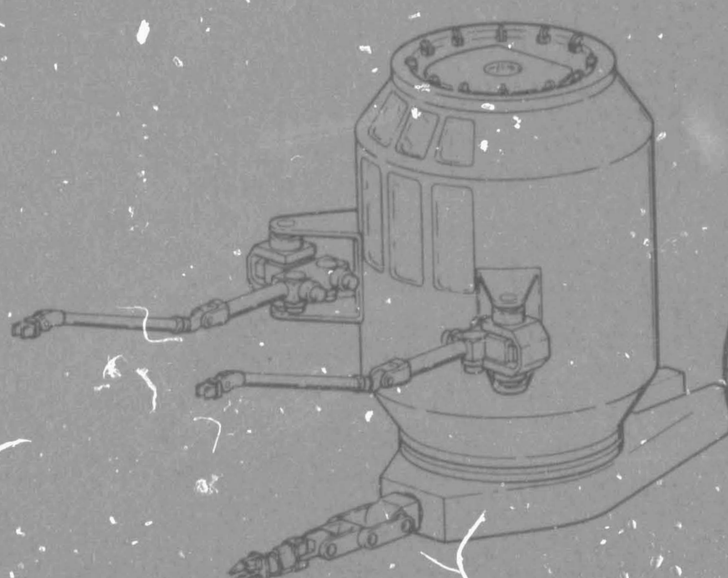

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MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

FINAL REPORT — EXECUTIVE SUMMARY

Prepared for

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
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By

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FOREWORD

This document presents the final report of the Manned Remote Work Station Demonstration Article Study conducted by Grumman Aerospace Corporation for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, under Contract NAS9-15507. A summary of the 12-month technical effort is reported in this volume. The other three volumes of the report present the full study results.

The results presented are due to the contribution of the following Grumman personnel: Messrs. F. DeRespinis, R. Pratt, O. Vescio, A. Frank, J. Hussev, G. Harms, R. Olsen, and S. Coryell. Contributions have been made by TeleOperator Systems, SPAR Aerospace Products, Ltd. and Hamilton Standard. Special acknowledgement goes to the NASA COR, Mr. S. Nassiff, for his direction and coordination.

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R. Johnson
Director, NASA Advanced Systems

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CONTENTS

CONTENTS (contd)

ILLUSTRATIONS

TABLES

Section 1

INTRODUCTION

The exploration and utilization of space have witnessed a continuous growth in spacecraft size and weight. Many applications are now envisioned which require ultra-large space structures for implementation. Because of restrictions in payload and volume of current and projected launch systems, these ultra-large structures must be assembled in space. This contract has addressed concepts and applications of a key piece of space construction support equipment needed to assemble these large structures and to provide other unique services such as servicing satellites and Spacelab experiments. Many tasks can most efficiently be performed by man. Concepts for safety and conveniently placing a man at a work-site have been studied and designs for a Development Test Article for use in simulation developed.

The Manned Remote Work Station (MRWS) is a universal crew station to be used as a cherry picker, space crane turret, railed work station, airlock and a free flyer (Figure 1). In these modes of operation, the MRWS will provide support for construction, maintenance, repair, and servicing operation. Early versions of an MRWS will be as an extravehicular activity (EVA) work station or

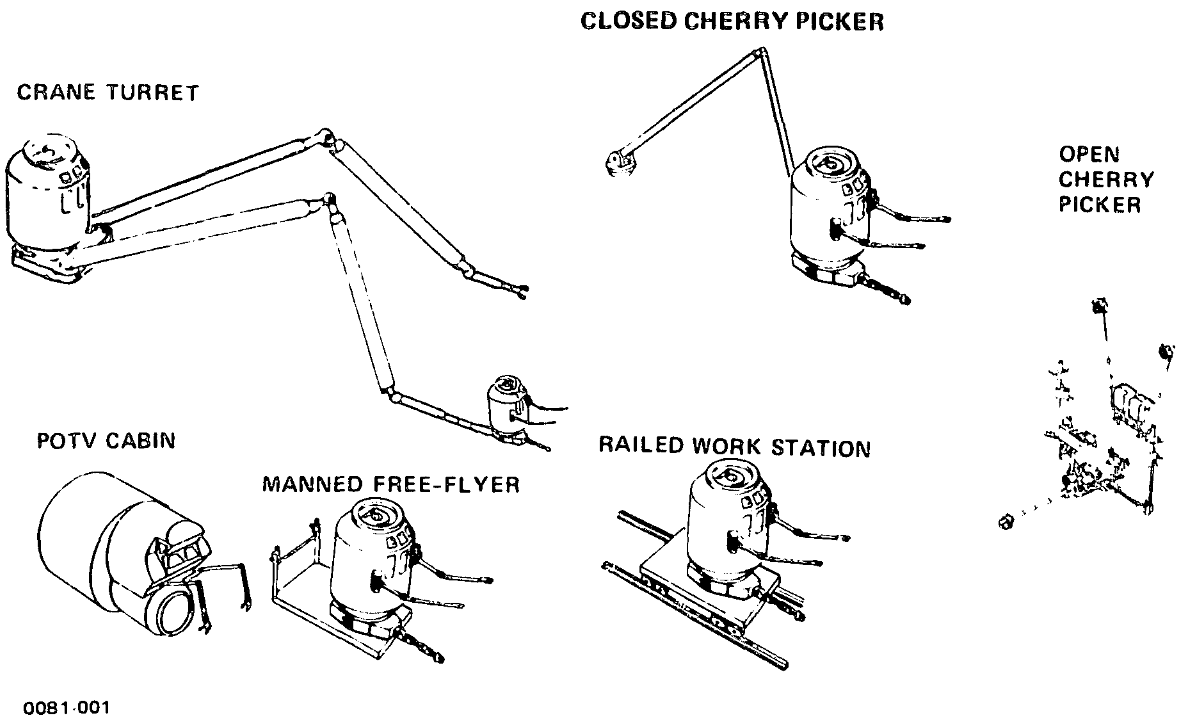

Figure 1. MRWS Multirole Concept in Support of Large Space Systems

open cherry picker (OCP) for use on the Shuttle. This OCP will be mounted to the end of the Shuttle Remote Manipulation System (RMS) and used to transport a suited astronaut along with mission peculiar equipment and tools to a satellite, which is attached in the cargo bay, for servicing or to a large structures assembly area. This contract has analyzed the requirements for these work stations, and derived concepts for each role. Key issues which require simulation were identified and used as a basis for formulating a five-year simulation program at the Johnson Space Center (JSC) Manipulator Development Facility. The simulation program begins with testing an open cherry picker through study of the key subsystems of the closed cabin MRWS.

Concepts and a program scenario for the MRWS are shown in Figure 2. Near-term applications of MRWS are in support of Shuttle operations as an OCP mounted to the end of the RMS. This MRWS provides a platform for EVA satellite servicing, deployment, and retraction of Spacelab and other planned Shuttle payload experiments, and assembly of large space structures. This work platform reduces the cost of EVA operations by avoiding the need to man-rate all hardware in the path of the astronaut during transport to the work-site and minimizing physical contact with the payload once the astronaut is at the work-site.

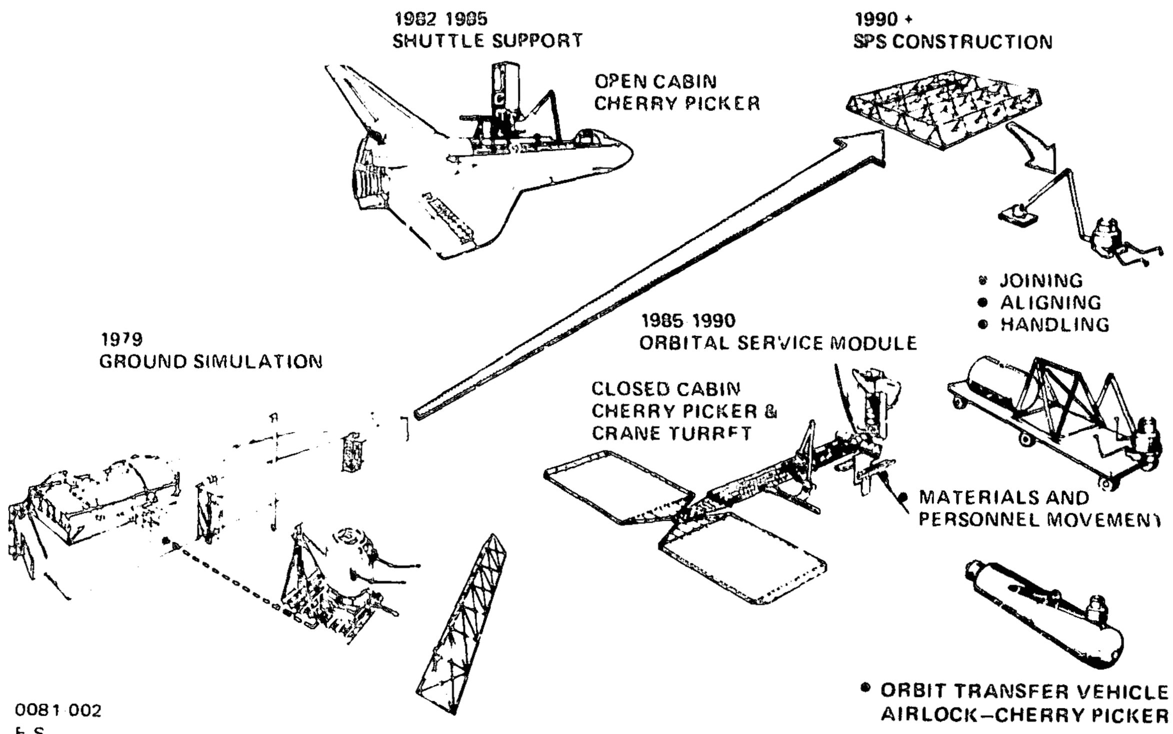

Figure 2. Orbital Construction Support Equipment Development Universal Manned Remote Work Station

In the mid to late 1980's, several planned programs will utilize Manned Remote Work Stations. The initial construction base utilizes an MRWS as a crane turret and as a closed cabin cherry picker for assembly of large antenna and solar power development articles. These longer duration and multi-shift missions will benefit from a closed cherry picker in terms of reduced radiation and longer crew work periods.

The ultimate application of the MRWS is in constructing the Solar Power Satellite (SPS). The varied roles of the MRWS apply to both Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) operations. The MRWS crane turret and cherry picker is joined in SPS construction operations by free flyers, control center cabins, and railed work stations.

Because the OCP is the first piece of orbital construction support equipment needed, emphasis was placed in this contract on the detail design of an OCP Development Test Article (DTA) for use in the Manipulator Development Facility, located at JSC Building A. The drawings manufacturing plans, and test plans produced under this contract will be used to manufacture a DTA in 1979 followed in 1980 by engineering simulation evaluations.

This report summarizes the mission requirements for the MRWS flight article and defines the MRWS OCP-DTA.

Section 2

STUDY OBJECTIVES

The objectives of the Manned Remote Work Station Development Article Study (NAS9-15507) are first to evaluate the MRWS flight article roles and associated design concepts for fundamental requirements and embody key technology developments into a simulation program. The second objective is to provide detailed manufacturing drawings and schedules for a simulator development test article.

The approach outlined in Table 1 establishes flight article requirements based on past studies of the SPS, orbital construction support equipment, construction bases, and near-term Shuttle operations.

In the process of studying flight article requirements, simulation objectives were established for those technology issues that can best be addressed on a simulator. Concepts for full-scale and sub-scale simulators were then studied to establish an overall approach to studying MRWS requirements. Emphasis was then given to design and specification of a full-scale development test article to be used in the JSC Manipulator Development Facility (MDF).

TABLE 1

PROGRAM OBJECTIVES

(1) ANALYZE & DESIGN MRWS THAT CAN OPERATE FROM END OF LARGE CRANE & OTHER MULTIROLE FUNCTIONS

(2) DEVELOP DESIGN, SPECIFICATIONS, DRAWING, MANUFACTURING REQUIREMENTS, COST & SCHEDULE FOR MRWS SIMULATOR.

APPROACH

- STUDY OCSE SPS & NEAR-TERM (1980's) CONSTRUCTION SCENARIOS & SHUTTLE SUPPORT FUNCTIONS FOR MRWS MULTIROLE REQUIREMENTS
- SPECIFY SIMULATION OBJECTIVES
- DESIGN ALTERNATE SIM CONCEPTS FOR FULL-SCALE & SUB-SCALE TESTING WITH VARYING DEGREES-OF-FREEDOM
- SELECT INITIAL APPROACH BASED ON COST & SCHEDULE SIMULATOR GROWTH TO PICK UP ALL OBJECTIVES
- DEVELOP PRELIMINARY DESIGN, SPECIFICATION & TEST PLAN FOR SELECTED INITIAL CONCEPT
- DEVELOP DETAILED DRAWING, MANUFACTURING REQUIREMENTS, SCHEDULES & COST

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Section 3

STUDY APPROACH

The 12-month effort was broken down into the three parts shown in Figure 3. Each of the three study parts was scheduled for four months. The milestones include NASA review/decision points at System Requirements Review (SRR), Preliminary Design Review (PDR), and Contract Design Review (CDR). Program status reviews were held at the end of the 3rd, 7th, and 11th months. In-house MRWS review board meetings were scheduled at mid-monthly intervals prior to NASA reviews.

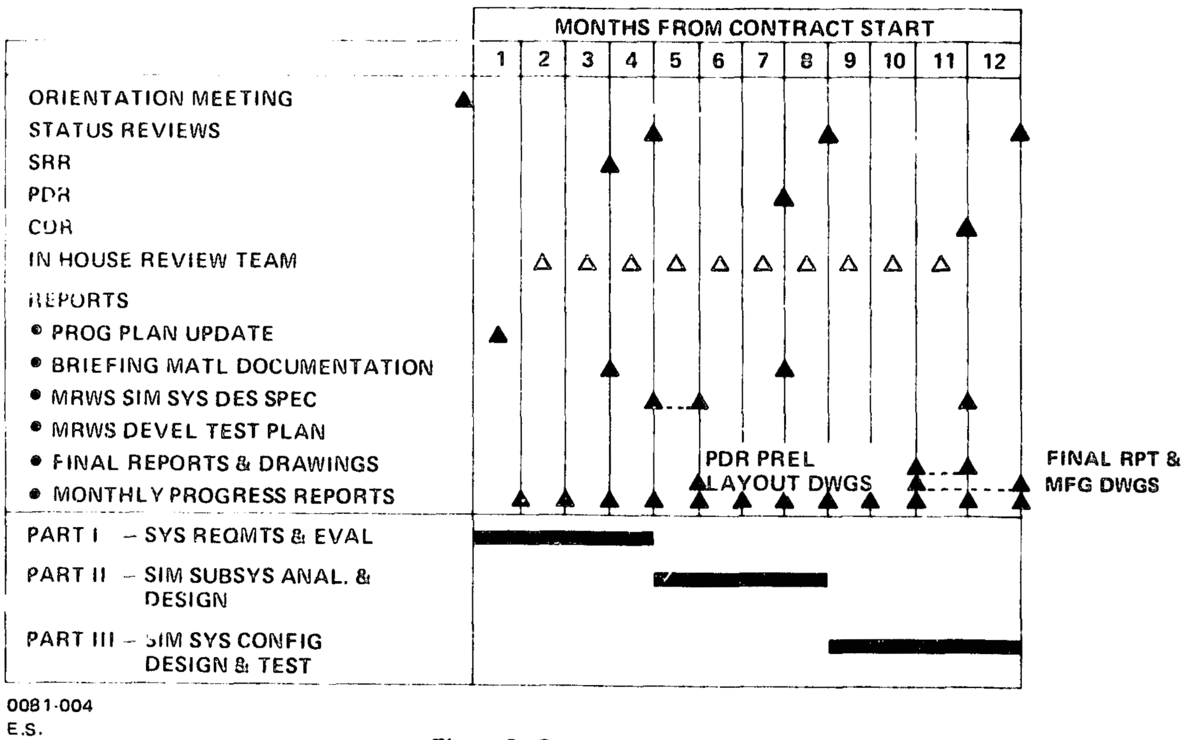


Figure 3. Program Schedule

Part I utilized mission scenarios from past construction studies to define near-term and longer range mission level requirements for an MRWS. After analysis and evaluation of alternate MRWS flight article concepts and subsystems, baseline concepts were selected as the basis for definition of the DTA. Concept designs for the DTA were prepared, with emphasis on the cherry picker mode, and simulator/DTA growth options evaluated to identify the incremental costs and viability of utilizing the DTA in alternate applications, e.g., as a free flyer. These concepts were evaluated and simulation/DTA requirements defined for the SRR.

Part II of the program developed a preliminary design of the open cherry picker DTA based on agreed-upon NASA guidelines emanating from the SRR. Each DTA subsystem (computers, displays, controllers, etc.) was sized and defined to sufficient depth for the PDR. Analysis and definition of facility integration were also performed, and preliminary test requirements for DTA installation and checkout were prepared.

During Part III of the program, detailed drawings, wiring schematics, and installation test procedures were prepared. Cost and scheduling information was developed to a level where, after CDR signoff, fabrication/assembly of the DTA could be initiated.

Section 4

SYSTEM REQUIREMENTS AND EVALUATION – PART I

The first four months concentrated on analysis of MRWS flight article requirements in support of Shuttle operations, initial construction base operations, and construction of the SPS. This analysis defined technical issues that need simulation for resolution. Simulation approaches were then studied and a program plan convering five years was formulated. The over-all study logic used is presented in Figure 4.

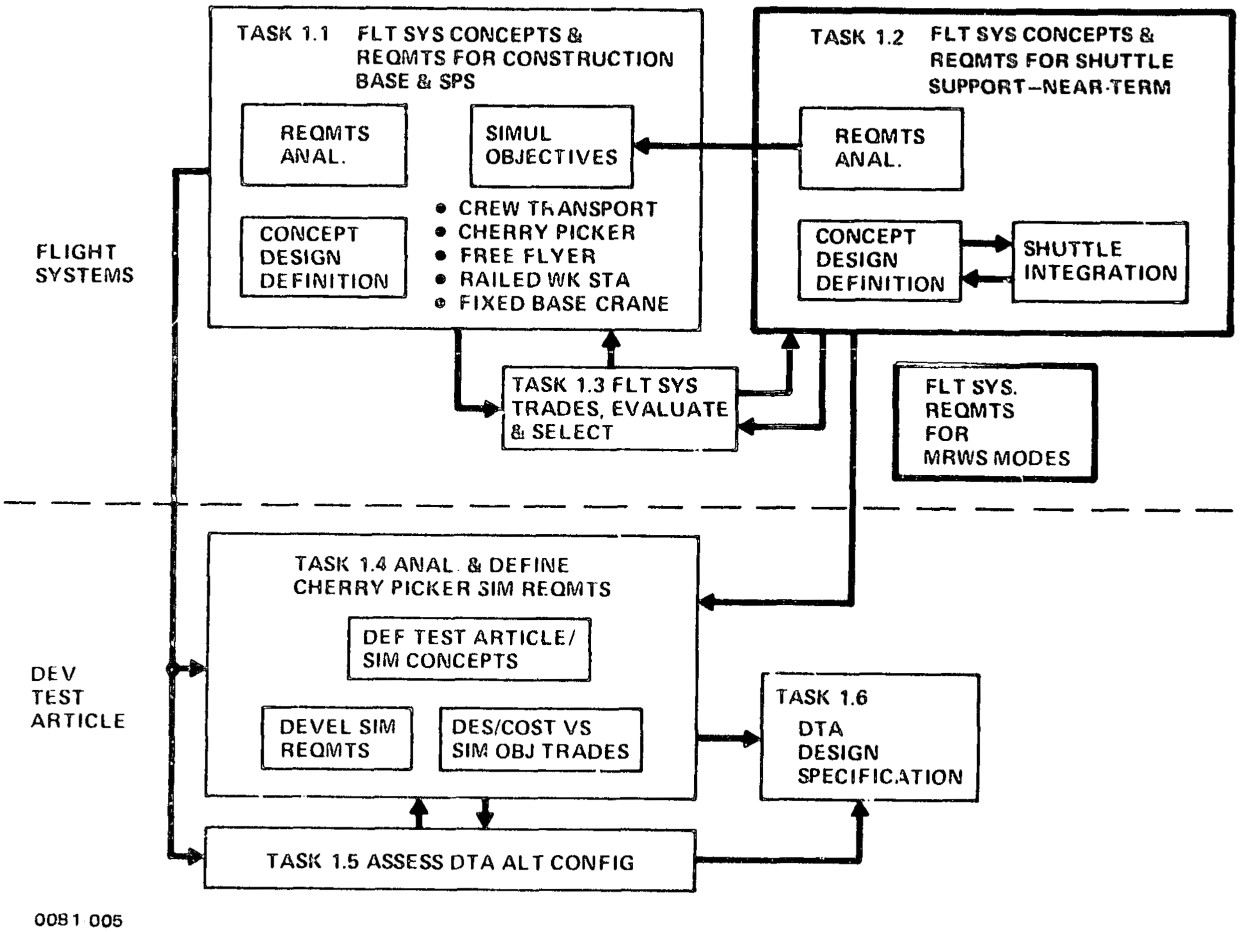


Figure 4. Part I: System Requirements and Evaluation

Tasks 1.1 and 1.2 were the focal point of the flight article definition. Key outputs were functional requirements and top level descriptions of the cherry picker flight system and configuration. Expanded functional analysis of appropriate operational tasks, as well as an identification of the simulation objectives were included. The configurations, functional analyses, and simulation objectives of the unique features of alternate MRWS roles (crane, free flyer, etc) were also treated and reported in Volume I of this report.

Flight article tradeoff studies, Task 1.3, were limited to key issues, such as crew size, docking port locations, and the mounting geometry for the external manipulator arms. Issues best resolved by simulation were studied to establish a likely range of options and parameters. Appendix B of Volume I reports the results of these trade studies.

Based on the MRWS flight article mission requirements and the capabilities of the MDF, Task 1.4 developed alternative simulation concepts. These concepts focused on the cherry picker role and used various scale and modular DTA buildup approaches to provide development flexibility. Selections were made and reviewed with NASA at the SRR.

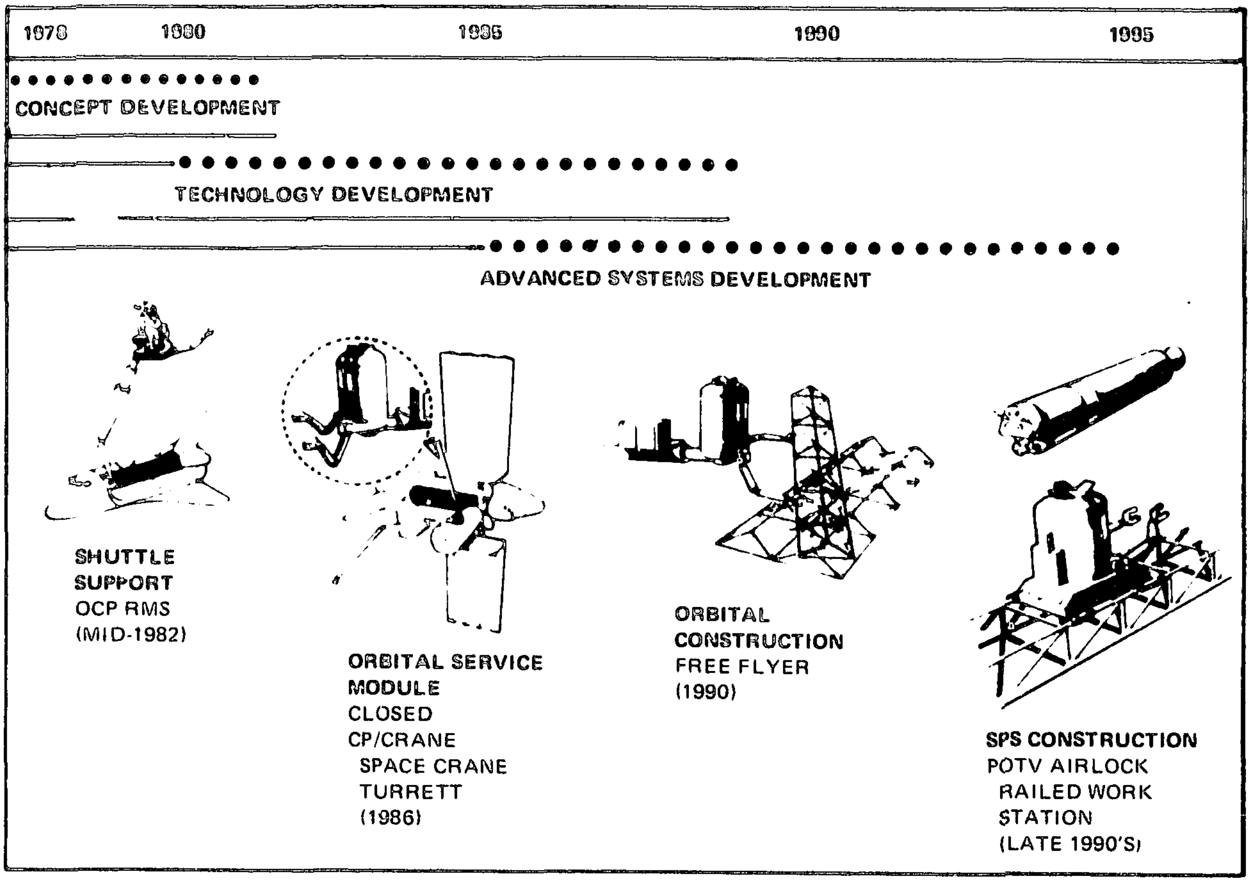
In Task 1.5, unique operations that go with the crane and free flyer MRWS roles were identified, and ways of simulating them with least expense were explored.

The output of Task 1.6 was the DTA design specification which covers the simulation program and the key subsystems. This specification was based on flight article mission requirements from Task 1.1, the selected cherry picker simulation concept from Task 1.4 and the added simulation features identified in Task 1.5. The results of this effort can be found in Appendix A, Volume II of this report.

The study efforts resulted in the overall long-range planning schedule shown in Figure 5 (Ref. 1). The program is shown as overlapping concept and technology development which includes design, manufacture, and ground tests/simulations of the OCP and closed pressurized configurations. The advanced systems development effort includes development in the state-of-the-art for computers, controls and displays, life support systems, and dexterous manipulators.

Initial use of the MRWS will support Space Shuttle operations for experiment service/repair and initial space construction demonstrations and verification. MRWS support for the Space Shuttle will be an open "cherry picker"/manned EVA configuration attached to the end of the Orbiter RMS and is planned to be operational about mid-1983.

The closed pressurized MRWS can be used on the end of a large Space Crane in one mode of operation and as the base turret control station for the Space Crane in another mode. In these modes, the MRWS would provide support for assembly of large power modules, deployment of large diameter antennas, in-space construction of orbiting elements with maintenance and repair, and berthing large modules. Assuming the Space Construction Base is available at that time, these MRWS modes of operation are envisioned to be operational by the mid-1980's.



REF. 1. Orbital Construction Support Equipment, Manned Remote Work Station, Samuel H. Nassiff, AIAA/IES/ASTM 10th Space Simulation Conference, Oct. 16-18/79.

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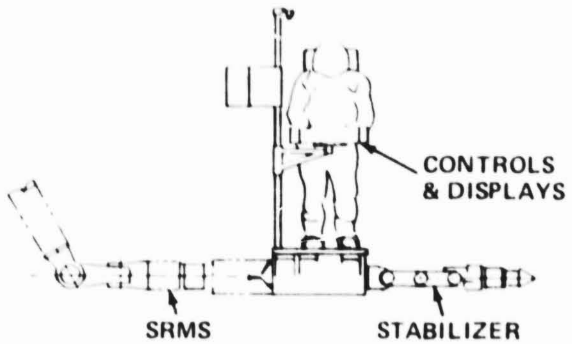
Figure 5. MRWS Development Program

The MRWS free flyer, Personnel Orbital Transfer Vehicle (POTV) airlock, and railed work station would be needed to support very large orbiting structural systems and are envisioned to be operational in the early to mid-1990's.

4.1 OPEN CHERRY PICKER CONCEPT

The uses and applications of an OCP are varied and broad in scope. Figure 6 lists the functions of an OCP in support of Shuttle operations with a need as early as 1983.

A platform mounted at the end of the Shuttle RMS provides a means of conveniently transporting an EVA astronaut, tools, and mission hardware about the Shuttle Cargo bay. Similar in application to terrestrial cherry pickers used by power utilities, the OCP will enhance productivity during six-hour EVA periods.



FUNCTIONS IN SUPPORT OF
SHUTTLE OPERATIONS

- AUTOMATED PAYLOADS
  - MMS SUBSYSTEM INTERCHANGE
  - LDEF SAMPLE TRAY INTERCHANGE
  - SPACE TELESCOPE SERVICING
- CONSTRUCTION R&D
  - DEPLOY FIXTURES
  - RESUPPLY FAB MACHINES
  - JOINING & ALIGN OPERATIONS
  - DISASSEMBLE STRUCTURE
- SHUTTLE INSPECTION/REPAIR
  - FORWARD RCS
  - RADIATORS
  - EXPERIMENT TIE DOWNS
- SPACELAB
  - DEPLOY & RETRACT EXPERIMENTS
  - DATA RETRIEVAL & DATA STORAGE SYSTEM RESUPPLY
  - UNSCHEDULED MAINTENANCE

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Figure 6. Open Cherry Picker Missions

The concept of in-orbit servicing of automated payloads can be enhanced with use on OCP. The Multi-Mission Spacecraft (MMS) with its replacement subsystem modules is particularly suited to service using an astronaut in an OCP. The replacement module and the torque tools needed to withdraw the spent module and insert the new module can all be conveniently located on the OCP. In-orbit servicing of the long Duration Exposure Facility (LDEF) can also be accommodated by OCP. The LDEF experiment trays, slightly larger than the MMS subsystem modules, can conveniently be serviced by an OCP. Other automated payloads which can benefit from OCP servicing include the Space Telescope currently being designed with EVA replaceable components.

The most extensive use of an OCP can be envisioned for support of construction R&D activities useing the Shuttle as the construction platform. Many studies performed over the past few years call out the need for EVA crews to deploy assemble fixtures, fasten and align structure, and install subsystems. The OCP provides a convenient means of crew transport and provides a stable work platform once the crew is at a work-site.

An OCP can also have application in the checkout and in-flight repair of the Shuttle itself. All subsystems within reach of the RMS, including the cargo bay doors, forward mounted Reaction Control System (RCS), and Guidance, Navigation & Control (GN&C) equipments, could be serviced.

The OCP will enhance Spacelab Sortie mission operations by providing a convenient means of deploying and retracting pallet-mounting experiments. The cost of experiments needing mechanical extension, needed to clear the cargo bay, can be reduced by utilizing EVA assistance in the deployment/retraction operations. The OCP can also position an astronaut who can replace film or recording tapes, thereby minimizing the need for data interfaces between experiment and Shuttle.

Figure 7 shows a rendering of the OCP servicing the MMS. The platform is 91-cm (36-in.) wide and houses a foot restraint assembly on a rotary bearing for full 360° rotation by the astronaut. A stabilizer is mounted to the platform and is used to grapple a work-site to minimize RMS motions during crew detailed work periods. A control console which includes hand controllers and essential RMS controls and displays is used for "flying" the OCP on the end of the RMS. This console rotates from forward to aft positions. This feature also allows the astronaut to rotate the control panel to the rear while working from the front of the cherry picker. Mission peculiar handling devices similar to the clamp mechanism shown for the MMS subsystem module are also mounted on the payload handling device which is mounted to the OCP platform via a rotary joint. Two light stanchions are mounted to the rear of the platform and provide the astronaut with 50 ft-c of illumination at the work-site.

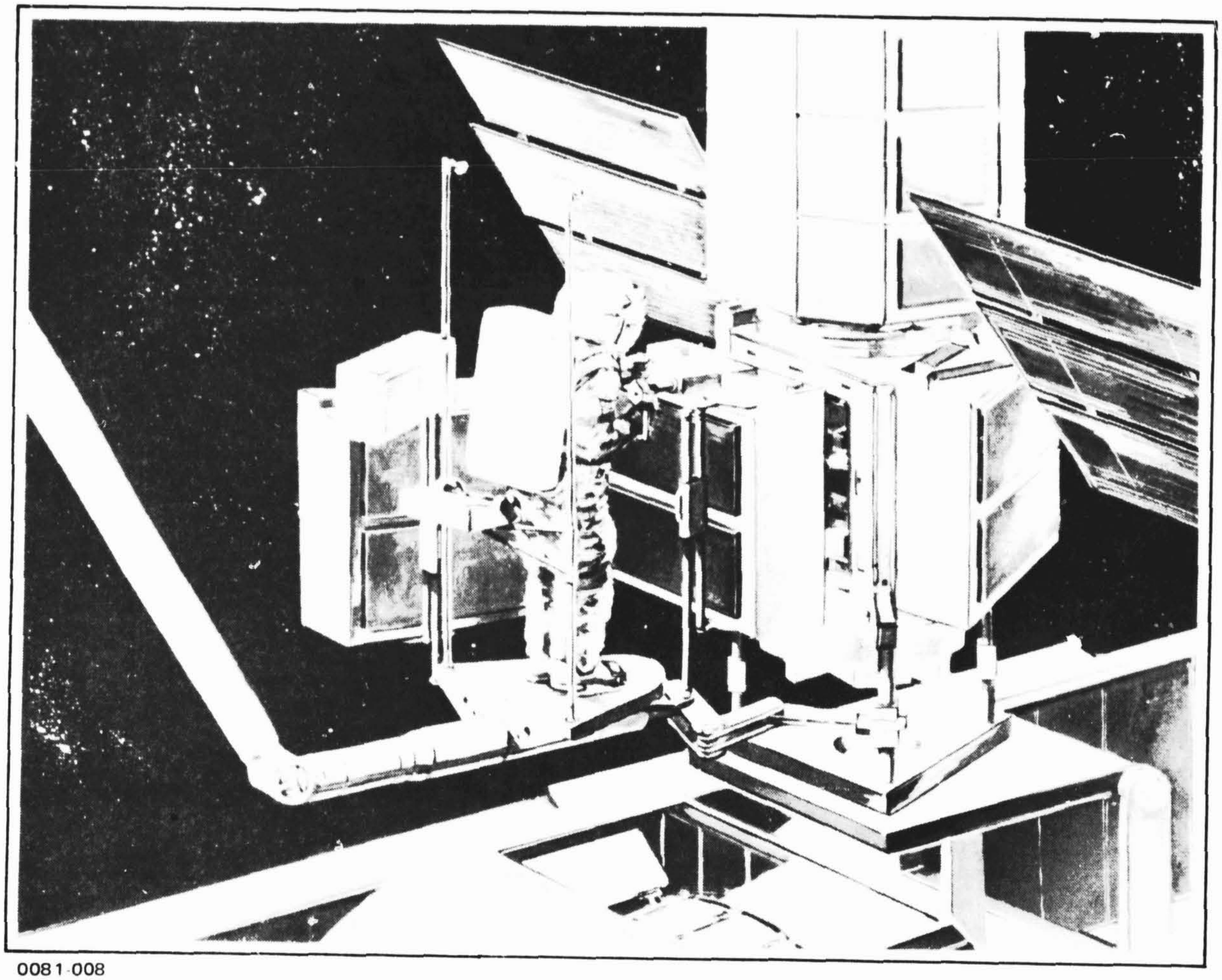

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Figure 7. Open Cherry Picker Servicing MMS (Rendering)

The concept shown is designed with mechanisms so that it can be packaged into a 106 x 152 x 91 cm stowed volume. The OCP is stowed in the forward starboard section of the cargo bay at the structural attachment points established for the Manned Maneuvering Unit (MMU). The overall mass of the OCP is 273 kg, including 25% contingency.

Mechanical and electrical interface with the RMS is through the standard snare-type end-effector. The 250 watts of power provided as a payload service at the end-effector is adequate for OCP operations. A data bus system available using twisted shield wire pairs in the RMS up to the end-effector, can be utilized for signal interfaces with the OCP. An additional 12 signal lines are also available for dedicated analog signals.

As much as 49% of planned satellites in the 1980's require some form of servicing. A review of the NASA STS Mission Model (JSC – 13829 Rev. 1) issued in October of 1977 indicates the trend for servicing shown in Figure 8. In this figure, a satellite with the need for services is indicated in the year of its launch though actual servicing will be performed two to three years later.

Representative satellites in each satellite category listed in Figure 8, were evaluated in terms of potential requirements imposed on the open cherry picker. Three such satellites are shown in Figure 9 with a listing of their potential need for servicing.

AUTOMATED PAYLOADS	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
LAUNCHES													
• PHYSICS & ASTRONOMY			1	3	3	6	5	7	5	6	5	8	95
• LUNAR & PLANETARY			2		1	1	2	1	2		2	1	12
• APPLICATIONS		2	1	3	6	6	4	3	2	3	3	1	34
• SPACE TECHNOLOGY	1		1		2	1	1	1	1	1	1	1	11
• NASA RELATED	2	3	1	2	2	2	5	4	6	5	6	6	44
TOTAL	3	5	6	8	14	16	17	16	16	15	17	17	150
SERVICEABLE SATELLITES													
• PHYSICS & ASTRONOMY				1	2	2	2	4	2	4	2	4	23
• LUNAR & PLANETARY													0
• APPLICATIONS		1	1	2	2	3	4	1	1	1	3		19
• SPACE TECHNOLOGY	1		1		2		1	2	2	2	2	2	15
• NASA RELATED		1	1	1	1	1	2	2	2	2	2	2	17
TOTAL SERVICEABLE	1	2	3	4	7	6	9	9	7	9	9	8	74
% SERVICE	33	40	50	50	50	38	53	56	44	60	53	56	49

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Figure 8. Satellite Services Mission Model

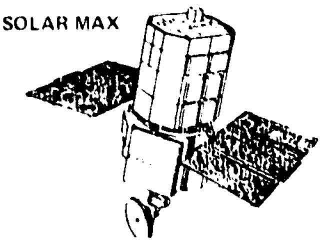
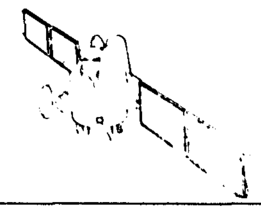
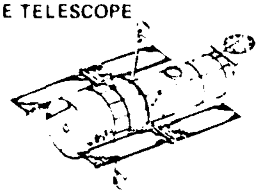
SATELLITE	SERVICES	
	MECHANICAL	OTHER
SOLAR MAX 	• REMOVE & STOW SOLAR ARRAYS (1ST SMM) • REMOVE & STOW ANTENNA (1ST SMM) • SUBSYS MODULES (SECOND SMM)	• RECALIBRATE INSTRUMENTS
GAMMA RAY 	• EXCHANGE EXPERIMENT PACKAGES GAMMA RAY DETECTOR IMAGING COMPTON TELESCOPE • RECOVER SOLAR PANELS • REPLACE MMS MODULES IF USED	• RESUPPLY CRYOGENICS (CURRENTLY SUPPLIED FOR 2 YR) • CALIBRATE & C/O INSTRUMENTATION
SPACE TELESCOPE 	• REPLACE SUPPORT SYS MODULES SCIENTIFIC INSTR • CONTINGENCY REPLACE HI GAIN ANTENNA APERATURE DOOR SOLAR ARRAY	• CALIBRATE & TUNE OPTICS SUPPORT STRUCTURE

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Figure 9. Representative Candidates for Services Analysis

The first need for an OCP could be in late-1982 to mid-1983. The Solar Maximum Mission (SMM) is scheduled for launch in 1979 on an expendible booster, but will be retrieved by the Shuttle three years later. Though no plans are being made for on-orbit replacement of satellite subsystems, the OCP could be used to salvage the satellites solar arrays at considerable cost savings. The current mission plan for SMM will jettison the solar arrays so that the vehicle can be retracted into the Shuttle cargo bay for return to the ground.

Operations to salvage the SMM solar arrays can be performed in a single six-hour EVA period using the open cherry picker. Figure 10 summarizes the steps to fold the three-panel array, install stowage ties, disengage the array from the spacecraft, and stow the array in a rack located under the MMS Flight Support Structure. The total operation can be performed in approximately 42 min. per array.

The Space Telescope (ST) is particularly suited for EVA servicing. Current plans for the ST will utilize EVA operations on the first launch as a backup for contingency repair of deployment mechanisms, such as the communications antenna and solar arrays. A maintenance mission is then planned two and one-half years later, at which time the SSM components will be serviced, as will elements of the scientific instruments. Figure 11 shows the use of the OCP in these operations. The ST is mounted to a rotating berthing ring and the Orbital Replaceable Units (ORU's) are located in a rack mounted to the upper side of the Orbital Maneuvering System (OMS) kit. The RMS with the OCP can reach these storage areas and move the ORU's to the appropriate ST service bay.

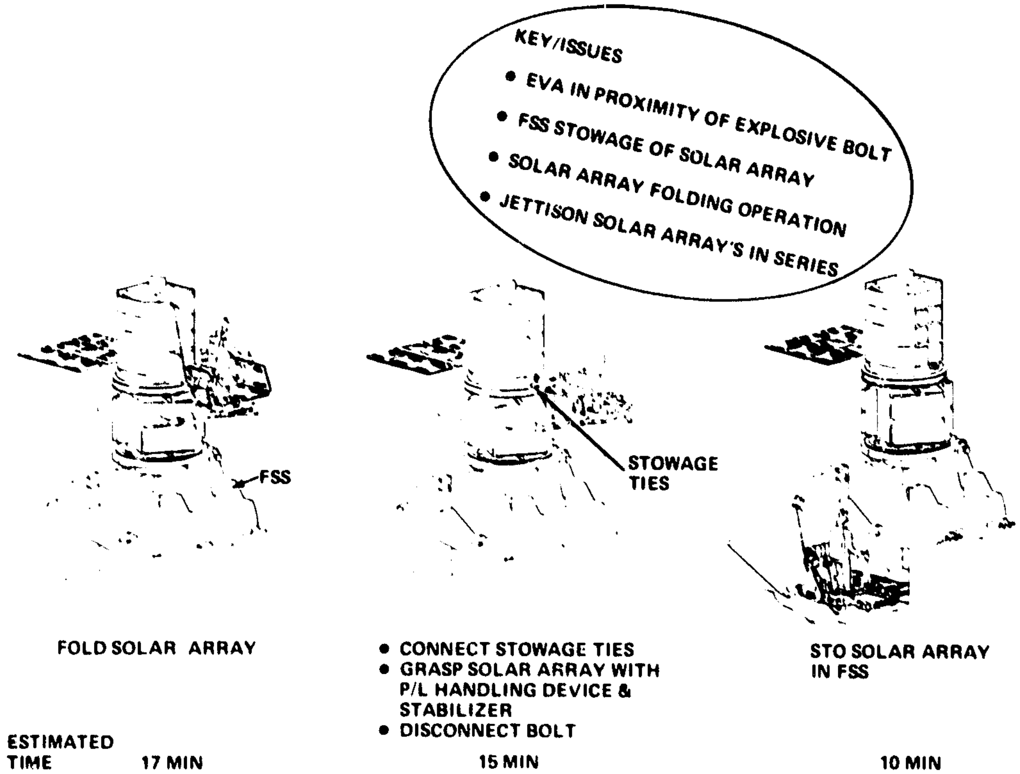

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Figure 10. Solar Arrav Salvage Operation

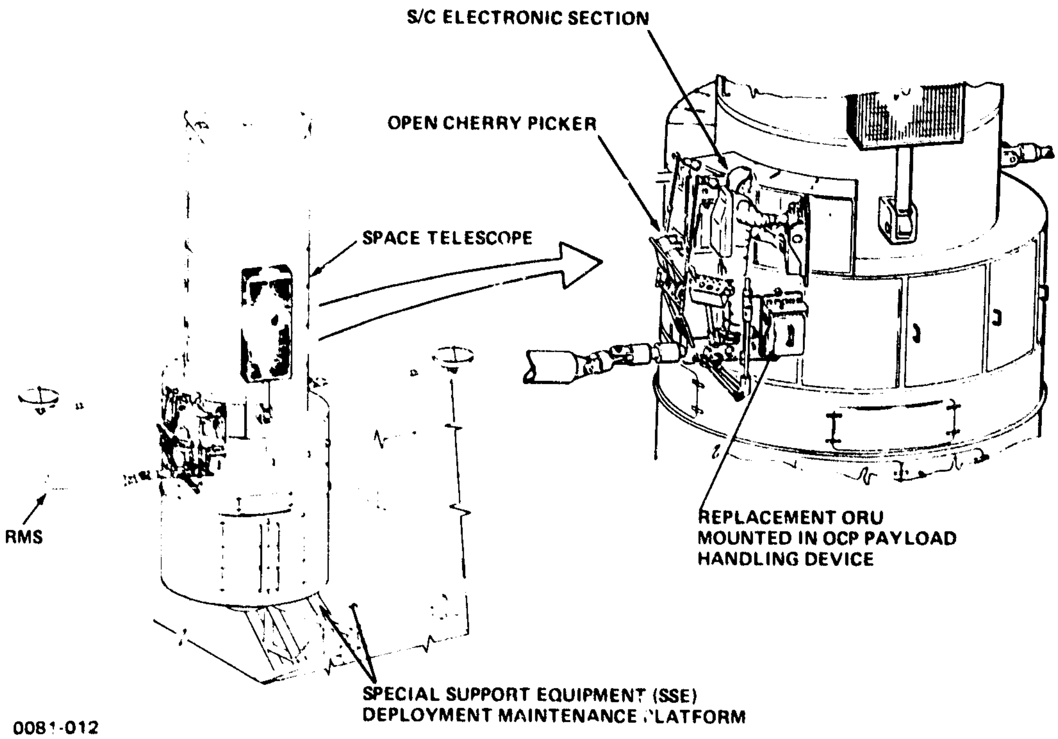

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Figure 11. Space Telescope Electronic ORU Replacement

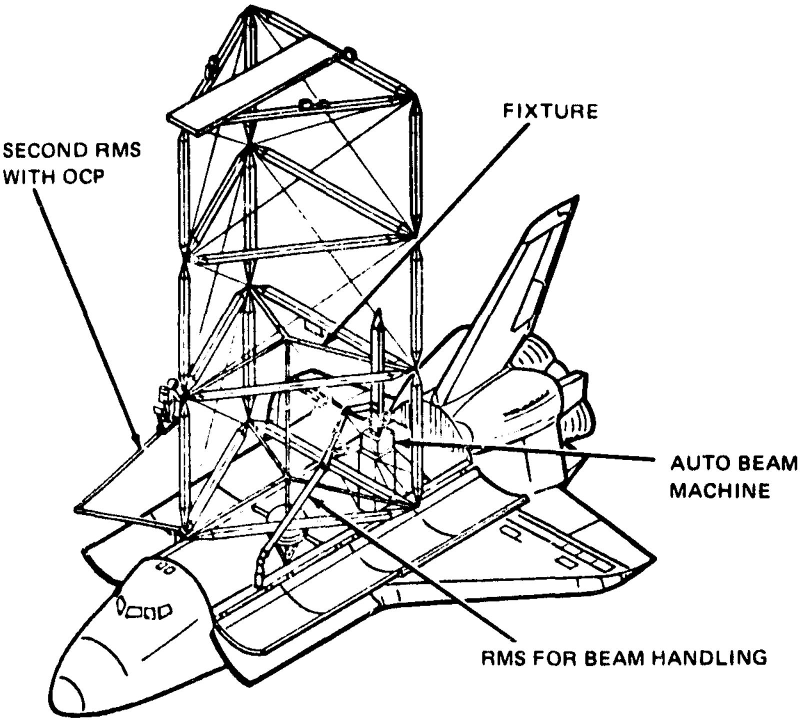
Analysis of concepts for construction directly from the Shuttle cargo bay identified many unique requirements for the OCP. Several recent studies, including the Systems Definition Study for Shuttle Demonstration of Large Space Structures (NAS8-32390) and Space Construction Automated Fabrication Experiment Definition Study (NAS9-15310), were used as the basis for OCP requirements definition. Key control and payload handling requirements such as the need to serially control two Remote Manipulators from the OCP were identified.

Some of the construction functions performed by the OCP crewman are listed on Figure 12. The OCP payload handling device and stabilizer must handle structural elements as large as 1 m in depth and 15-m long, as well as subsystems and scientific instruments 700 kg and 3-m long. Construction tasks include installation and alignment of assembly jigs, resupply of automated beam fabrication machines, fastening and alignment of structural elements, and the installation and checkout of subsystems, power lines, and instrumentation.

The advantage of an OCP construction operation over a purely EVA operation is indicated in Table 2. Underwater simulation at Manned Space Flight Center (MSFC) using two astronauts was used as reference for transporting large 10-m long truss griders from a stowage area in the shuttle cargo bay to a fixture where the beams were assembled. The time to perform this operation was 45 min., excluding an adjustment for attaching tethers. The basic time and motion data of this simulation were used to estimate time to assemble if the Shuttle RMS is used to transport the truss girders while one astronaut performs the assembly operations. In this case, the estimated time of assembly is reduced approximately 29%. Using the same basic data, an OCP was introduced into the scenario, thus improving the time for astronaut movement. The use of an OCP decreases estimated assembly time 33% relative to purely EVA operations. If more beam assemblies are included, a saving of as much as 50% in time could be realized.

The mission analysis of OCP operations, including construction, satellite servicing, Spacelab support and Shuttle inspection and repair defined the following top level requirements (Ref. 1, p. 11):

- Provide a stable EVA platform which can be used to react forces and moments in zero-g
- Enhance Orbiter near-vicinity (limited to RMS reach envelope) EVA productivity and visibility
- Facilitate operations with large structures
- Provide crewman with capabilities for large-mass handling
- Support assembly operations when the Orbiter is used as a construction base
- Provide for inspection of the Orbiter, payloads, and orbiting satellites
- Facilitate service, maintenance, and repair of Spacelabs payload and satellites
- Facilitate deployment and retraction of experiment equipment, such as antenna, cannisters, film, and recording tape.



OPEN CHERRY PICKER FUNCTIONS

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

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Figure 12. Support Construction of LSS Platform

TABLE 2
ASSEMBLY TIME COMPARISON EVA & OCP

	THREE BEAM ASSEMBLY					
	UNDERWATER SIMULATION (TWO CREW)		ONE CREW & SRMS		ONE CREW OPEN CP & SRMS	
	TIME, MIN	OPERATION (NO TETHER)	TIME, MIN	OPERATION (TETHER)	TIME, MIN	OPERATION (FOOT RESTRAINT)
					4.0	DEPLOY PLATFORM & MOUNT
					1.2	C/O OPEN C.P.
	5.0	TRANSLATE TO BEAM STOR.	5.0	TRANSLATE TO ASSY AREA	0.3	TRANSLATE TO ASSY AREA
	1.0	REMOVE BEAM	2.0	ALIGN & FASTEN BEAM		
	5.0	TRANSLATE BEAM TO ASSY	1.5	TRANSLATE TO OTHER END	2.0	ALIGN & FASTEN BEAM
11	2.0	ALIGN & FASTEN BEAM	1.0	ATTACH RESTRAINT	0.2	TRANSLATE TO OTHER END
	1.0	ADJUST BEAM END	1.0	ADJUST BEAM END	1.0	ADJUST BEAM END
	2.0	ALIGN & FASTEN BEAM	2.0	ALIGN & FASTEN BEAM	2.0	ALIGN & FASTEN BEAM
13	2.0	TRANSLATE TO BEAM STOR.	0.5	RELEASE RESTRAINTS		
	11.0	REPEAT ABOVE	16.0	REPEAT ABOVE 2 TIMES	10.4	REPEAT ABOVE 2 TIMES
	13.0	REPEAT ABOVE				
	3.0	TRANSLATE TO HATCH	3.0	TRANSLATE TO HATCH	0.3	TRANSLATE TO HATCH
	45.0	TOTAL	32.0	TOTAL	21.4	TOTAL

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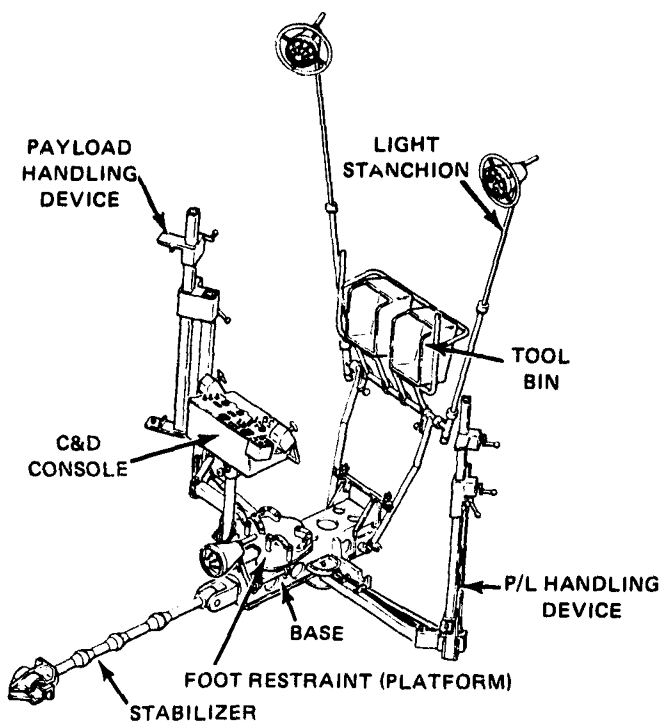
The resulting open cherry picker concept design (Figure 13) features a small (8 x 8 x 36 in.) base that supports the RMS snare end effector grapple, a payload handling device, a stabilizer, a standard shuttle foot restraint, a controls and displays (C&D) panel for control and interface with the shuttle RMS control electronics, and a light stanchion that houses a bin for stowage of standard and medium sized mission peculiar tools. The OCP is stowed in the forward 48 in. of the orbiter cargo bay that is reserved for EVA support systems. The bulkhead pickup points used for MMU storage can also be used for support of the OCP while electrical interface with the orbiter is through the standard lines provided to any special end-effector on the RMS. The main data flow between the orbiter Manipulator Control Interface Unit (MCIU) and the cherry picker C&D panel is accomplished using serial buses. Two interface units needed to accommodate the OCP is easily added to the Shuttle system.



ELEMENT	WEIGHT (LB)
• BASE MODULE	22.0
• PLATFORM	20.0
• C&D CONSOLE	60.0
• LIGHT STANCHION	30.0
• P/L HANDLING DEVICE (2)	90.0
• TOOL BIN	25.0
• STABILIZER	100.0
TOTAL	347.0

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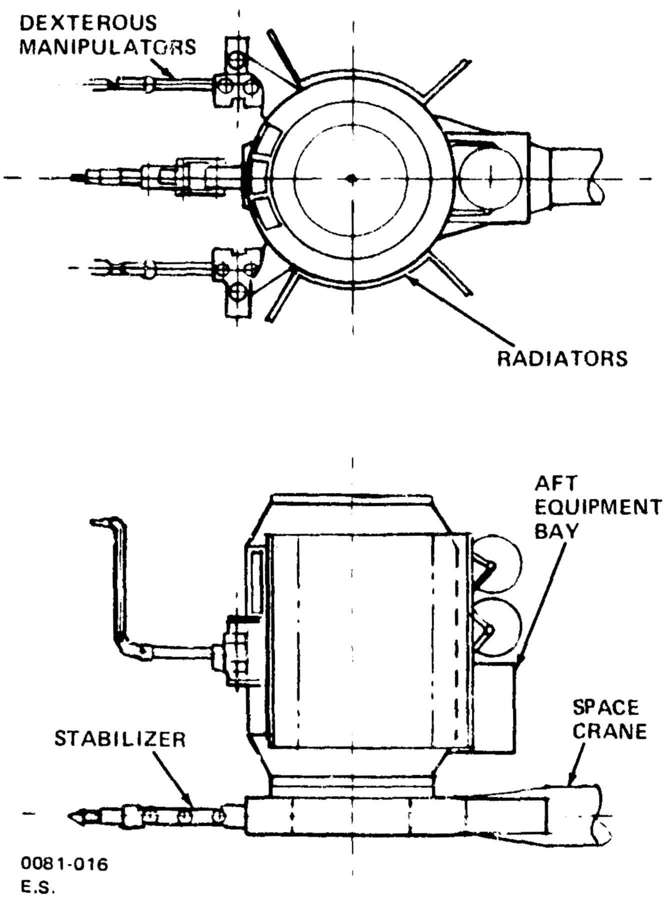
Figure 13. Open Cherry Picker Configuration/Mass

4.2 CLOSED CABIN PRESSURIZED CONCEPTS

In the mid-1980's, it is planned to deploy an initial construction base as an outgrowth of the power module. This base will initially be in a Shuttle-tended mode, meaning that the Shuttle provides the habitat during construction operations. Eventually, permanent habitats will be added and construction scenarios that require three-shift operations of up to 90 days per Shuttle launch will be required.

Figure 14 summarizes the functions performed by a closed cabin cherry picker (CCP) and the types of structure expected to be assembled by the MRWS. Studies performed over the past few years indicate that likely candidates for in-space construction are large radiometers, multibeam communications antennas, and solar power satellite development articles. The MRWS will perform handling, joining, aligning, and checkout functions associated with in-space construction, as well as those functions associated with general maintenance and repair of the construction base.



FUNCTIONS IN SUPPORT CONSTRUCTION & MAINTENANCE

- HANDLE STRUCTURE & SUBSYSTEMS USING STABILIZER
- ALIGN & JOIN STRUCTURE & SUBSYSTEMS
- CLOSE INSPECTION & CHECKOUT
- BASE MAINTENANCE & REPAIR

REPRESENTATIVE CONSTRUCTION ARTICLE IN 1985 TO 1990 TIME FRAME

- SOLAR POWER DEVELOPMENT ARTICLES
- RADIOMETERS
- MULTI–BEAM COMMUNICATIONS ANTENNA

REPRESENTATIVE TASKS FOR FULL–SCALE SPS CONSTRUCTION

- CONTROL OF BASE TRANSPORTER
- STRUCTURAL FASTENING
- RESUPPLY AUTOMATED EQUIP
- BUS/SWITCH GEAR INSTALLATION
- MONITOR REPAIR SOLAR BLANKET INSTALLER & MW SUBARRAY INSTALLER
- GENERAL BASE MAINTENANCE

Figure 14. Closed Cabin Cherry Picker Missions

Longer mission duration and need for three-shift operations at the initial construction base, force consideration of a closed pressurized environment for the MRWS. When the open-platform constraints (Figure 15) impact construction operations, the following advantages of a closed cabin MRWS are apparent: extended on-station work time, improved crew productivity, and reduced hazardous operations. Preparations by EVA require 3¼-hour prebreathing and 1½-hour post-EVA activity. For an 11-hour work day, less than 6 EVA hours are spent on construction tasks. Radiation protection is required for continuous synchronous orbit operations while low earth orbit activities are impacted by the South Atlantic anomaly radiation hazards. A closed cabin MRWS reduces the time for construction (Figure 15) by extending the work shift by two hours. For three-shift operations, the closed cabin further reduces construction time. Third-shift EVA in an OCP is hazardous, because of South Atlantic anomoly radiation. Therefore, no advantage is gained by adding a third EVA shift.

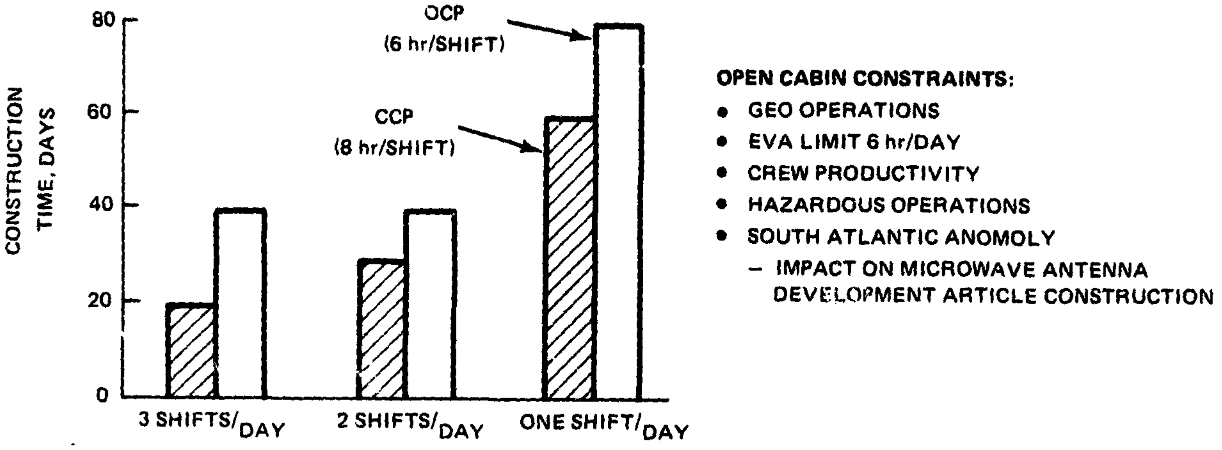


Figure 15. Transition from Open to Closed Cabin

The space crane, which is a 7 degree-of-freedom (DOF) manipulator that is 35-m long, is also introduced at initiation of the construction base. This mechanism requires a manned work station located at the base of two space crane arms, one of which supports a cherry picker version of the MRWS. Figure 16 presents an outline drawing of the MRWS crane turret that houses the controls and TV monitors required to operate the two crane arms.

The ultimate MRWS application is in the construction of the SPS. Small pressurized cabins have application for each major construction function identified in the Solar Power Satellite Systems Definition Study. Cherry picker MRWS's are required to position 816-m long beams, then align and join them in an operation similar to that shown in Figure 17. Crew cabins are required to monitor and control beam fabrication machines, to install power buses and associated switch gear, to monitor and control solar blanket deployment machines, to install microwave system elements, and to assemble the antenna gimbal system. A free flyer version of the MRWS is required for quick repair, rescue, debris collection, and assembly of structure.

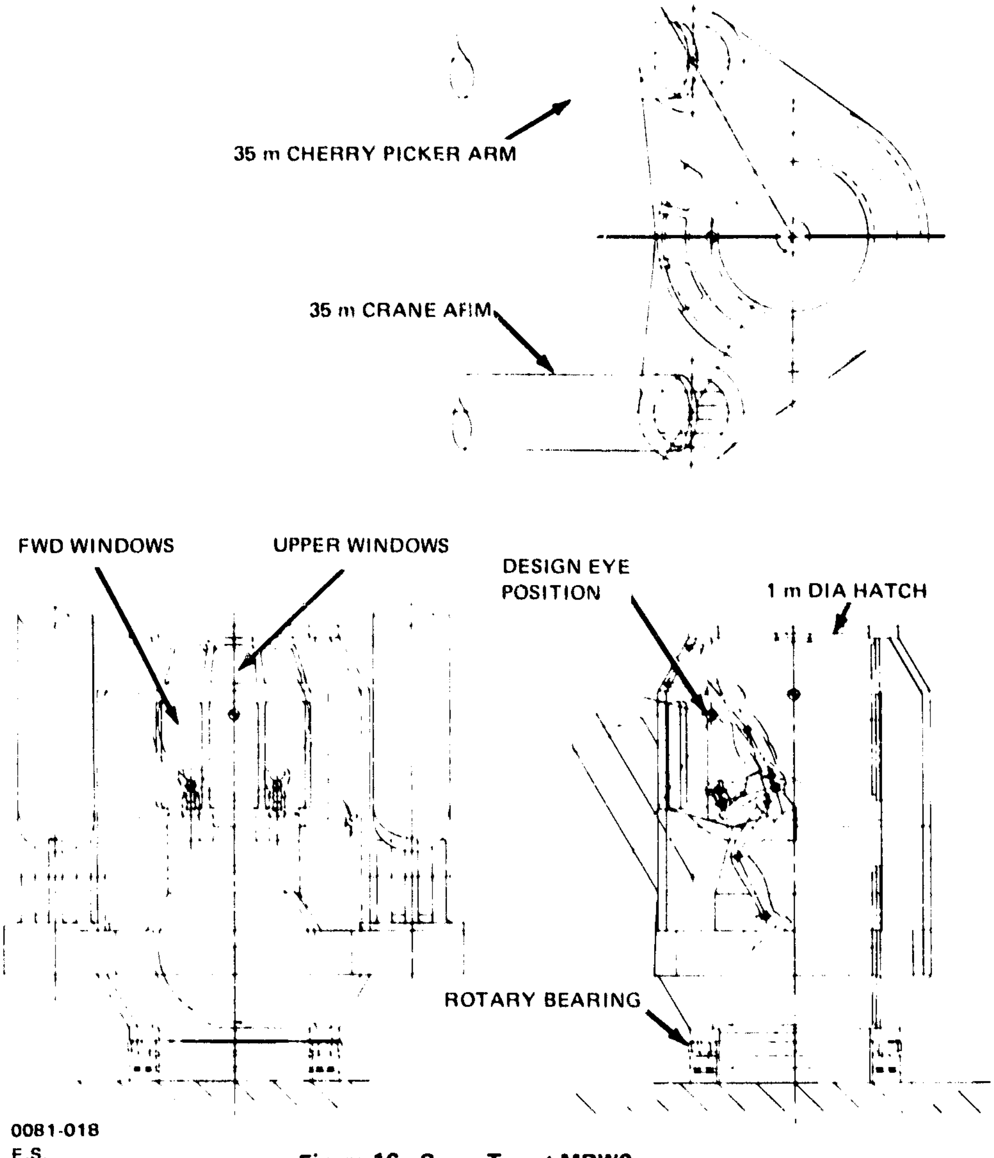
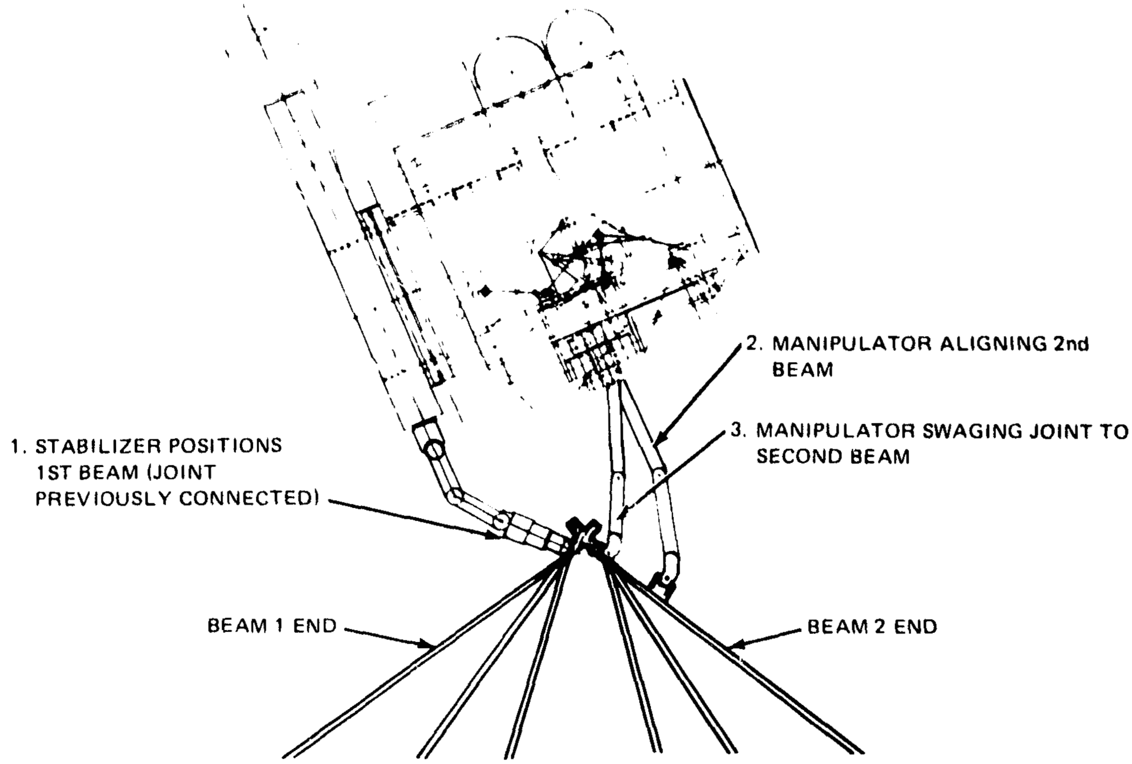


Figure 16. Crane Turret MRWS



SOLAR ARRAY BEAM CHARACTERISTICS

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

MRWS REQUIREMENTS

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

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Figure 17. Cherry Picker Joining Beams

Table 3 lists some of the requirements and possible issues that have been identified for the MRWS flight article (Ref. 1, p. 11). The requirements are extensive and cover the range of operating modes required of the flight article including the following basic groundrules:

- The MRWS must be able to support various types of construction operations in low and high earth orbit
- The flight article shall be reuseable and multipurpose
- The MRWS must be capable of being transported to and from orbit in the Space Shuttle Orbiter
- The MRWS design shall be essentially independent of the large system constructed in space.

TABLE 3

FLIGHT ARTICLE REQUIREMENTS/ISSUES MATRIX

FLIGHT ARTICLE REQMTS & ISSUES	CLOSED PRESSURIZED CABIN				
	CP	CRANE TURRET	FREE FLYER	AIRLOCK	RAILED WS
• STABILIZATION					
– TYPE GRAPPLER (DOF)	X		X		
– GRAPPLER ATTACHMENTS	X		X		
– CONTROLLERS	X		X		
• MANIPULATORS					
– DEXTEROUS MANIPULATOR/CRANE PERFORMANCE	X	X	X		X
– FATIGUE/TASK DURATION	X	X	X		X
– DEGREES OF FREEDOM	X	X	X		X
– TYPE CONTROLLERS	X	X	X		X
• MAN-MACHINE INTERFACE					
– LIGHTING & VISIBILITY	X	X	X	X	X
– RESTRAINTS	X	X	X		X
– WORK-SITE ACCESSIBILITY	X	X	X		X
– C&D TYPES/ACCESS/LOCATION	X	X	X	X	X
• SAFETY					
– RESCUE OPERATIONS	X	X	X	X	X
– ONE MAN VS TWO	X	X	X	X	X
– CREW TRANSFER	X	X	X	X	X
– HATCH OPERATION	X	X	X	X	X
• SUBSYSTEMS					
– STATION KEEPING/GUIDANCE				X	
– THRUSTERS/CONTROL ELECTRONICS			X		
– OBSTACLE AVOIDANCE	X	X	X		
– PARALLEL MRWS/RMS OPERATIONS	X				
– PARALLEL MRWS/SPACE CRANE	X	X			
• HABITABILITY					
– PERSONNEL HYGIENE	X	X	X		X
– WATER/FOOD	X	X	X		X
– STOWAGE	X	X	X	X	X
– WASTE MANAGEMENT	X	X	X		X

CP – CHERRY PICKER

WS – WORK STATION

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4.2.1 Closed Cherry Picker Configuration

Figure 18 is a rendering of a CCP. The CCP is configured for one-man operation from a single control console utilizing bilateral force-reflecting (BFR) manipulators. The manipulator slaves are 2-m long, while the masters located in the cabin are 50-cm long. Test data indicate that men operating BFR manipulators have the same productivity as a man in a EVA suit, but benefit from the convenience of a shirtsleeve environment and can probably work longer shifts without fatigue.

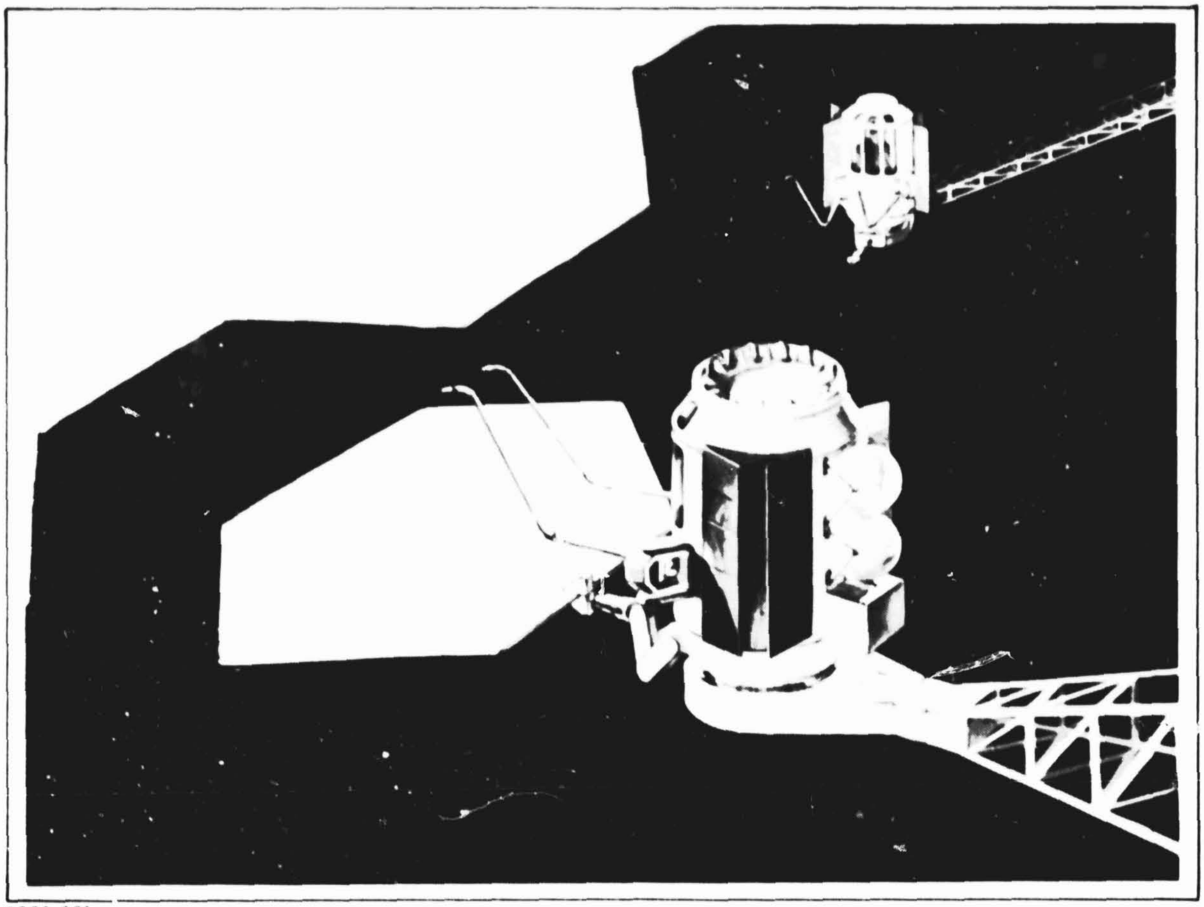

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Figure 18. Closed Cabin Cherry Picker (Rendering)

The CCP has a 170-cm diameter dictated by the need for a 1-m egress hatch at the top and bottom. The cabin height is 250 cm, resulting in an internal volume of 4.76 m^3. The atmosphere of the cabin uses a two-gas system operated at 14.7 psi. A console area of 2.1 m^2 is available for the subsystem controls and displays. All subsystems are located in an aft equipment bay, with a separate heat rejection system. The cabin heat rejection system that operates at 75° to 85°F requires 13.4 m^2 of radiator area. The small size of the cabin requires installation of four deployable, two-sided radiator panels. The overall mass of the CCP is 2244 kg, including a 25% contingency. The structure (549 kg) and mechanical system (555 kg) make up the major portion of the total mass.

A key issue needing resolution through simulation is the optimum crew size for the cherry picker. A brief cost study indicates that a cabin configuration that can house two men, with one man operating the manipulator systems and the second in a standby role, may be cost effective. Though a smaller one-man crew station is lower in cost to develop and build, the operational cost advantage of the two-man station indicates selection of this approach. Data on men operating BFR indicate that a two-hour work period is reasonable with a period of rest required between periods. In a two-man station, crewmen can interchange roles, thereby significantly increasing the utility factor of the two-man station relative to the one-man station. This fatigue factor must be determined through simulation before configuration selection is made.

4.2.2 Free Flyer

A rendering of an MRWS free flyer repairing a damaged structural element is shown in Figure 19. The MRWS cabin is mated to two rings that contain the needed propulsion and electrical subsystems, maintaining a clean transition for the cabin from the roles of cherry picker and crane turret to that of a free flyer. The subsystem elements that must be added to the cabin itself are the GN&C system, including a rendezvous sensor and inertial system as well as added displays of key flight parameters such as range, range rate, and line-of-sight rates.

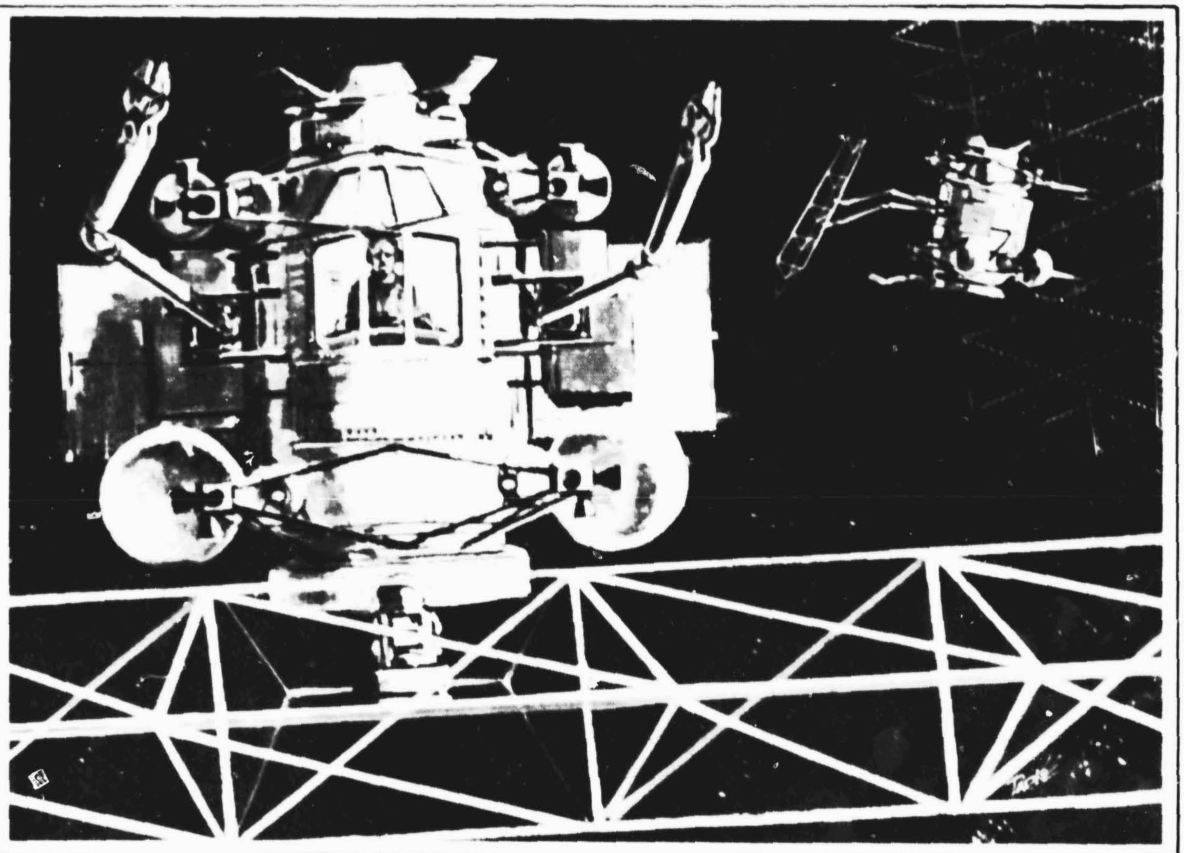

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Figure 19. Free Flyer

Propulsion and attitude control system requirements for the free flyer were developed based on the following criteria:

- An operating period of 10 hours; 25% free-flying
- Translation of two 10 km trips at a ΔV of 40 m/sec
- Stationkeeping 5 km above or below station for 1 hour requiring a continuous thrust level of 10.8 lbf
- Attitude control authority of $10^{\circ}/sec^2$
- Twenty 180° slew rates at 1 deg/sec
- Attitude deadband of $\pm 0.1^{\circ}$
- Translational acceleration of 0.1 m/sec^2

Thruster plumes on manipulators and into work volumes are to be avoided. Additionally, thruster interference with cabin rotation, payload handling, and center of gravity shifts are to be minimized. A tentative system selection has been made using monopropellant hydrazine (N_2H4) with a bilevel thrust approach using 80 lb and 5 lfb thrusters to reduce limit cycle propellant consumption.

4.2.3 Multi-Role Applications

The CCP configuration can be broken down into the six structural/functional elements (Figure 20): namely, (1) berthing port; (2) cabin core; (3) rotary bearing; (4) stabilizer base; (5) lower berthing interface; and (6) crane arm interface. By adding an interface module for (7) a docking ring and (8) a crane turret, the basic MRWS configured for a cherry picker can be used as a free flyer, crane turret, POTV air lock/cherry picker.

The cabin core provides the structural elements common to all four MRWS vehicles, such as pressure shell, windows, hatches, console support structure, flooring, restraint system platform, and mounting provisions for external equipment. The CCP and crane turret MRWS have a berthing port interface added to the top of the cabin core, while the free flyer and POTV MRWS vehicle have a docking ring interface. All four vehicles have identical rotary bearing and lower berthing interfaces added to the bottom of the cab core. The CCP, free flyer and POTV MRWS vehicles have the stabilizer base installed between the rotary bearing and berthing interface, while the crane turret MRWS has a crane turret added between the cabin core and rotary bearing. The controls and displays can be tailored to meet the requirements of each MRWS with minimum impact to the common cabin core.

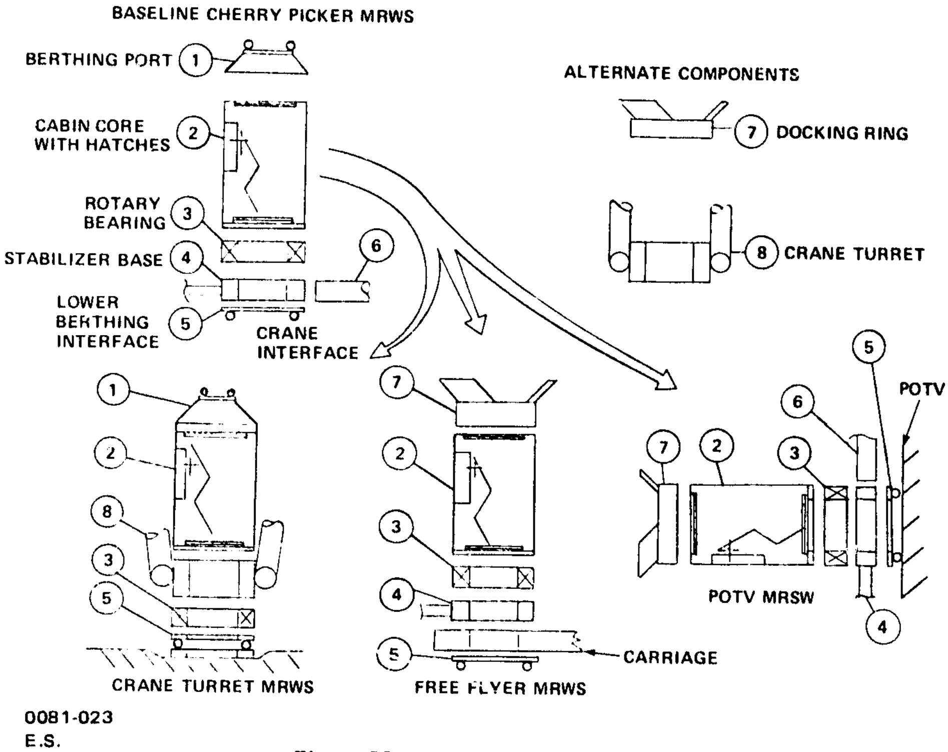

Figure 20. MRWS Modularity

4.3 SIMULATOR REQUIREMENTS AND CONCEPTS

Analysis of MRWS flight article requirements led to the identification of design issues that could only be resolved through simulation. The basic approach used to formulate a simulation plan and associated DTA requirement is defined in Figure 21. Flight Article requirements and trades, reported in Volume I, along with design concepts were used to list issues and simulation objectives (See Volume II). Concepts for simulation included using air bearings, neutral buoyancy, and various combinations of full-scale and sub-scale motion bases were evaluated in terms of achieving needed zero-g fidelity. Those issues that could best be addressed using an air bearing and a full-scale MRWS DTA was then used to define a phased simulation program.

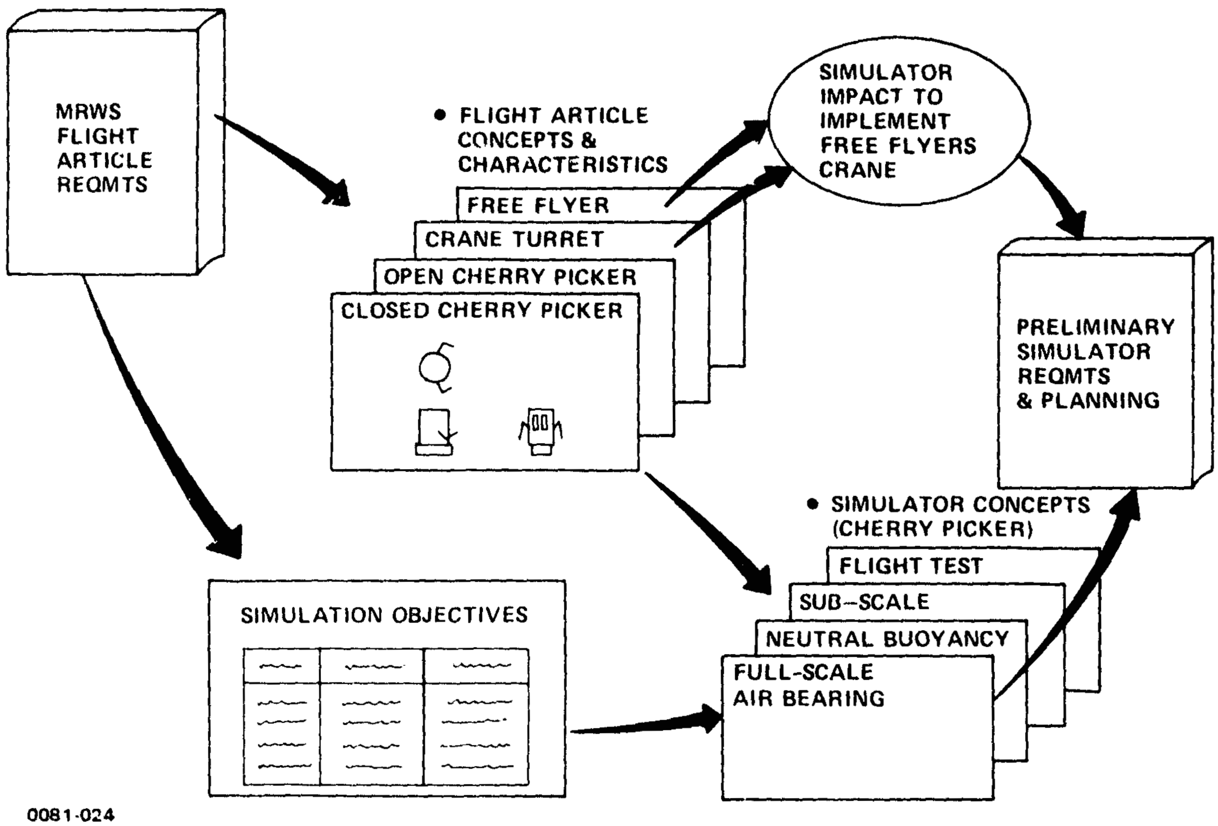

Figure 21. Simulator Requirements Definition Approach

Simulation objectives were grouped into the five categories shown in Table 4 for each MRWS configuration. A typical cabin design factor (Category 1) is to determine through simulation the relationship between work duration and the crew size of the MRWS. As discussed in the previous sections, a two-man crew station, though more costly to develop and build, may be more cost effective than a one-man station, if fatigue operating the BFR manipulator is severe.

TABLE 4

SIMULATION OBJECTIVES: CATEGORIES

CATEGORY 1 – CABIN DESIGN FACTORS	CATEGORY 2 – EQUIPMENT DESIGN FACTORS
• WORK DURATION	• MANIPULATOR REQUIREMENTS
• METABOLIC LOAD	• CONTROLLERS
• DISPLAYS	• CCTV UTILIZATION
• VIEWING	• GRAPPLER REQUIREMENTS
• LIGHTING (INTERNAL)	• END EFFECTOR DESIGN
• MEN & CONSOLES	• EQUIPMENT/TOOL STOWAGE
CATEGORY 3 – PROCEDURES DEVELOPMENT	**CATEGORY 4 – MAN/MACHINE INTERFACE FACTORS**
• COMPONENT HANDLING	• WORK SITE ACCESSIBILITY
• STRUCTURAL JOINING & ALIGNING	• WORK TASK ACCESSIBILITY
• CONSTRUCTION EQUIPMENT SERVICING	• WORK SITE CONFIGURATION
• FIXTURE INSTALLATION	• LIGHTING & VISIBILITY
• SUBSYSTEM INSTALLATION	• FATIGUE/TASK DURATION
– ELECTRONIC	• LEARNING CURVE
– POWER	
– FLUID	
CATEGORY 5 – CONSTRUCTION BASE INTERFACE FACTORS	
• DESIGN LOADS	
• RESCUE OPERATION	
• CREW TRANSFER	
• COMM/POWER/SIGNAL INTERFACE	

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A closely related simulator objective is to determine the manipulator design factors (Category 2) that result in maximum MRWS utility and crew productivity. Many candidate manipulator approaches exist that emphasize different control techniques and mechanization. The ideal laboratory manipulator should have the ability to investigate the various options to be considered. A preliminary requirements list for a laboratory device that can be used to investigate options, such as: (1) type of control – BFR versus resolved rate; (2) extent of controller indexing; and (3) the force sensitivity in master and slave that reduces operator fatigue, is shown in Table 5. The laboratory device should be designed as a BFR, master/slave manipulator with the ability to interchance the master controller with a 6-DOF resolved rate hand controller. The slave should be 2-m long and be mechanized with a counterbalance system to achieve high fidelity zero-g simulator.

The simulator design must consider the fidelity of zero-g, not only in the design of the equipments but also in the mechanization of work sites for addressing the Category 3 objectives. One approach that shows considerable promise for achieving 6-DOF simulation of typical large structure elements is to use helium-filled balloons. To minimize inertia mismatch, the balloon should be located in the internal volume of the beam. As shown in Figure 22, the weight per meter of three typical construction beams is plotted. Near-term space construction activities will use 1-m deep beams and the SPS will use 7.5-m beams. The lifting capacity is plotted for each beam, assuming the entire internal volume of the beam is filled with helium. As can be seen, the internal volume of a 1-m beam is not large enough to hold enough helium to support its weight; a 1-m beam would have to be supported with external helium-filled balloons, or structural material lighter than the 15 mil aluminum elements used in their construction. The external helium-filled balloons would result in an inertia mismatch of 200% for a 10.5-m long beam. The larger beams can accommodate an internal balloon that results in a mismatch in inertia of only 30%.

TABLE 5

RECOMMENDED LABORATORY MANIPULATOR SYSTEM

• NO. OF DEXTEROUS ARMS – 2	• ACCURACY/RESOLUTION – ±5 mm ± 1mm
• TYPE OF CONTROL – REPLICA MASTER SLAVE	• DEADBAND @ MASTER WRIST: TRANSLATION – 1.5 mm; ROTATION – 0.5°
• FORCE REFLECTION (BFR)	• MAX FRICTION @ MASTER: TRANSLATION – 1.1N (4 oz); ROTATION – 0.28 N·m (40 in.oz)
• BFR SENSITIVITY – 1.4N (5 oz) FROM S TO M	• POWER – ELECTRO MECHANICAL
• ARM LENGTH: SLAVE – 2 m; MASTER – 0.6 m	• TRANSMISSION – TENDON DRIVE
• VELOCITY RATIO: S/M – 3.3	• COUNTERWEIGHTS – DRIVE MOTORS
• DOF: MASTER – 6 + OPEN LOOP YAW; SLAVE + END EFFECTOR – 7 + 1	• MANUAL LOCKING OF SLAVE DEXTEROUS ARMS AND/OR END EFFECTOR – YES
• DEXTERITY: MASTER – S(R,P)E(P)W(R,P,Y); SLAVE – S(R,P,Y)E(P)W(R,P,Y)	• M/S SYNCHRONIZATION AT STARTUP
• TWO-ARM WORK VOLUME – 2200 ft^3	• FAIL SAFE LOCKS AT PWR LOSS
• MAX TIP SPEED: SLAVE – 0.75 m/sec (30 in./sec)	• OTHER FEATURES – PROVIDE ABILITY TO EVALUATE INDEXING – PROVIDE SEVERAL MASTER & SLAVE SHOULDER LOCATIONS
• MAX TIP FORCE: SLAVE – 67N (15 lb); MASTER – 22-31N (5-7 lb)	

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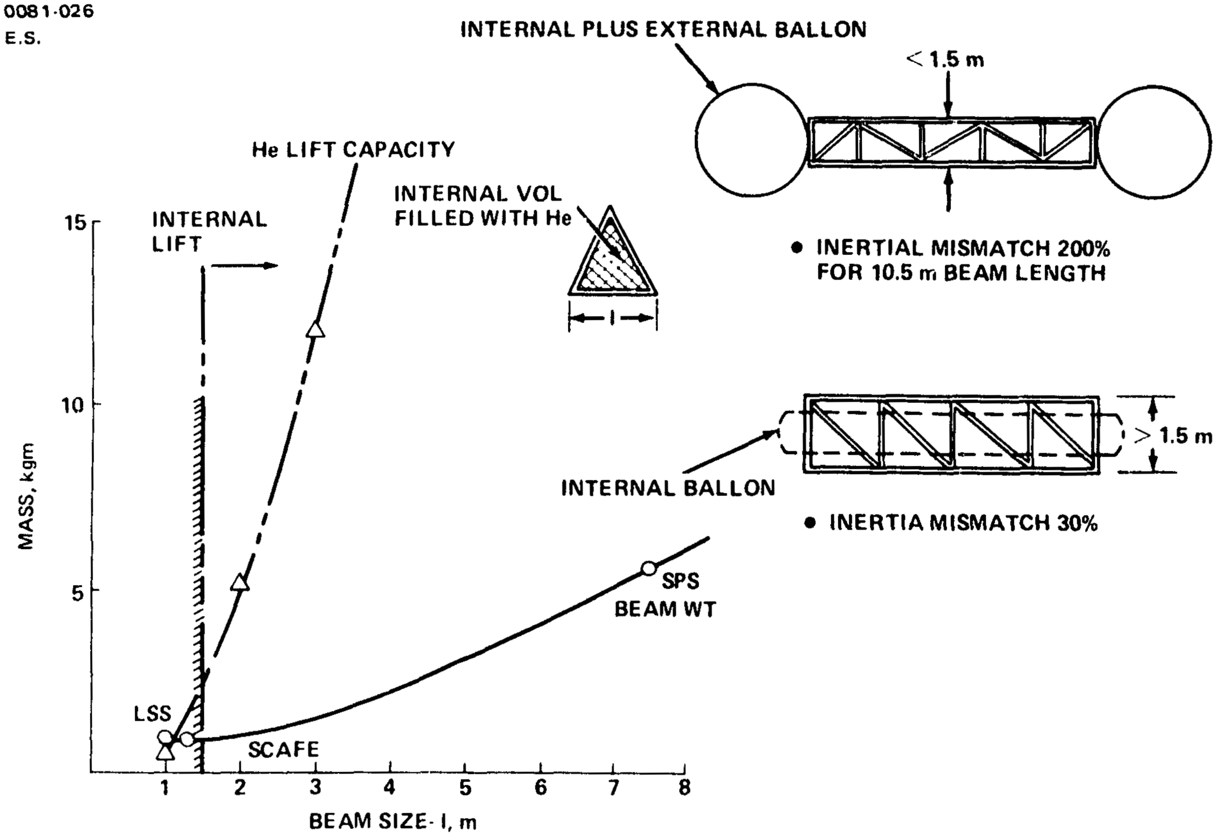

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Figure 22. Helium-Filled Beams

The initial simulator should emphasize full-scale development test articles and work-sites to determine man-machine interfaces while performing the detailed assembly and servicing tasks expected in early 1980's missions. This requirement can be readily met using the JSC Manipulator Development Facility utilizing the facilities RMS and air bearing floor in an arrangement similar to that shown in Figure 23. Most of the immediate requirements for simulation can be met with this arrangement, though some simulation objectives must eventually be addressed using sub-scale models and virtual image displays. Many of the work-sites and travel distances for the free flyer and crane turret MRWS applications, for example, are beyond the physical capability (size) of the MDF, requiring sub-scale simulation.

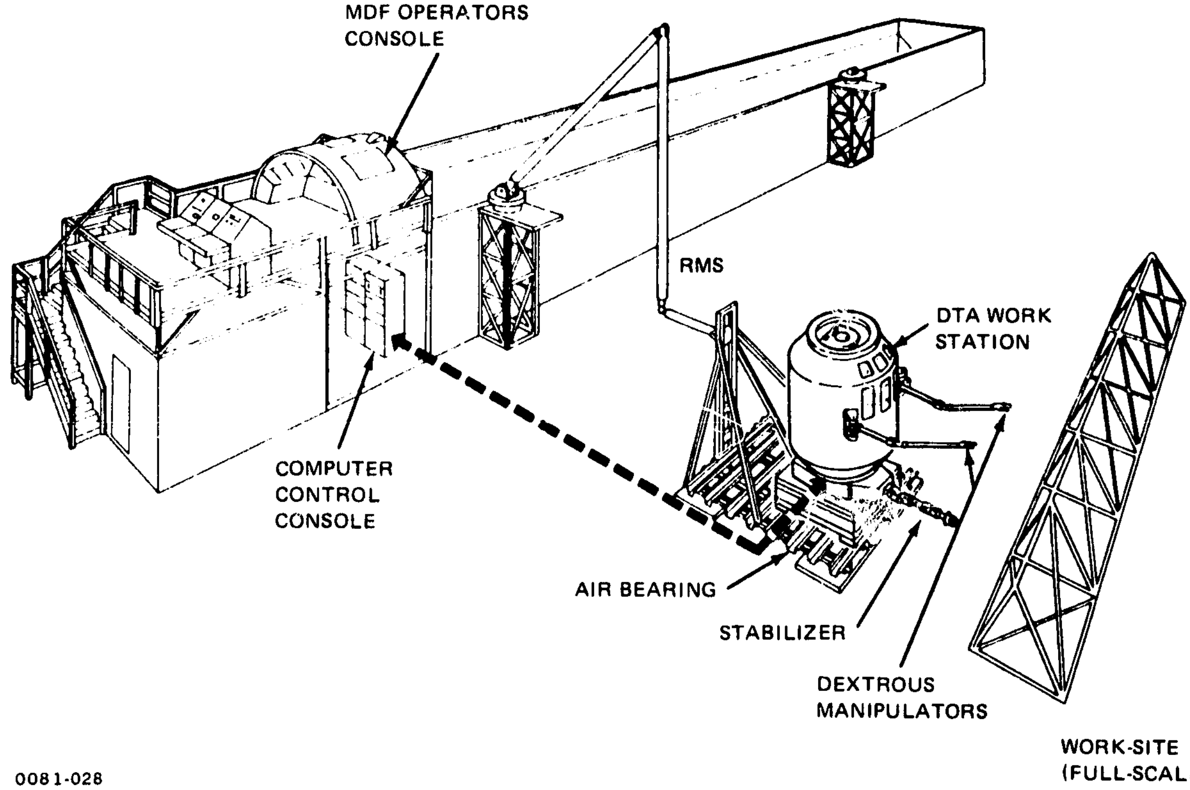


Figure 23. Simulator Approach Using MDF Air Bearing Table

Two simulator program options using the MDF were studied that provide a growth in simulator capability over the next five years. The first approach (Figure 24) is centered around a concept of modular buildup of the DTA so that both the OCP and CCP can be evaluated using the same hardware. In the second option, two dedicated DTA's are fabricated: the first is a high fidelity version of the OCP and the second is a high fidelity article of the CCP.

Program Option 1 stresses modularity in which the lower sections of the DTA are used in OCP simulation. After two years of operation as an OCP, the upper sections of the DTA including the supporting controls and displays are added.

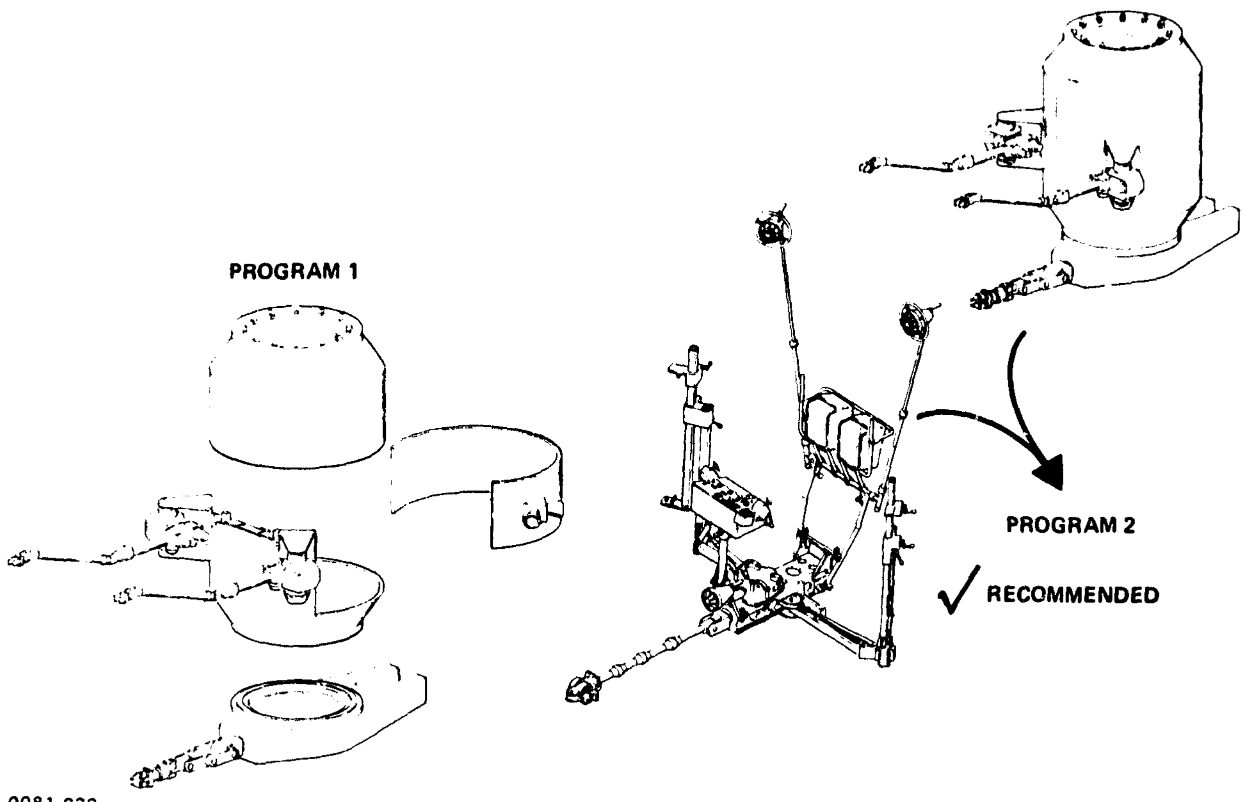


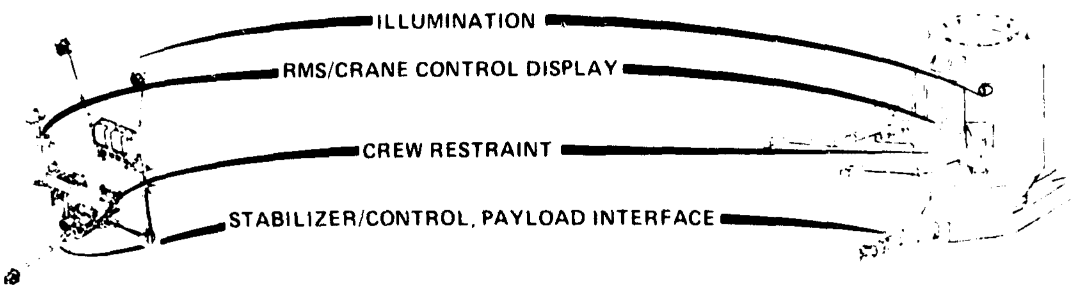
Figure 24. Simulator Program Options

Program Option 2 emphasizes early development of the OCP by fabricating a DTA that is functionally and geometrically the same as the expected flight article. This is followed by fabrication of a CCP that is not compromised by OCP functions.

It was recommended that program Option 2 be selected. This program supports the development requirements for the flight article by emphasizing OCP design. This program also provides a one year period for design and fabrication of dexterous manipulators. A survey of existing BFR manipulator designs indicated that a new design that is based on existing techniques and components was needed.

Figure 25 summarizes the elements and technologies that carry over from the OCP to the CCP. The major hardware developments include design of the stabilizer, display and control system functions, crew restraint systems, and the lighting system. Functional similarities between the OCP and CCP are the control of two crane arms from the cherry picker, techniques for obstacle avoidance, and determination of a standard of performance in terms of time for construction that must be enhanced by the CCP.

The significant level of technology carryover supports selection of designing, fabricating, and operating the lower cost OCP first, and then utilizing the lessons learned in the design of a CCP. Program 2 was then selected by the NASA and the remainder of the study concentrated on the design of the OCP development article.



<u>FUNCTIONAL TRANSFER</u>

- CONTROL OF SECOND RMS/CRANE
- PARALLEL OCP & RMS/CRANE OPS
- OBSTACLE AVOIDANCE
- DESIGN LOADS
- STRUCTURE & SUBSYSTEM ASSY PROCEDURES
- WINDOW VISIBILITY
- CONSTRUCTION TIMELINES

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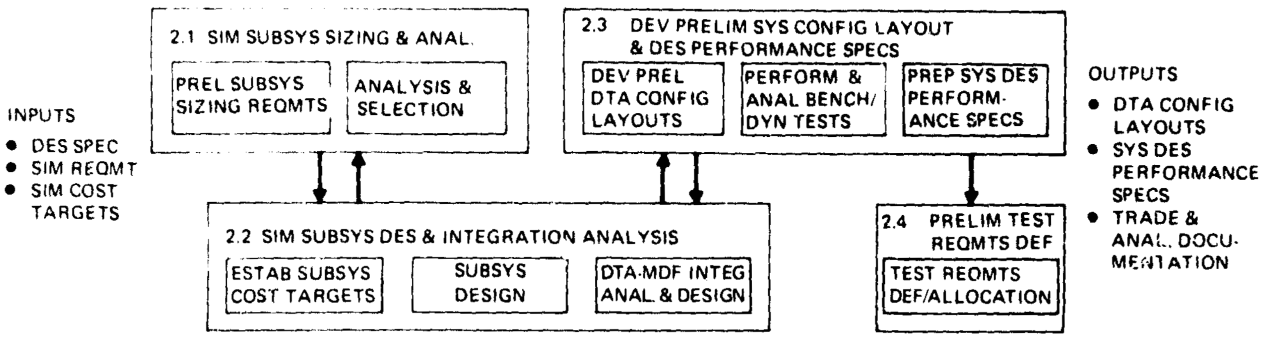
Figure 25. Technology Follow-Through from Open Cherry Picker to Closed Cherry Picker

Section 5

SIMULATOR SUBSYSTEM ANALYSIS AND DESIGN – PART II

The key output of Part I was the selection of the OCP as the program element that will be emphasized in early simulation. Part II of the effort, performed the tasks listed on Figure 26 to provide a preliminary design of an open cherry picker Development Test Article and performance specifications for review at PDR. Included as part of the process was the integration of the DTA with the Manipulator Development Facility. Particular attention was given to the test requirements during actual simulation to determine the flexibility that must be designed into the DTA to meet simulation objectives.



TASK OBJECTIVES:

TASK 2.1	–	**DETAIL SUBSYSTEM SIZING & ANALYZE SIMULATOR PERFORMANCE**
TASK 2.2	–	**INTEGRATION OF SIMULATOR SUBSYSTEMS**
TASK 2.3	–	**PROVIDE PRELIMINARY SYSTEM LAYOUTS & DESIGN PERFORMANCE SPECIFICATION – INTEGRATE HARDWARE BENCH TESTS & DYNAMIC TESTS INTO SYSTEM DESIGN & SPECIFICATION**
TASK 2.4	–	**DEFINE PRELIMINARY TEST REQUIREMENTS FOR EQUIPMENT CHECKOUT**

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Figure 26. Part II – Simulator Subsystem Analysis and Design

5.1 SIMULATOR SUBSYSTEM SIZING AND ANALYSIS

The OCP-DTA is designed to accommodate varying operator size, from 5 percentile female to 95 percentile male. Payload handling considerations dictated the size and configuration of support equipment, lighting requirements, and tool storage necessary to facilitate orbital operations. MDF operating requirements sized structural components and safety features of the configuration.

A crewman's reach area capability was established (Figure 27). The reach envelope capabilities of the full-range EMU suited astronauts, as well as vision requirements, were the key design requirements for design of handling components. The EMU suited astronaut body can tilt 40° forward, bend at the waist 90°, and rotate at the arm 150° from straight down to over the head. Table 6 summarizes astronaut anthromorphic data used for sizing man-machine interfaces.

Using this anthromorphic data with the ankle as a datum pivot, a one-hand reach envelope (Figure 27) that is broader than two-hand operations was constructed and used in design.

Operator weight, including Extravehicular Mobility Unit (EMU), and strength capability were the basis for the design loads shown in Table 7. Loads associated with transportation, handling, stiffness, frequency response, and failure were also used to define these design loads.

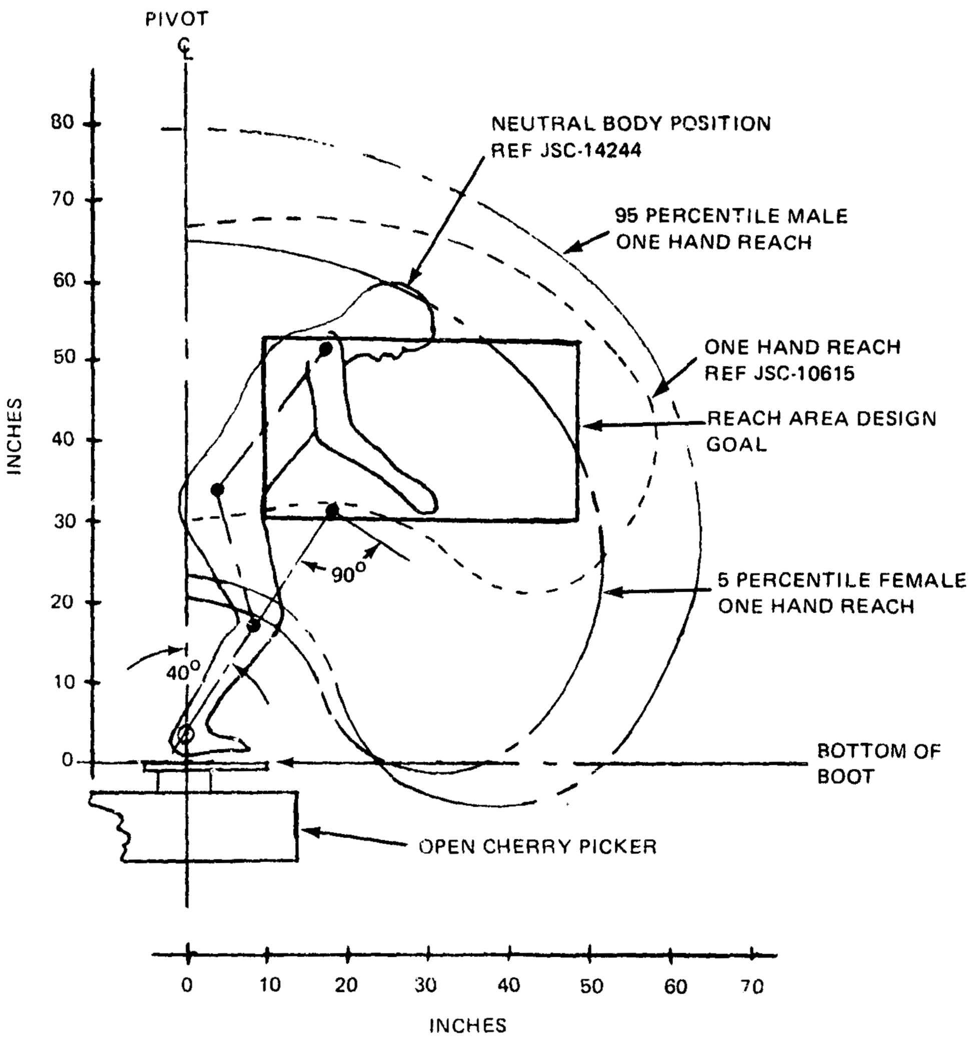

Figure 27. Astronaut Reach Relative to Pivot Axis

TABLE 6

ASTRONAUT SIZE DATA

PARAMETER	5TH PERCENTILE FEMALE – (in.)	95TH PERCENTILE MALE – (in.)
EYE HEIGHT, ERECT	56.4	70.4
EYE LOCATION FORWARD OF PIVOT POINT, ERECT	4.5	6.0
HAND REACH	17.0	21.3
SHOULDER PIVOT	50.0	61.0
ANKLE PIVOT	3.0	4.0

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TABLE 7

DTA – DESIGN LOADS AND CRITERIA

TRANSPORTATION (PACKAGED) MIL STD 810C	A. VIBRATION RAIL, AIR, SEA, OR SEMI TRAILER FREQ 5-200 Hz; LEVEL 1.5g; SINUSOIDAL CYCLING 84 MIN/AXIS SWEEP 5-200-5 IN 12 MIN.
	B. SHOCK 20g TERMINAL SAWTOOTH 11 MS PULSE IN EACH OF 3 AXIS
OPERATIONAL LIMITS LOADS	A. 1g STEADY STATE (GRAVITY)
	B. HOIST – 2g WITH DIRECTIONS UP TO 20 FROM LOCAL VERTICAL
	A. PLATFORM AND BASE MODULE ASSY EMU SUITED OPERATOR (430 LB) CAN APPLY SUDDEN LOAD (M.F. = 2) VERTICALLY WHILE STEPPING INTO PLACE.
	B. HANDHOLDS 187 LB IN ANY DIRECTION PER JSC 10615. OPERATOR CAN APPLY THIS LOAD TO CONSOLE, TOOL BOX AND STANCHIONS WITHIN HIS REACH.
	C. FOOT RESTRAINT 140 LB (ULT) IN TORSION PER JSC 10615
	D. STABILIZER TIP FORCE 50 LB IN ANY DIRECTION 400 IN. LB TORSION
	E. MFD RMS INTERFACE LOAD THE RMS IS CAPABLE OF APPLYING A LOAD OF 100 LB IN ANY DIRECTION PER JSC-11029
SUDDEN STOP	A. CONSOLE THE CONSOLE SHALL WITHSTAND 3.7g ACTING ALONE, AND 1.4g WITH THE WEIGHT OF EMU SUITED OPERATOR (430 LB) ALSO ACTING
	B. TOOL BOX THE STANCHIONS SHALL WITHSTAND 4.5g WITH THE TOOL BOX ACTING ALONG AND 2g WITH THE WEIGHT OF THE OPERATOR ALSO ACTING.
STIFFNESS AND FREQUENCY REQUIREMENTS	A. CONSOLE THE CONSOLE SHALL DEFLECT LESS THAN 0.2 INCHES UNDER A 60 LB LOAD.
	B. OPERATOR VERTICAL FREQUENCIES OF THE OPERATOR IN THE RANGE OF 4-8 Hz SHALL BE AVOIDED HORIZONTAL FREQUENCIES OF THE OPERATOR LESS THAN 2 Hz SHALL BE AVOIDED
DROP TO OFF LINE POSITION	A. CONSOLE THE CONSOLE SHALL WITHSTAND 7.5g IF DROPPED TO THE OFF-LINE POSITION
	B. TOOL BOX THE TOOL BOX SHALL WITHSTAND 30g IF DROPPED TO THE OFF-LINE POSITION WHEN FULL AND 50g IF DROPPED TO THE OFF-LINE POSITION WHEN EMPTY.

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The need for a stable platform to permit effective accomplishment of work tasks was used to establish OCP stiffness requirements and dictated the installation of a stabilizer. The stabilizer must be capable of grappling a variety of hard points, e.g., EVA rails and spacecraft support structure to take the work platform load off the RMS while not damaging the hardware grappled. Reach-around capability and the need to locate the astronaut close to work areas require a stabilizer with a minimum shoulder, elbow, and wrist joint that provides up to 7 DOF.

Control and Display functions were analyzed for mode control, safety, and reliability of operating the RMS and OCP subsystems. This C&D panel must have the following functions:

- RMS manipulator control switches for individual joints
- Attitude and translational hand controllers
- Caution and warning of RMS function
- RMS mode control selection
- Computer freeze
- RMS rate selection
- Manipulator power controls
- Lighting controls
- Stabilizer control switches (if electromechanical).

Up to 0.036 m^3 of storage volume should be provided for storage of small general purpose tools and medium sized mission peculiar tools, such as the MMS modular exchange tool which is 33 cm long by 46 cm wide.

A handling device that can assist the crewman in the transportation and alignment of payloads was sized to handle the MMS subsystem module (119 x 119 x 46 cm) and LDEF experiment tray (127 x 96.5 x 15 cm). The payload interface mechanism for this device should be easily changeable with mission peculiar equipment for handling payloads such as large 183-cm diameter fluid tanks and 1-m deep light weight truss girders.

The DTA lighting system should provide the ability of simulating a wide variety of lighting conditions. The system should accommodate tests of overhead lights for the 5 percentile female to the 95 percentile male while brightness should be controlled from the C&D panel for investigation of illumination requirements up to 50 ft-c at the work-site.

Because the DTA must operate in a 1-g environment, a safety/rest restraint system must be provided that protects the operator from a sudden stop from a velocity of 2 ft/sec. This restraint system must also provide a rest support for the operator during simulation test sessions. This restraint system is unique to the DTA and will not be needed on the flight article.

A complete definition of the OCP-DTA design requirements can be found in Appendix A of Volume II of this report.

5.2 DEVELOPMENT TEST ARTICLE PRELIMINARY DESIGN

Figure 28 depicts the OCP configuration selected for fabrication and test. It consists of a base module or strongback sized to interface with the stabilizer and the standard Shuttle foot restraint platform configurated to provide 360° rotation with a lock position every 45°. The C&D console pivot is mounted concentrically with the foot restraint platform pivot and is capable of being rotated independently of the platform to five discrete positions; from forward to aft in 45° increments with four operating positions (90°, 99°, 108°, and 117°). Lighting is provided with three flood lights. One light fixture, mounted forward and low, is adjustable in azimuth and elevation for illuminating the stabilizer and grapple area. The two remaining lights are mounted to the light stanchions which are mounted aft on the base module. The stanchions consist of a series of telescoping tubes which provide light fixture adjustment in height and width (fore and aft positions), as well as azimuth and elevation.

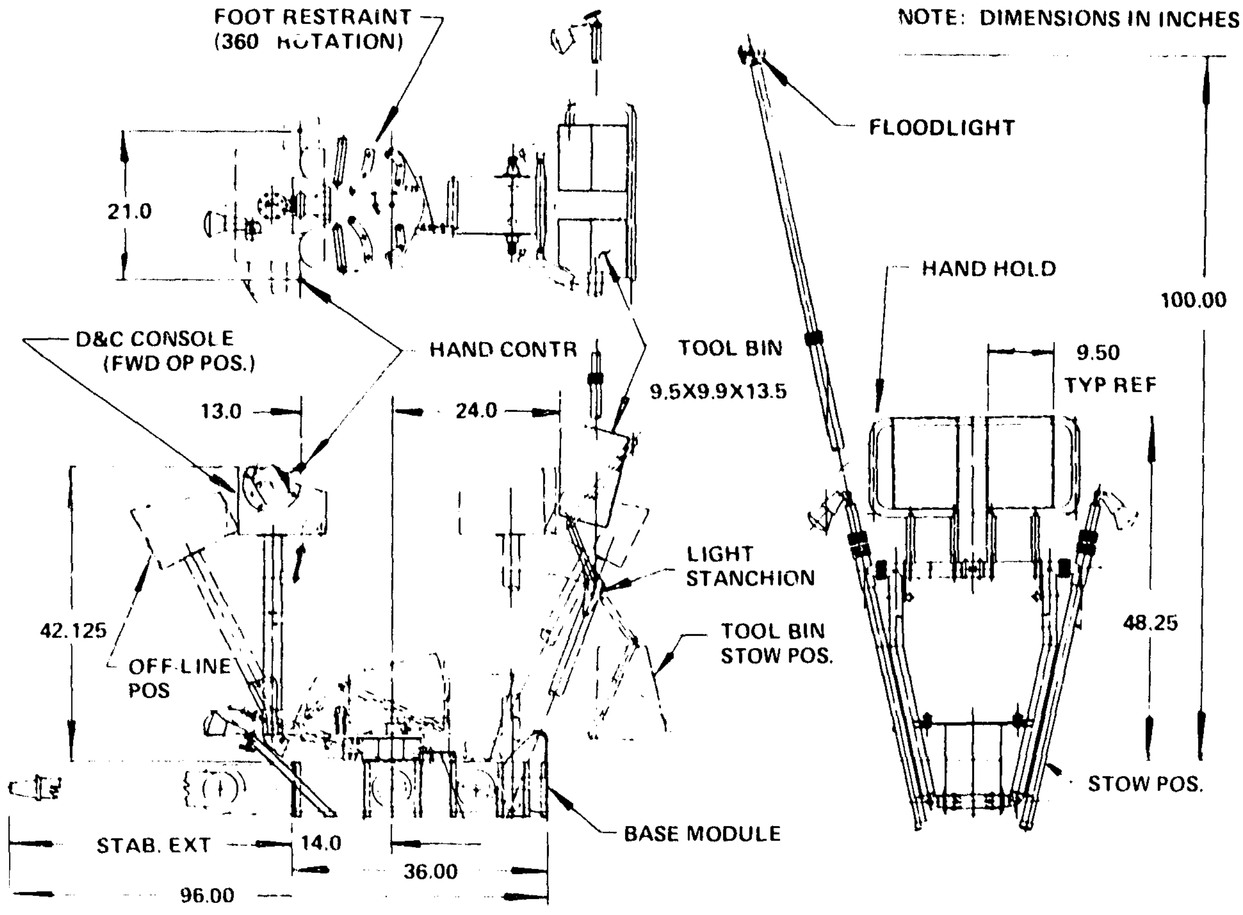

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Figure 28. Open Cherry Picker General Arrangement

Three handholds are provided to aid the EMU suited operator to ingress/egress the foot restraints as well as assist him in rotating the foot restraint platform. One handhold is located in the C&D console and the other two are built off the light stanchion and provide the structural frame for supporting two tool boxes.

The tool boxes provide storage for both small and medium sized tools. The boxes can pivot 180° down to an off-line position (compatible with storage) to provide increased visibility to the operator when the C&D console is placed in the aft operating position. While in this configuration, a 48-in. clear cylindrical envelope (C&D console off-line position) will permit freedom of movement for a EMU suited operator standing on the foot restraint platform.

5.2.1 Foot Restraint

The standard Shuttle foot restraint system is used to provide proper restraint for EVA operations. The restraint system consists of a flat plate with a pair of toe bars and a set of heel restraints rigidly mounted to a plate (Figure 29). A boot-to-restraint interface is also provided on the space suit assembly. Both the foot restraint fixture and the boot interface are passive elements with restraint provided by pivoting the boot into the heel fitting.

The shuttle foot restraint is designed for operation in a zero-g environment with a rotating mechanism that was considered unsatisfactory for the 1-g test environment. For this reason, a lazy susan roller system capable of handling the 1-g loads in an easily rotatable platform arrangement was substituted for the shuttle platform design (Figure 29). The platform-mounted foot restraint fittings (heel and toe) which interface with the EMU boots house platform latch system actuated by a lanyard that provides a latch position every 45° for the entire 360° of platform rotation and can operate independently of the position or rotation of the C&D console support.

5.2.2 Controls and Displays Console

The C&D console support is mounted around the same shaft that supports the foot restraint platform and has five latched positions from forward to aft. Three console operating positions are provided (forward, side, and aft) and at each of these positions the lock mechanism activates a micro-switch that inputs to the MDF computer to change the control axis to match the C&D console position. The foot restraint platform and the C&D console are attached to the base module by one ¼-in. diameter bolt that is accessible through an access cover in the side of the base module.

5.2.3 Light Stanchion and Tool Box

A storage location for tools is provided on the light stanchion at the aft end of the vehicle. Two tool boxes, each 9.5 x 9.9 x 13.5 in. provide a total volume of 1.25 ft^3 (Figure 30). One tool box is shown arranged with Skylab-type pullout drawers and is capable of holding small tools typically required for general work. The other box is shown holding a medium sized tool which may or may not be mission peculiar. In the event of a mission requiring a significant number of mission peculiar medium size tools, a special tool box can be designed for that mission and readily installed to replace the present box shown.

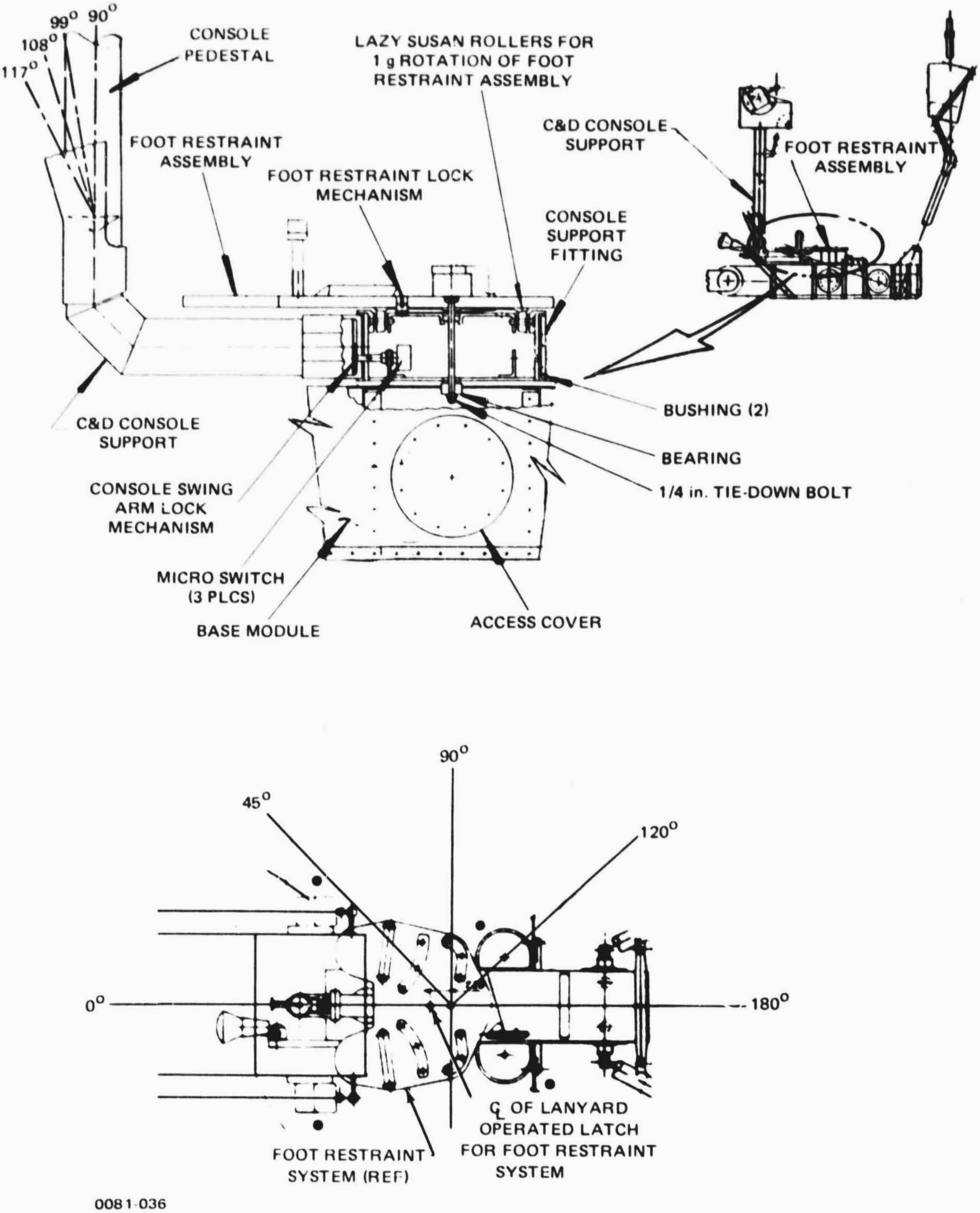

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Figure 29. DTA Foot Restraint and Console Attachment to Base Module

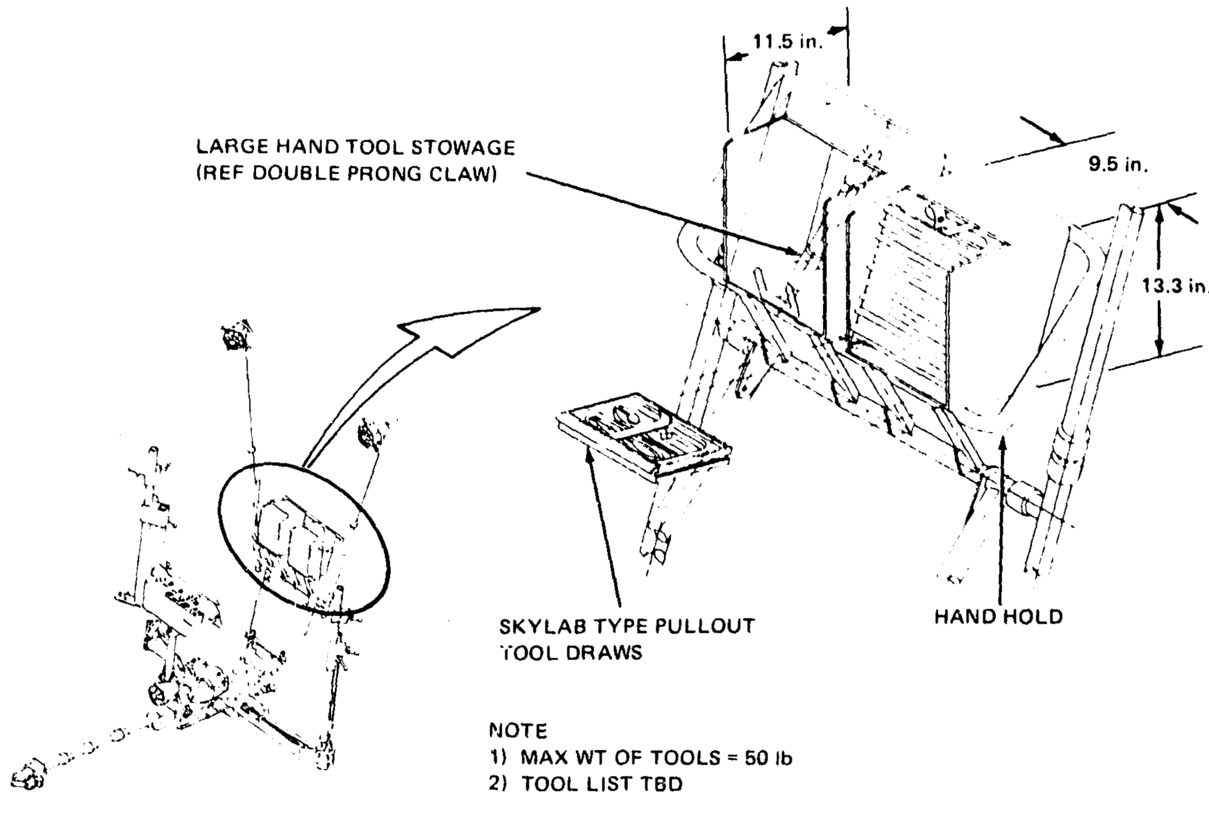

Figure 30. DTA Tool Bin Stowage Arrangement

5.2.4 Payload Handling Device

An important feature of the OCP is to assist the EVA crewman in handling large bulky payloads and mission peculiar tools. Two payload handling devices (PHD) are provided on the OCP, one to handle a replacement unit and a second to hold the unit replaced. Flexibility has been incorporated into the payload handling device to permit compatibility with a large range of undefined payloads in the shapes and sizes shown in Figure 31.

A perspective of the left hand installation of the payload handling device is also depicted in Figure 31 with appropriate identification of the major components discussed below:

- Payload Interfaces – Two payload interfaces are shown to accommodate rectangular shapes such as the MMS subsystem module. The lower interface is fixed to a pedestal; the upper interface is vertically adjustable and lockable on the pedestal by the astronaut. This permits the attachment of various height payloads
- Pedestal – A pedestal is provided to support the payload interfaces. The pedestal can be vertically adjusted and locked to the support stanchion by the astronaut. This allows the astronaut to adjust the vertical position of the interfaces for optimum alignment and translational clearances for the load

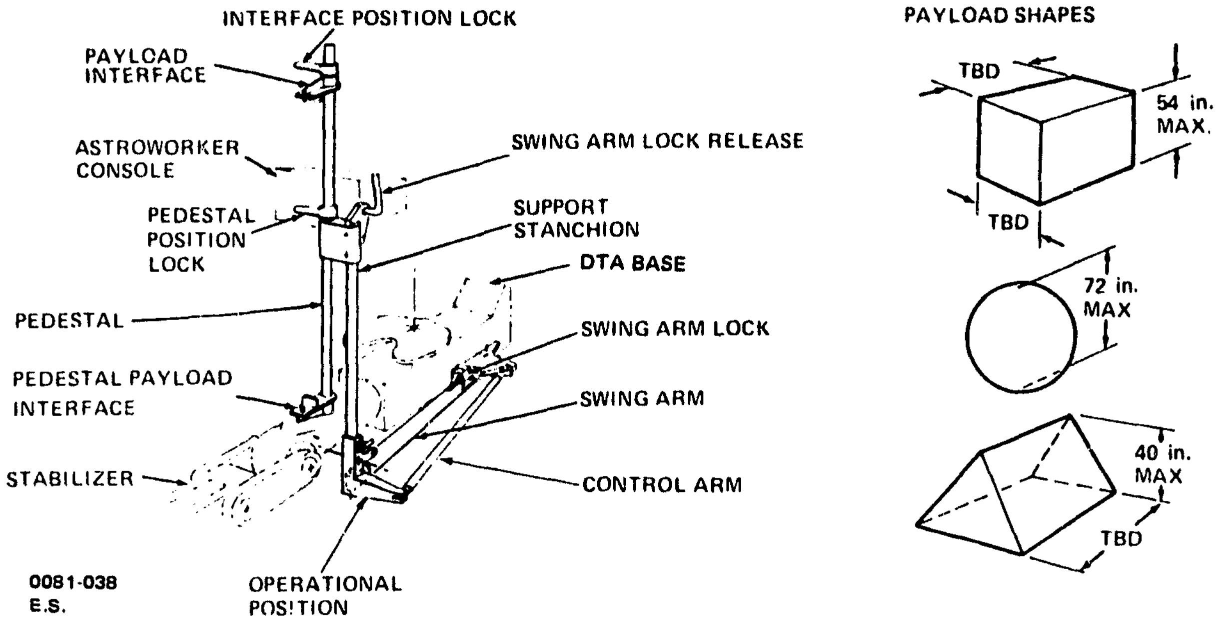

Figure 31. Payload Handling Device

- Support Stanchion – A support stanchion is provided to support the pedestal and interface with the swing arm, and to furnish the optimum location of a swing arm release
- Swing Arm/Control Arm – A swing arm is provided to support the payload and to swing it to an off-line position (payload stow position). The control arm makes up the four-bar linkage arrangement to provide the required payload swing clearances
- Swing Arm Lock – A swing arm lock system is provided to lock the swing arm at three specific positions: operational for payload pickup, stow for PHD stowage, and off-line for payload stowage or payload replacement unit. Any number of intermediate positions may be obtained.

5.2.5 Stabilizer

Another feature of the OCP is the stabilizer, the purpose of which is to grapple the work-site or a part of the Shuttle payload bay to rigidize the OCP work station by reducing loads on the Shuttle RMS. The options considered for this role are summarized in Figure 32. These options range from a simple mechanical device to a new design, electromechanical device. It is recommended that the P-FMA be used in a simulation program as a means of defining requirements for an electromechanical device in the event the all-mechanical system is found to be unacceptable.

5.2.6 Folding Operations

Seven steps are required to manually fold the development test article. Figure 33 illustrations indicate the folding sequence of the OCP from the fully deployed position to the fully folded configuration. The operator starts the folding sequence while still standing on the foot restraint platform in the following manner:

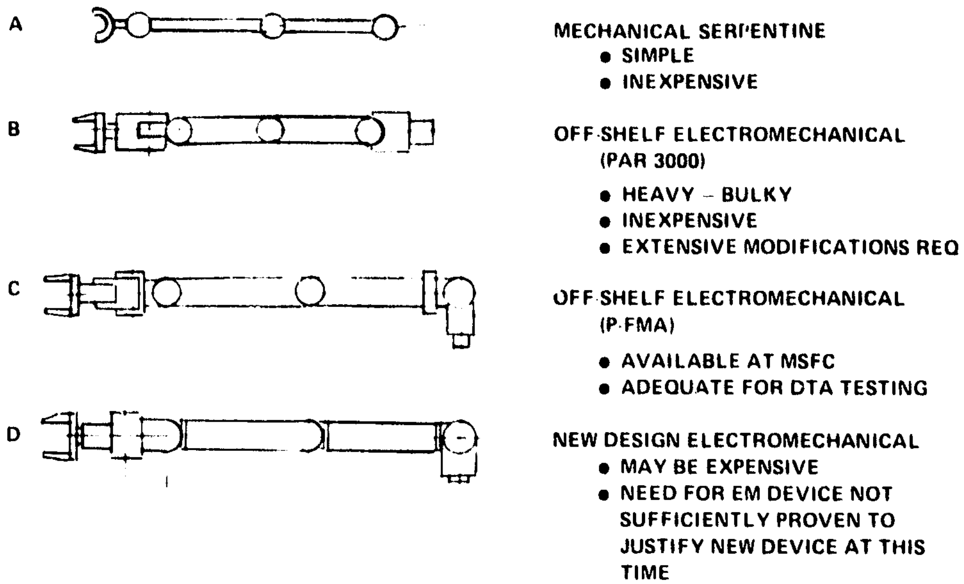

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Figure 32. Stabilizer Options

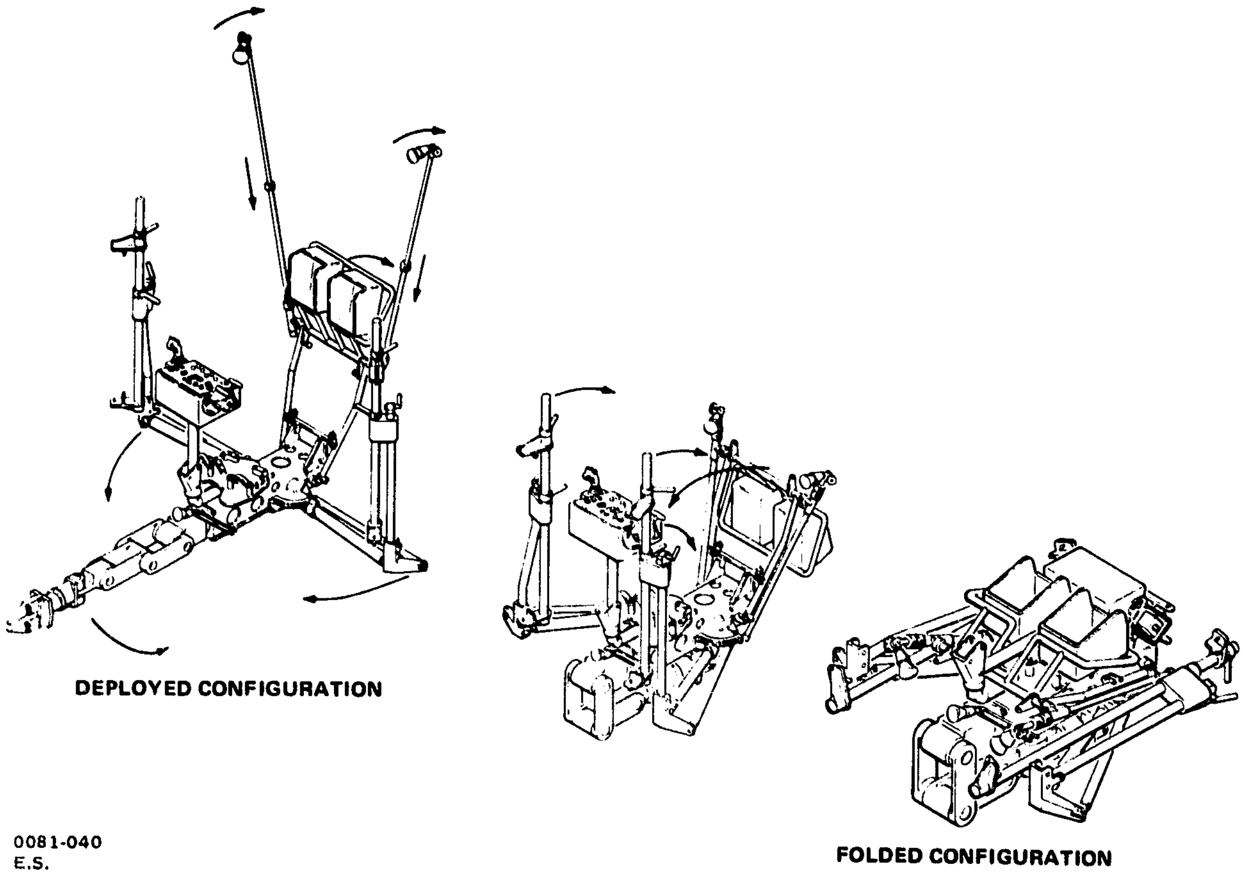

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Figure 33. Open Cherry Picker Folding Sequence

1. The operator using the C&D console lowers the stabilizer to its stowed position under the strongback
2. The operator lowers the lights on the telescoping tubes to their minimum height, rotates them to line up with the lower support frame, and then telescopes them in to their minimum width
3. The operator lowers tool boxes from their upright positions to the off-line positions
4. The operator rotates payload handling device to forward position and then folds them down to their stowed position
5. The operator now rotates foot restraint platform to forward position and detaches himself from the OCP
6. The light support frame is now lowered forward to its stowed position over the foot restraint platform
7. The C&D console is now unlocked, folded aft, and latched in its stowed position, trapping the light stanchion support frame and the tool boxes.

5.3 SIMULATOR INTERFACES

The OCP-DTA will be used in the Johnson Space Center Manipulator Development Facility (Figure 23). This facility, located at building 9A, contains a 56-ft by 80-ft air bearing floor and a 50-ft hydraulically actuated manipulator arm for simulating the Shuttle RMS. The DTA will be mounted to one of various sized air bearing platforms that can be mounted to the simulator manipulator. The facility uses a SEL 32-35 computer to control the manipulator arm and Shuttle aft crew station controls and displays. Because the DTA controls and displays are replicas of the Shuttle system, the existing analog to digital equipment and software can be used in OCP simulation.

5.3.1 Mechanical Interfaces

The two major mechanical interfaces are the tie down hardware of the OCP to the air bearing platform and the interface hardware with the RMS snare end effector.

A DTA/Air Bearing Platform arrangement is shown on Figure 34. Two 5-in. deep x 36-in. long aluminum channel outriggers are attached to the forward and aft ends of the base module. These outriggers are used to span and attach to the two top braces of the air bearing sled. The bolted attachment is typical at four locations.

This arrangement places the DTA operator approximately 2½ ft above the air bearing floor and provides an overall operating envelope of 10 x 3 x 11 ft. The DTA is positioned on the air bearing platform to allow clearance for the 22-in. diameter capture envelope required for the automatic mating of the MDF arm shuttle snare-type arm effector.

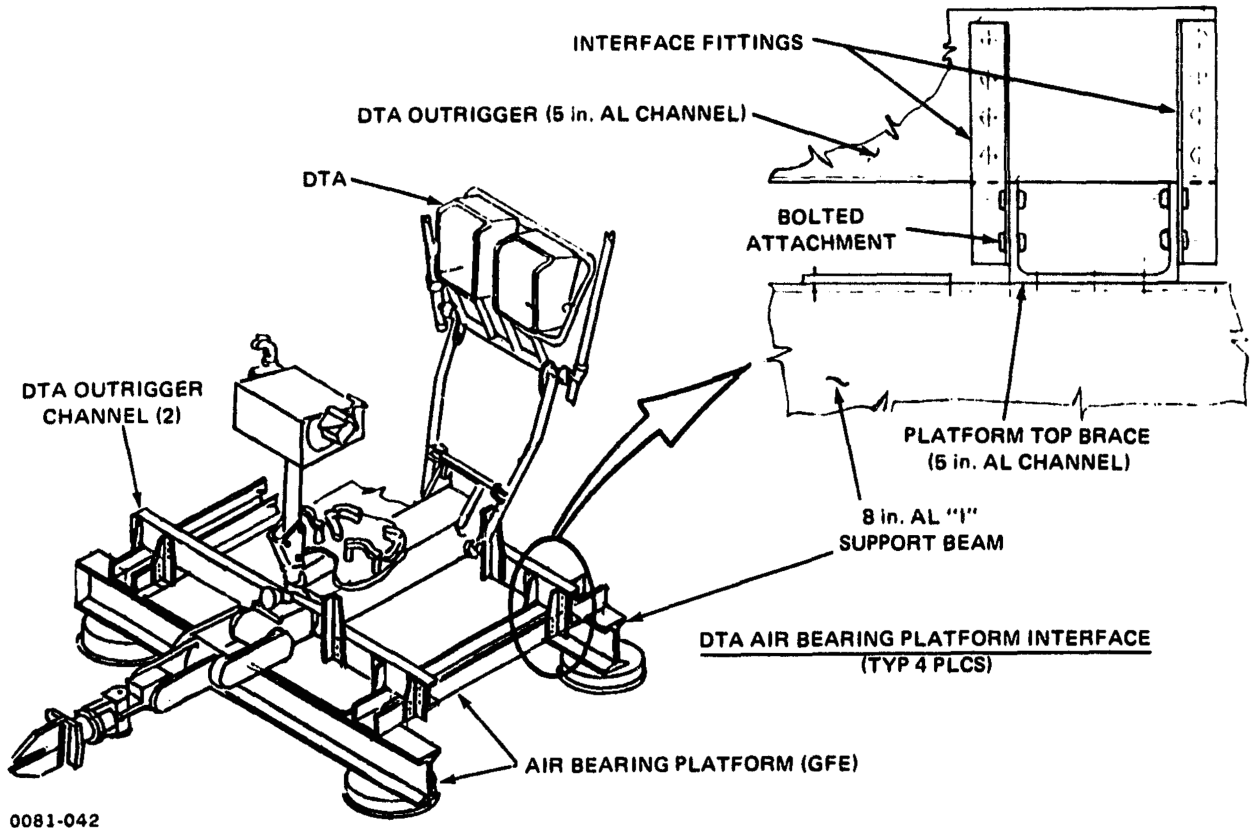

Figure 34. DTA/Air Bearing Platform Structural Interface

5.3.2 Electrical Interfaces

5.3.2.1 Displays and Controls Console – The various controls and displays necessary to operate the OCP-DTA are located on the C&D console. Because the selection of controls and displays are one of the critical design issues to be solved during the simulation test program, a modular approach was used in the layout of the panel. All the switches, indicators, and annunciation for the selection of the mode of control and operation of the MDF-RMS are located in one section of the panel (Figure 35). The lighting section of the panel contains the switches for varying the intensity of the panel illumination, annunciators, indicators, and external flood lights. A utility power switch and receptacle are provided on the panel. A section of the panel is left blank so that during the simulation program any controls or displays can be added at a later date.

The 3-DOF rotational and translational hand controllers for MDF-RMS manual augmented control are located external to the panel. This will allow a quick change during the simulation program to evaluate using switches in place of hand controllers for control of the MDF-RMS. A sub-panel, which is GFE, is mounted on the side of the console and contains the wiring for the OCP-DTA intercom system and controls for the MDF computer and MDF-RMS.

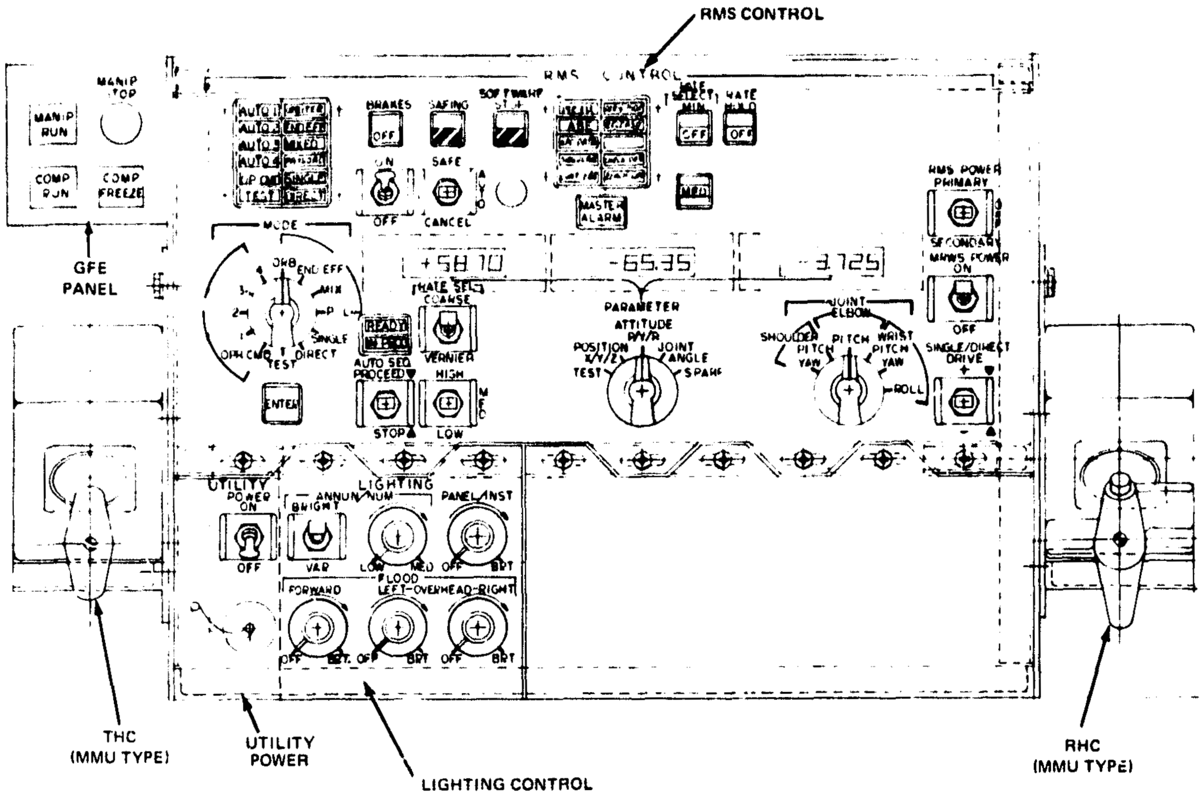

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Figure 35. Controls and Displays Console

5.3.2.2 Electrical – The functional schematic (Figure 36) depicts the various electrical interfaces and signal flow between the components of the OCP-DTA and the MDF. The center dash line indicates the OCP-DTA to MDF interface point. The various connections between the components on the OCP-DTA and the MDF computer and RMS for the control and operation of RMS are shown. The intercom and power distribution networks are also depicted.

5.3.2.3 RMS Subsystem – The functional schematic (Figure 37) depicts the primary signal paths for all OCP-DTA directed MDF-RMS subsystem functions. The RMS can be controlled in the manual augmented mode by means of the 3-DOF rotational and translational hand controllers or in the direct mode by means of individual joint switches. A mode selection switch is used to select not only the drive mode but also the coordinate reference system. Various annunciators and indicators are provided to indicate the status of the RMS and to indicate any failures or unsafe modes of operation of the RMS. Switches are provided which control power to the RMS joint drive motors and brakes, and vary the rate of the RMS end effector. Coordinate transform switches, activated by the C&D pedestal position, permit "fly to" control from the 0°/90°/180° C&D pedestal positions.

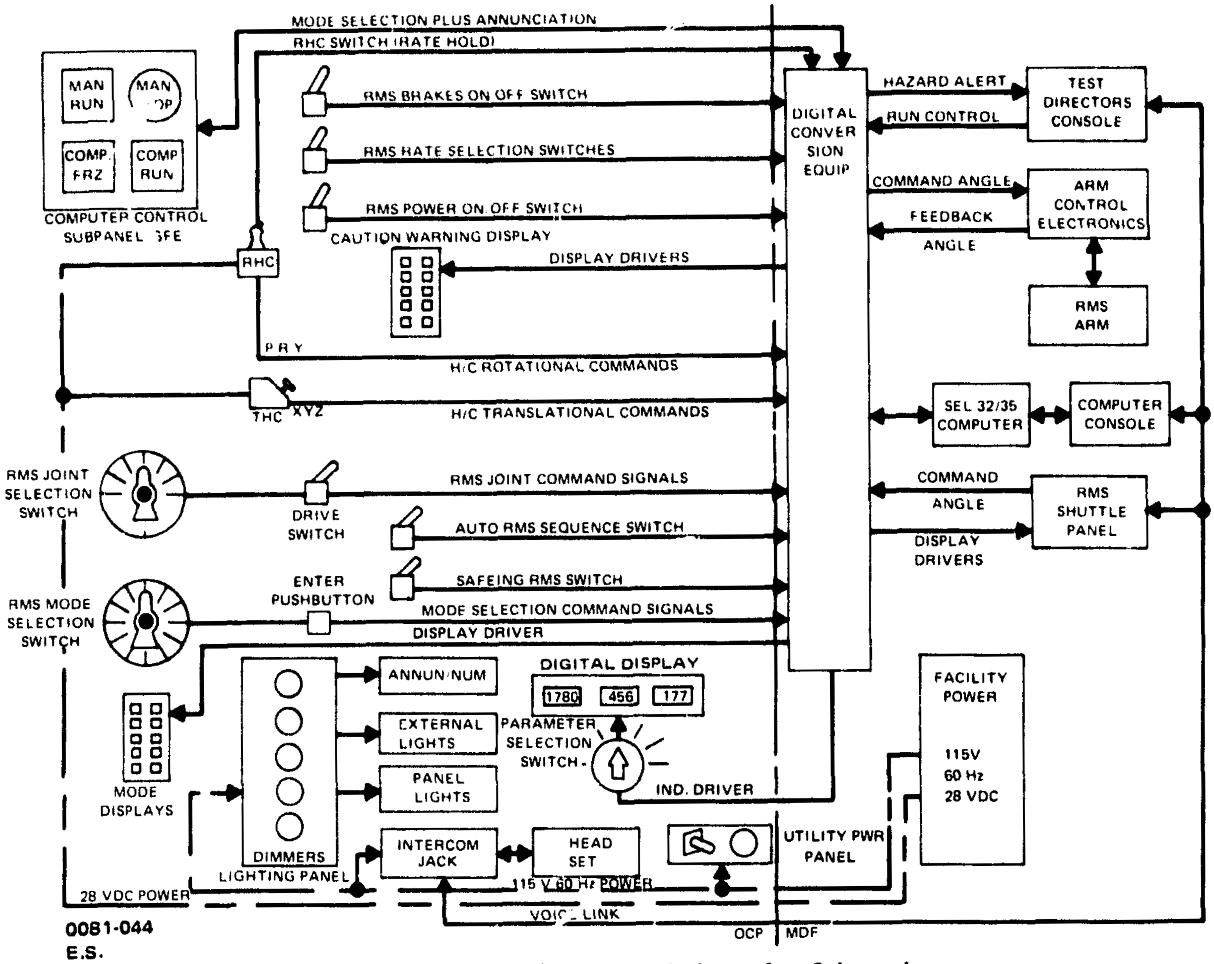

Figure 36. OCP-DTA/MDF Electrical Interface Schematic

5.3.2.4 Preliminary Test Requirements Definition – A preliminary set of test requirements was developed for the OCP-DTA which will demonstrate the readiness of the DTA to initiate the simulation development test program. The test requirements were broken down into three test levels: component/subsystem checkout, checkout of integrated DTA, and DTA/MDF integration and checkout at JSC (Figure 38). For each test requirement that was established at each test level, top level test procedures were developed; test data and tolerances to be measured were indicated; and any GSE/support equipment necessary was identified. Test requirements were allocated so that standard laboratory equipment will be utilized for the checkout of the DTA.

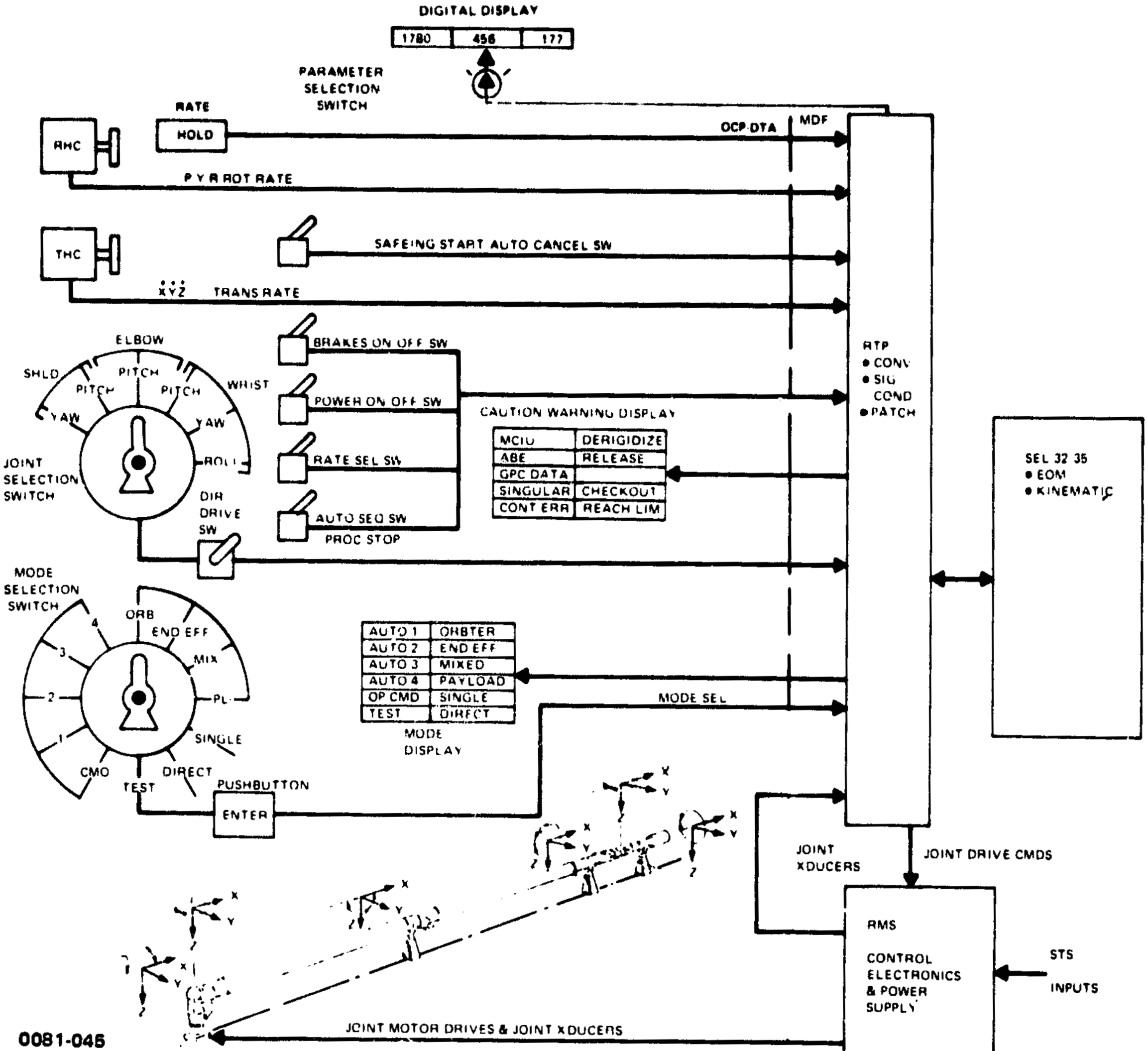

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Figure 37. Manipulator Electrical Schematic

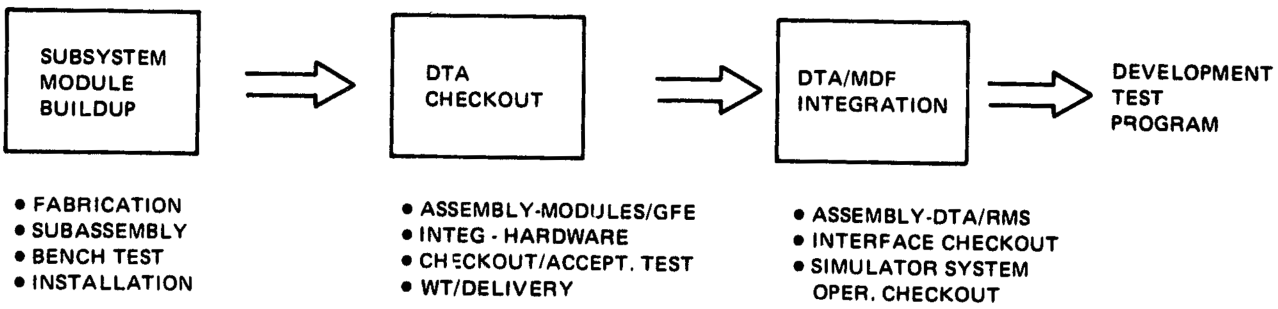

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Figure 38. OCP-DTA Integration and Checkout

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Section 6

SIMULATOR SYSTEM CONFIGURATION DESIGN AND TEST – PART III

The objective of this part of the effort was to provide the design drawings, manufacturing requirements, test plan, and procedu^{res} required for a DTA of the OCP. Manufacturing schedule and cost estimate details for the fabrication of this DTA are provided in Report Number NSS-MR-RP021.

The task flow (Figure 39) identifies the Part I and II inputs used in performing Part III as well as the tasks, their interrelationships, and products.

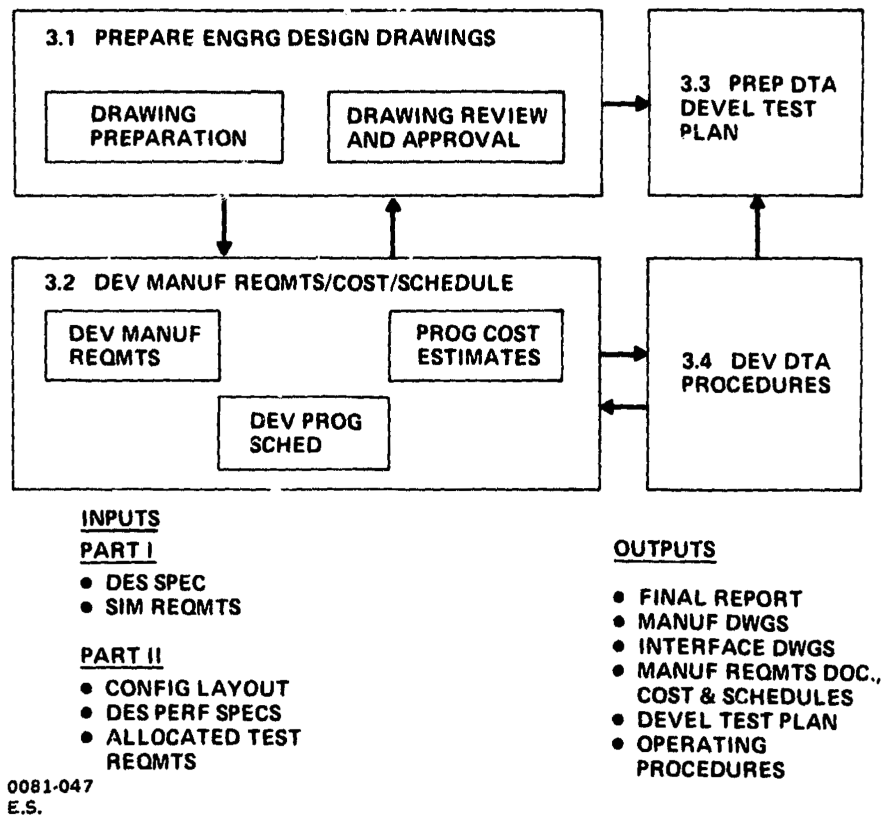

Figure 39. Part III – Simulator System Configuration Design and Test – Task Flow

6.1 ENGINEERING DESIGN DRAWINGS

Engineering drawings have been delivered to NASA under letter NSS-MR-LR012. These drawings, which follow the drawing tree system shown on Figure 40, combine details, assemblies, and installations and are all traceable to the top level drawing C76-200. The number of parts, type material, and manufacturing process are provided.

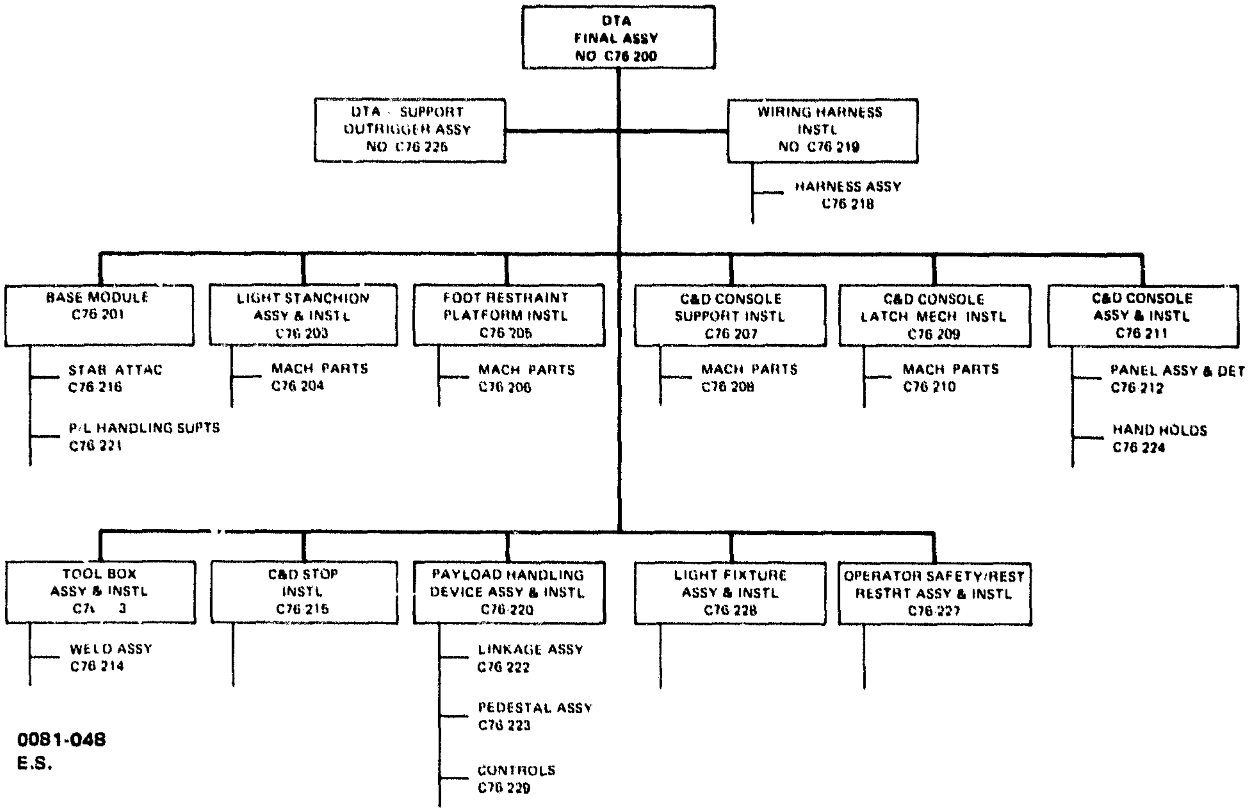

Figure 40. Open Cherry Picker – DTA Drawing Tree

Drawings are fully traceable and are filed in our Product Development Operations Center. All drawings have been reviewed and approved by Stress and Project Management.

6.2 MANUFACTURING REQUIREMENTS, COST, AND SCHEDULE

Details of the manufacturing requirements, cost and schedule can be found in Report Number NSS-MR-RP021. The top level schedule presented in Figure 41 is expanded in the above report in sufficient detail to provide an effective tool for management of the manufacturing/checkout phase of the program. The overall fabrication of the DTA and assembly checkout can be performed over a period of 6 months.

The detail parts of the OCP-DTA consist of standard shapes, or simple brake formed and/or machined parts. The subassemblies are built up using bolts, rivets, and a limited amount of welding. Final assembly is accomplished using rivets and hand driven fasteners. Throughout the fabrication and assembly a "jury rig" approach to tooling is employed, primarily where necessary to ensure aligned attachments. Materials used on the OCP-DTA consisted of readily available aluminum and stainless steel alloys weldable where necessary but usually selected for their availability rather tha their specific properties.

The quality control approach consists of receiving inspection of all purchased components, inspection of the parts, subassemblies, and assembled unit and checkout of the operation of the

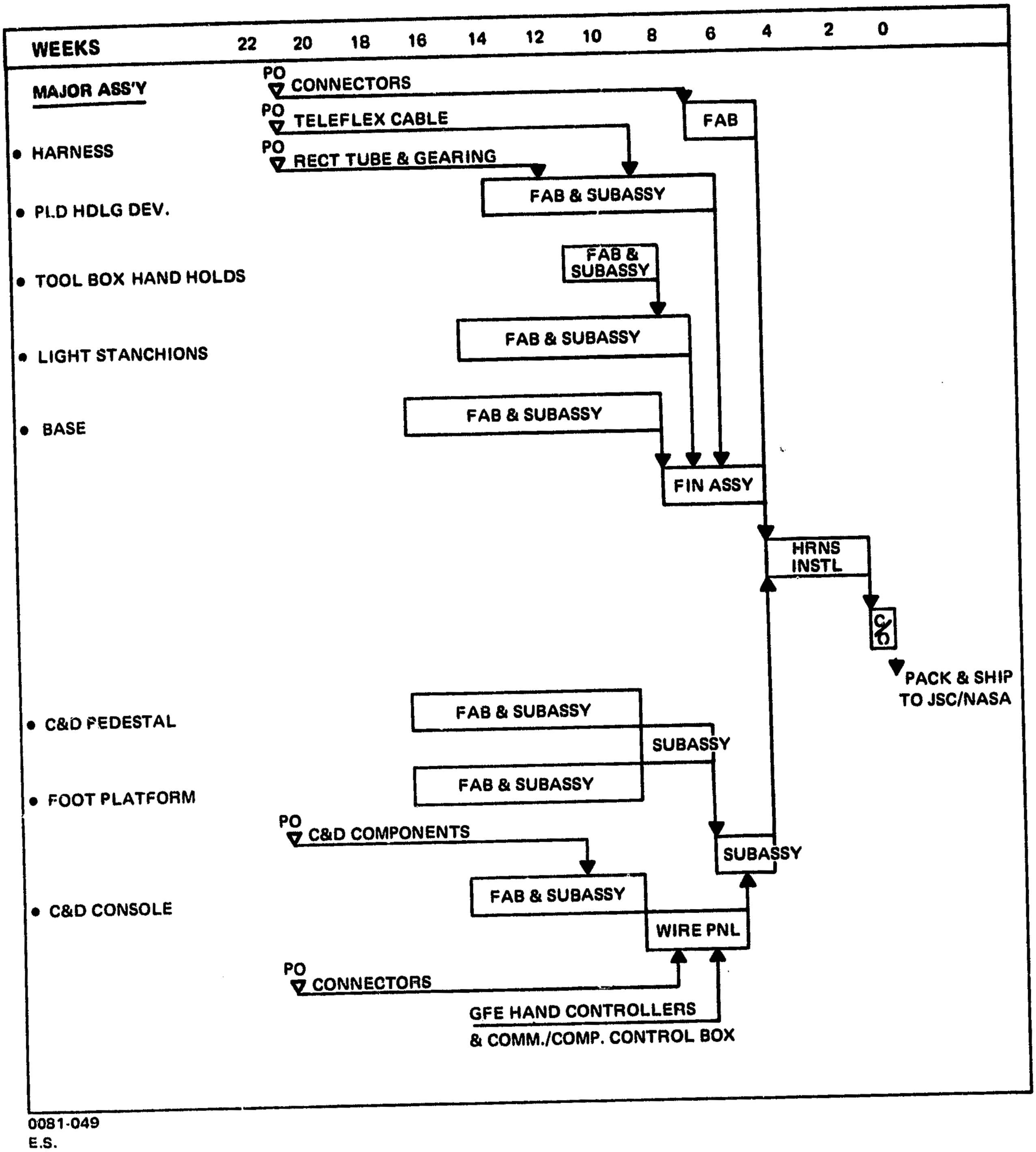

Figure 41. OCP-DTA Manufacturing Schedule

unit. On release of the part, installation and assembly drawings to the shop inspection points are established. The inspection points covers close tolerance areas and critical parts. During fabrication and assembly, quality control inspections are made for each previously defined point. At completion of the unit, an electrical and functional checkout is accomplished against an approved checkout procedure.

The schedule shown in Figure 41 depicts the major subelements of the OCP-DTA, the buildup of each of these subelements and its integration into a completely assembled unit. Procurement of items necessary to fabricate the OCP-DTA are shown with purchase order releases of critical parts from 3 to 4 months before completion. It is estimated that it requires 21 weeks from initial purchase order release to final checkout to fabricate the OCP-DTA.

6.3 DEVELOPMENT TEST PLAN

The Development Test Plan is reported in Volume III. This plan is broken down into two major sections: those associated with test during manufacture and checkout, and those related to the simulation program. The OCP simulation plan schedule is shown in Figure 42.

In the latter part of 1979, the OCP-DTA is delivered to JSC and integrated in the MDF. Figure 43 is a schedule of the integration and checkout of the OCP at JSC. After the OCP is delivered to JSC, it is unpacked and inspected. The OCP is deployed and all mechanical mechanism checked for proper operation. The OCP is then installed on the air bearing sled and the snare end effector fitting of the MDF-RMS installed on the OCP. The various electrical interfaces are verified before the

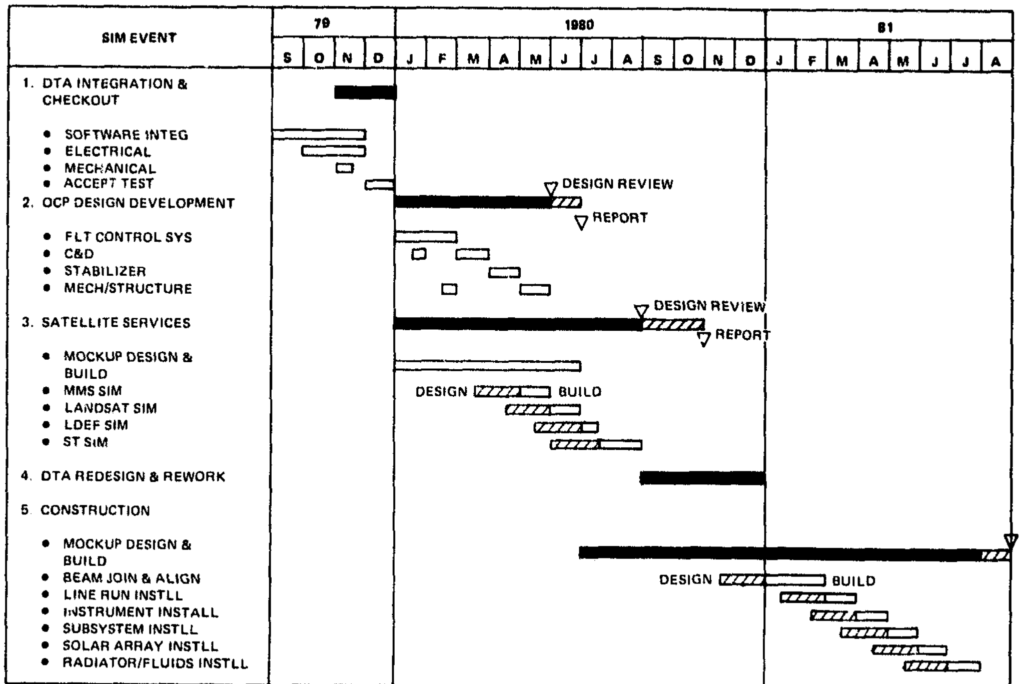

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Figure 42. Open Cherry Picker Simulation Plan

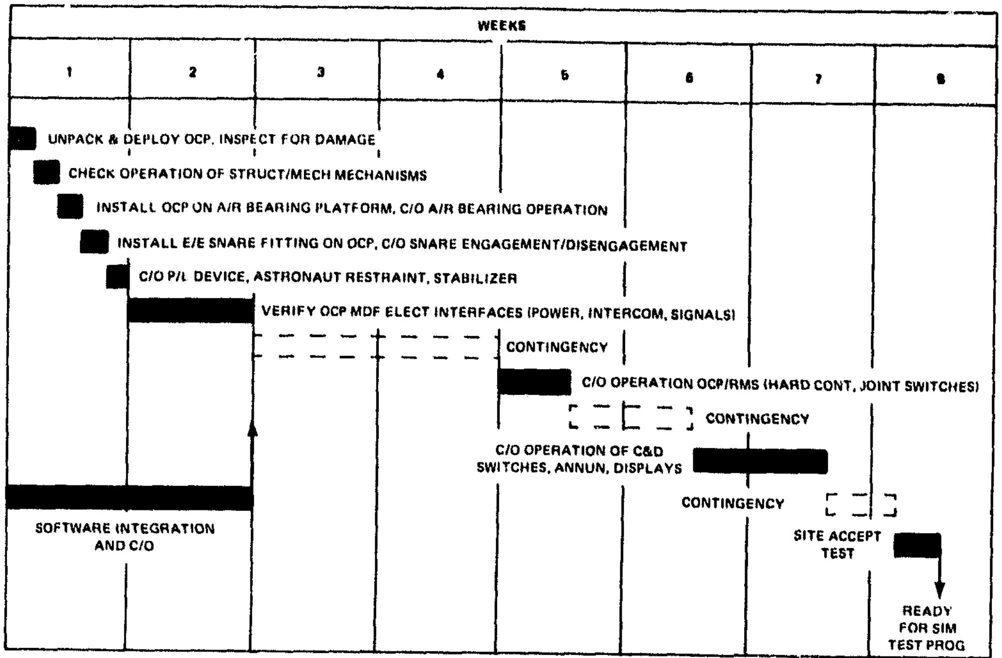

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Figure 43. Schedule – OCP-MDF Integration and Checkout at JSC

facility wiring is mated to the OCP. End to end checks are performed on the various systems of the OCP to verify that they are operating properly. Initial check-out is performed in a shirtsleeve mode.

The simulation program starts at the beginning of 1980 and runs to the latter part of 1981 (Figure 42). The first part of the simulation program will evaluate man-machine interfaces of the various elements of the OCP such as foot restraints, tool bin, C&D panel, etc. The second portion of the simulation program will involve evaluating the OCP design when it is used in a satellite serving role. Procedures, time lines, and adequacy of special tools will also be determined when performing various satellite serving tasks.

The last portion of the simulation program will evaluate the OCP design and determine procedures, time lines, and special tool requirements when the OCP is being utilized in its support of construction of large structures in space.

Water Immersion Facility (WIF) Tests

A mockup OCP-DTA was built by Grumman and delivered to the JSC-WIF (Figure 44). This mockup included a base, rotatable work platform, payload handling device, light stanchion/tool box, and C&D panel. Two test subjects operated the mockup DTA, performing functional tests including:

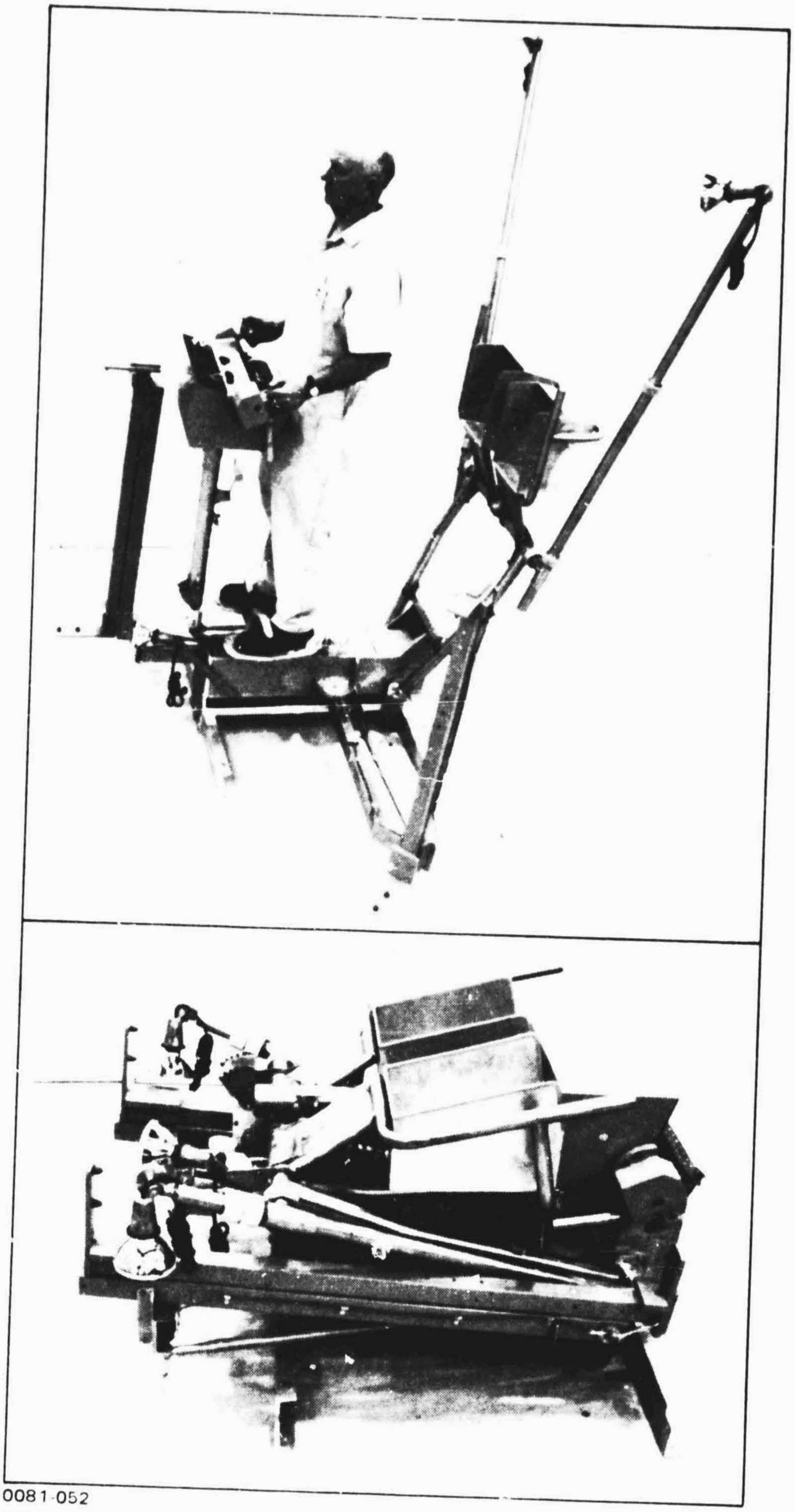

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Figure 44. DTA Mockup

- Rotating the work platform with and without the use of handholds and locking the platform in all detents
- Folding the tool box to the stowed location
- Tilting the controls and display panel to offline positions. Rotating the C&D console to all detent positions
- Adjusting the light stanchions for height, width and tilt
- Operating dummy C&D controls
- Changed out simulated MMS module and LDEF tray
- Push rod actuation to determine operator extended reach.

The results of these tests were promising for future OCP operations and can be summarized as follows:

- Ingress of the work platform was easily accomplished using handholds
- The work platform detent release lanyard was satisfactory but difficult to mount on EMU
- Tool box could easily be put in stowed position and returned
- Light stanchions adjusted easily; however, knurled knobs poor choice for EMU operations
- Payload handling device rotated easily
- Some test C&D controls should be larger and have improved clearance for ease of operation
- The work platform rotated with free hip movements but use of handholds is preferred
- C&D pedestal must be stiffer.

6.4 DEVELOPMENT TEST ARTICLE PROCEDURES

The procedures for operating the DTA are reported in Volume III. These procedures include definition for the installation service, checkout, and operation of the vehicle. Engineering design drawings, DTA specifications, vendor/GFE/MDF data, isometric drawings, and photographs of the engineering mockup will be used directly in the procedures. The procedure format will allow future expansion and modification as required by DTA evaluation by segmenting each procedure to allow easy removal/addition of sequences associated with specific DTA elements.

The DTA installation/checkout procedures will be used for assembly and integration of the DTA; and installation and integration of the DTA with GFE and JSC-MDF. The DTA operational procedures encompass DTA operation and servicing. The operational procedures include instructions for operation in any simulation test and provide theory of operation for familiarization of JSC personnel. The serving procedure will cover periodic calibration/maintenance requirements. Figure 45 depicts the procedure requirements flow by phases.

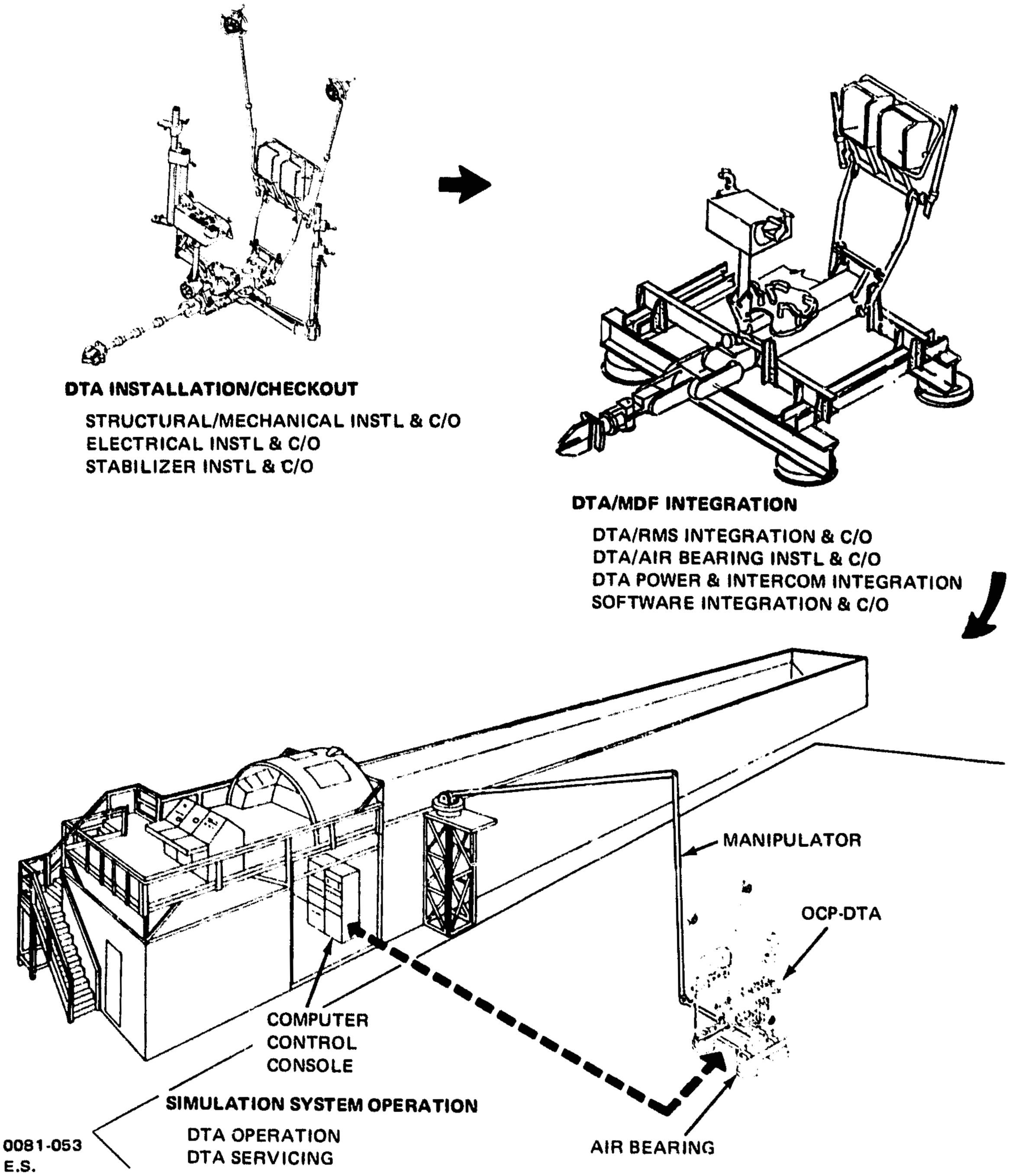

Figure 45. Procedure Requirements Flow by Phases

Section 7

CONCLUSIONS

The Manned Remote Work Station has many applications for near-term support of the Space Shuttle through support of attached satellite servicing, maintenance, repair and construction and maintaining space platforms. Initial MRWS Shuttle support requirements can be met with a simple open cherry picker that is mounted to the end of the Shuttle Remote Manipulator System. As the complexity of space construction activity increases with introduction of space platforms in the mid-1980's, the closed cherry picker operating from the end a 35-m long crane arm and the crane turret will come into play. Evenually, free flyers and other roles of the MRWS are needed as the construction bases for the Solar Power Satellite evolve.

A planning schedule for MRWS flight article development that meets mission requirements is presented in Figure 46. A ground simulation program that supports the flight article development should be initiated to address the key factors outlined in Section 3 of this summary. Initial simulation activity should concentrate on the open cherry picker and be followed by closed cabin and free flyer investigations. Dexterous manipulator design and testing for the closed cherry picker should be initiated in advance of the actual simulation on the air bearing floor to expedite the manipulator control system design.

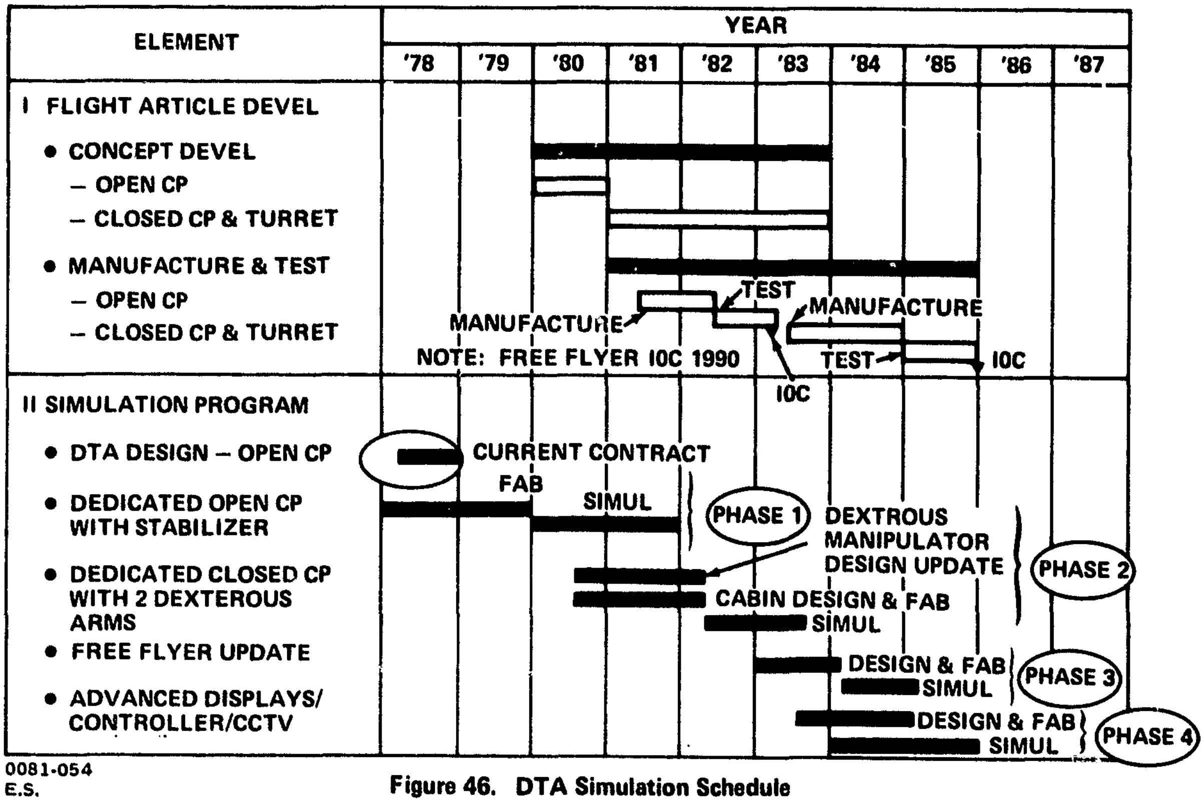

Figure 46. DTA Simulation Schedule

The early need for an open cherry picker suggests that the Development Test Article should be an integral part of the test program leading to flight article qualification. A program plan that utilizes the DTA in this manner is summarized in Figure 47. The approach utilizes the DTA-1 designed for 1-g operation at the Manipulator Development Facility as a tool for qualifying man-machine interfaces and selected self-locking mechanisms. This DTA-1 would then be updated to a high-fidelity simulator of the flight article and used as a trainer. A mockup should also be introduced into the inventory, namely, a lightweight model that is a mockup of the folded configuration for use in Remote Manipulator System grapple procedures development and the stow/unstow features of the open cherry picker to Shuttle interface hardware. The second DTA-2 is needed for Water Immersion Facility testing, and a third (DTA-3) as a structural test article. The flight article itself should be used as the qual-unit for functional, electromagnetic compatibility, and thermal/vacuum testing.

It is recommended that the open cherry picker be fabricated in 1979 and that MDF simulation activity be started in 1980. This will ensure needed technology development in time to meet a mid-1983 IOC. Design of a closed cabin cherry picker development test article along with Bi-Lateral Force Reflecting manipulators should be initiated in 1980 with fabrication and test starting in 1981. This will support a flight article IOC in 1/86.

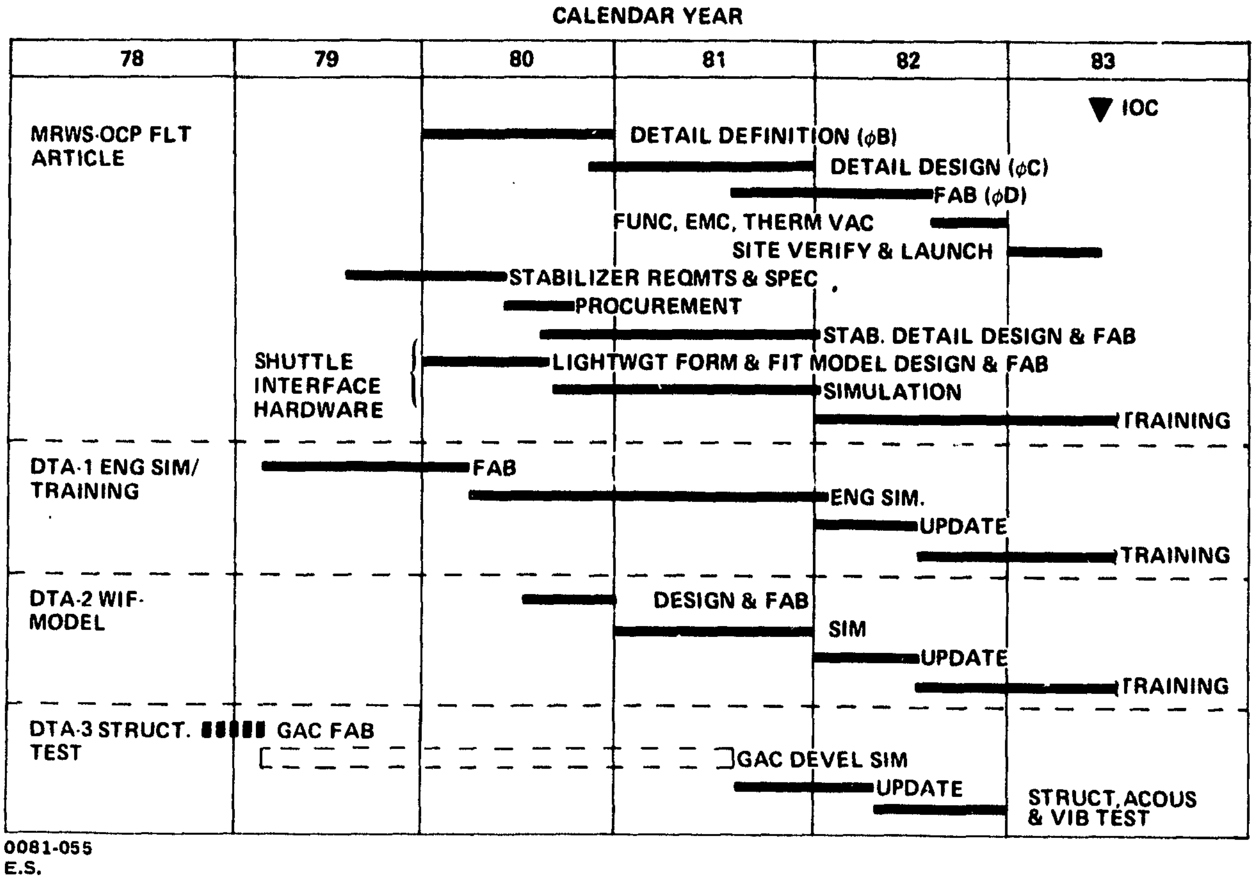

Figure 47. Preliminary MRWS Open Cherry Picker Program Schedule